PREVENTIVE MEASURES FOR PROJECT SCHEDULE CONTROL OF COMBINED CYCLE GAS TURBINE POWER PLANT

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The objectives of this research are to analyse the construction critical paths of the combined cycle gas turbine power plant projects and to determine the delay preventive measures for project schedule control. First, the planned and actual construction schedules of the combined cycle gas turbine power plants have been studied and analysed to see their critical paths and also the near-critical path which could potentially become critical. Construction schedules of four power plants constructed in Thailand have been obtained and analysed. Their capacities and main equipment arrangement are summarized in Chapter 5.1. The common work breakdown structures have been set up amongst all the four projects to categorize various activities in different projects schedules under the same group for further analysis.

The analysis results found that all the projects initially share the common critical paths on the notice to proceed issuance. Three out of four projects are subsequently found with critical paths on the turbines' procurement (either gas turbines or steam turbines) and erections of those while another project is found with the critical path on the pilings, foundations works and then the electrical balance of plant erections. After that, all the projects in this research are found with the common critical paths on the cold and hot commissioning works of turbines particularly when considering the steam turbine first steam afterward, subsequent common critical paths are the overall combined cycle commissioning works, performance test and commercial operation at the end of the projects. In consideration of different project sizes of Project D from others, it is noted that the erection and commissioning works of the main equipment (i.e. gas turbines and steam turbines) consume durations at the same range. The key difference contributing to the overall construction schedule is found on the time used during the main equipment procurement, starting from issuance of purchase order until the equipment arrival on site. Moreover, it is observed that the delay projects (Project B and Project C) are found with too many planned near-critical paths unnecessarily compared to Project A and Project D which were on time, also, their sequences of actual construction are found very confusing.

The possible preventive measures to control those critical paths are discussed including: i) expediting the procurement of main equipment to commence before the notice to proceed issuance. This however requires support from contractual languages agreed by all related parties which has to consider comprehensively from all aspects including legal and financial obligations; ii) ensure that the quality assurance and quality control (QA/QC) are well applied in all fabrication and erection activities to alleviate the problem of individual equipment functioning during the test run and commissioning. Opinions on the analysed results and preventive mitigation measures from two experts in this area have been obtained through interviews. Their experiences on critical paths are found align with the results of this research with some comments and recommendations for further studies provided.

Analysis results of the construction critical paths and near-critical paths together with the recommended preventive mitigation measures to control project schedule in this research are hopefully beneficial to those who will develop, construct or participate in the combined cycle gas turbine power plant projects in the near future.

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Pakorn Prabhawong

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Chapter 1. Introduction

1.1 General – overall electricity demand in Thailand

Thailand's economy is growing year by year. Many business sectors such as tourism, manufacturing and agriculture are enhancing their performance subsequently maximizing their profit which will contribute to that overall economic growth in a big picture. Behind the scene, the requirements of basic infrastructure to support those business are always present, these include transportation improvement such as road expansion, utilities such as adequate water supply, communication such as reliable telephone and internet connection, etc. Dependable and adequate electricity is also part of those requirements that is required as the backbone to support the growing economy.

To meet that growing electricity demand, there are many types of power plants which contribute to the generation of the electricity including solar farm, wind farm, coal fired and hydro power plant. However, the electricity in Thailand is now mainly generated by the power plant using natural gas as source of fuel. The gas-fired power plants are strategically located all over the country to provide reliable supply in each region. In 2018, the power generated by gas-fired power plants contributed to 59.7% of the overall power generation in the country. To be more precise, 54.5% of the total power generated were from the combined cycle gas turbine (CCGT) power plants (Energy Policy and Planning Office, 2019).

In the new Thailand's power development plan of the year 2018 (PDP2018) which has been officially announced by the government in early 2019, the CCGT power plant will still play an important role to support the power demand of the economic growth in the future. Though there is a great increasing proportion of supply from the renewable energy, according to the PDP2018, the CCGT power plants will still have the total generation capacity of 31,572 MW in the year 2037, contributing to 40.8% of the overall country's power demand (Energy Policy and Planning Office, 2019). Considering the aged power plants to be replaced, this results in a new 15,268 MW of CCGT power plant to be constructed (Energy Policy and Planning Office, 2019). Consequently, there will be many CCGT power plants which need to be installed and put into operation around the country in the near future.

In the development of each CCGT power plant, the project developer needs to have the unique and robust project development plan since the beginning of the project. This is because the particular CCGT power plant project will have its own characteristics which will be different from others such as site location, requirements from the power purchase agreement by the authorities, demand of power and/or steam from local industrial users (IUs), Engineering, Procurement and Construction (EPC) contractor selected, permits approved from the authorities, requirements from different financial institute (if loan apply) and etc. Dealing with all those concerns needs to be well contemplated so as to bring the power plant into commercial operation with best power plant's efficiency and availability which eventually will affect to the financial outcome of the project, thus, the better return to the developer and investor.

1.2 Power plant project construction

Construction is one of the key areas during development of the power plant project which contains many risks that are critical. These risks include delay, over budget, health and safety issues, quality of work and etc. Usually, the construction of the CCGT power plant will take around 2 - 3 years to complete starting from issuance of the notice to proceed (NTP) to the EPC contractor until achievement of the commercial operation date (COD), depending as well on the size of the project. The quality during the construction can significantly determine the long-term performance of the power plant, especially the plant's efficiency and the availability throughout its entire life, normally 25 years under the power purchase agreement with the authorities. Therefore, understanding of the construction activities in detail can help the related parties forecasting area of concerns and establishing the mitigation and prevention plans in advance, forming the protections to the project success since the early phase.

1.3 Successful construction project

Success in construction project can be measured by three main dimensions, time, quality and cost. Recently, safety is also taken into consideration. Time is crucial such that the project must be completed within the allowable and agreed timeline. The quality of the works, as mentioned in the above section, represents the power plant performance which at the bottom line will reflect to the operation efficiency of the project. Cost is also crucial to be controlled since the beginning and throughout the entire life of the project, this will reflect the profit of all related parties eventually. Without the robust project management, however, only 2 out of 3 would likely be achievable. Figure 1 shows relation of these three.

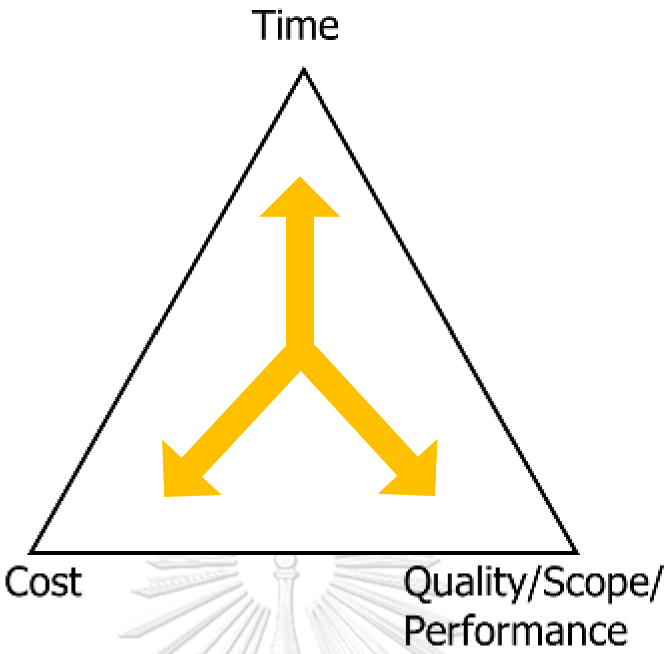


Figure 1 Traditional measures of project success (Adapted from Gardiner, 2005)

1.4 Time control for the project construction

Normally, the CCGT power plant will sale the electricity to the authority as the main off taker. Failure to complete the project within the agreed timeline can be a catastrophe. This is because negotiation for the extension of power purchase agreement with the authority as the major off taker of the power will have no ground especially in the case that the default is solely caused by the project developer. Moreover, the developer will have to provide the bid bond to the authority and this bond is normally required in high value, for example, a 90 MW CCGT power plants will have to provide the bond to the authority in the amount of THB 90 million. If delay occur, the authority is entitled to deduct the penalty from this bond until that project can achieve the commercial operation. In the worst case, the power purchase agreement can be terminated eventually if that CCGT project cannot reach commercial operation within the allowable timeline (Electricity Generating Authority of Thailand, 2011).

To control the project schedule, the project critical path is usually be a key consideration as it will determine the overall length of the project. Well managing of those activities that are laying on the critical path will help the project manager to be able to control the project master schedule in good shape.

1.5 Objectives and hypotheses

1.5.1 Research objectives

The objectives of this research are to analyse the planned and as-built construction schedule of the CCGT power plants in Thailand, whether they are sharing any common critical path or common construction problems. If they are, a general framework considering the CCGT power plant construction critical path will be determined for future project developers or related person to use it as a guideline to handle the critical activities in their project.

On the other hand, if a specific project presents a specific construction critical path then the lesson learnt can be summarized. Knowing this will let the project managers, developers and related persons to understand the potential problems which allow them to contemplate in advance and to adapt and apply the mitigation measures to their own areas and situations.

In the other words, the outcomes of this analysis would help any further CCGT projects in development to have a general guideline on what would be the potential areas of delay during construction phase so that the developer or related person can ensure that all causes are well mitigated and appropriate countermeasures are applied. This is, at the bottom line, to ensure that the construction will be completed on time, with the acceptable quality and within budgeted cost.

Risk management of the construction project will be studied as well to see where and how it could be applied practically to the construction project to help mitigating such risks to a minimum level.

It is expected that 3 - 4 construction schedules will be analysed. As there is not much information publicly available due to the confidential nature of the project development, the construction information will be shown in an anonymous basis, for example, project A, project B, project C and project D.

1.5.2 Hypothesis

As the construction timeline can vary significantly depending on other two key aspects which are cost and quality, therefore, to evaluate the construction critical path of different projects, some assumptions have been made as below.

1.5.2.1 Reasonable cost

The construction duration can be expedited by utilizing more resources such as overtime working, paying premium to the equipment manufacturer to obtain the equipment faster and etc., however, it will come with higher development cost. In this research, therefore, it is necessary to assume that the projects in consideration have a reasonable construction cost and provide the favourable financial return to the developer at the same level.

1.5.2.2 Acceptable quality

The construction timeline can also be expedited by lower the quality of works such as ignoring quality control process which can result in worse performance of the plant and its availability in the long run. In this research, it is assumed that the projects in consideration are built with acceptable quality to the same standard, reaching the acceptable industrial performance and are able to operate with high availability throughout the life of the projects.

1.5.2.3 No impact of different EPC contractor

In construction, different contractor appointed for such project can result in different construction outcomes. This is due to differences in their internal resources, their workload during that period, project team assigned and etc. Therefore, it is assumed in this research that different EPC contractors have almost the same construction performance. Impact of capability of different EPC contractors will have to be ignored.

Chapter 2. Review of Literature

2.1 What is the combined cycle gas turbine power plant?

The combined cycle gas turbine (CCGT) power plant is a plant with a purpose to generate electricity by combusting natural gas to gain energy in a form of heat, convert it into the mechanical energy via turbine which is connecting to the generator and eventually generate the electricity. The typical main equipment comprises gas turbine(s), heat recovery steam generator(s) (HRSGs), steam turbine(s) and auxiliary balance of plant equipment. In the CCGT power plant, natural gas will be first combusted in the gas turbine which is connected to the generator to produce electricity. The waste heat from combustion process which is specifically called the flue gas will be navigated through the HRSG and leave out the power plant to the atmosphere via the stack. In the HRSG, the flue gas will transfer its waste heat to the water which will be evaporated into the steam. The steam will be routed to the steam turbine which is coupled to the generator and the electricity will be generated again in this steam cycle.

The term “combined cycle” represents the use of waste heat from gas turbine in generating steam via HRSG which subsequently drive the steam turbine. There are two cycles of electricity generation in this circumstance, the gas turbine loop and the steam turbine loop, which are combined in one power plant. Its operational concept is based on the Brayton cycle and the Rankine cycle for gas-fired cycle and steam cycle respectively (Black & Veatch, 1996).

Figure 2 illustrates the typical concept of CCGT power plant process flow diagram. Figure 3 to Figure 4 show the theoretical concept of Brayton and Rankine cycle which the CCGT plant is operating on. The purpose of this arrangement from the broader perspective is to maximize the overall plant’s efficiency which in turn will reflect the benefit of the project.

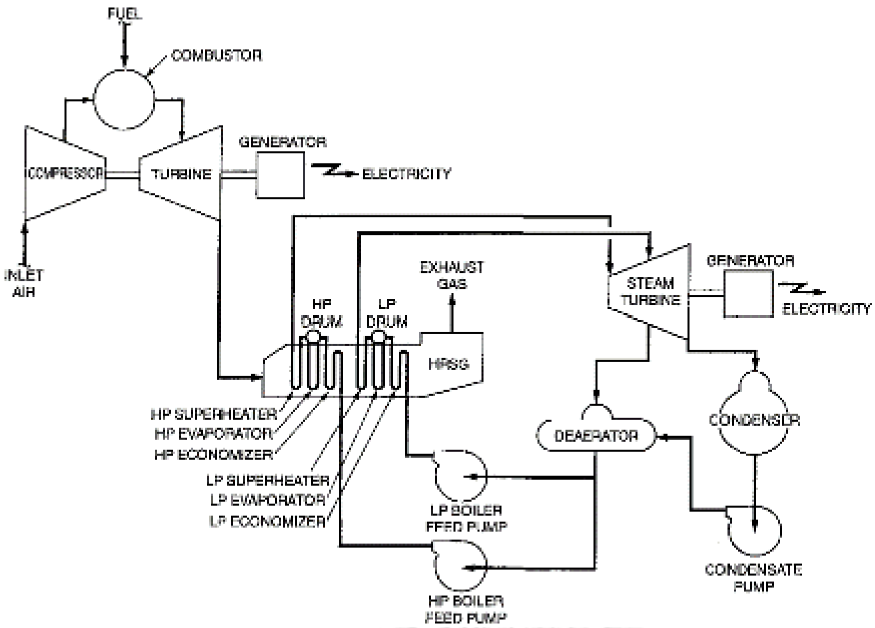


Figure 2 Typical combined cycle gas turbine arrangement (Black & Veatch, 1996)

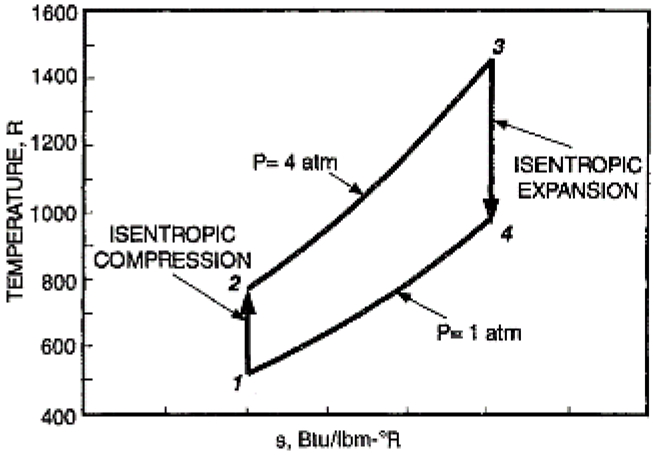


Figure 3 Brayton cycle for gas combusted in gas turbine (Black & Veatch, 1996)

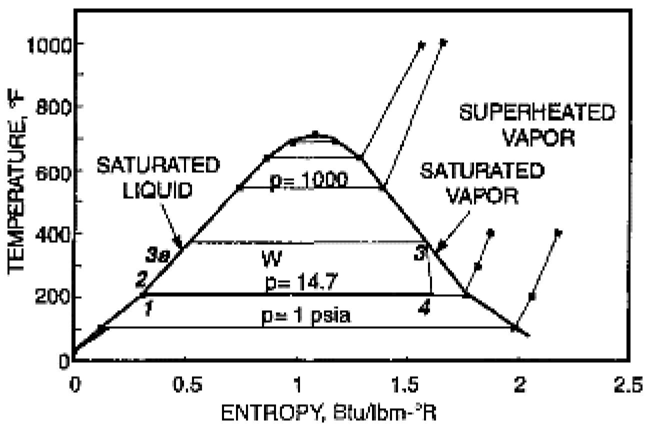


Figure 4 Rankine cycle for steam cycle in steam turbine (Black & Veatch, 1996)

2.2 Development of project management tools

Baldwin & Bordoli (2014) depict the evolution of the project management tools that they first started in the 19th century when Henry L. Gantt adapted the existing visualized bar chart to express his work tasks and progress while he was working in the steel company, the chart is thereafter called the "Gantt chart". However, they mention some deficiencies in the Gantt chart that it was not showing the correlation between the tasks, moreover, there was no effect to other tasks when one of them delay. Figure 5 illustrates the example of Gantt chart, the beginning point of project management tools.

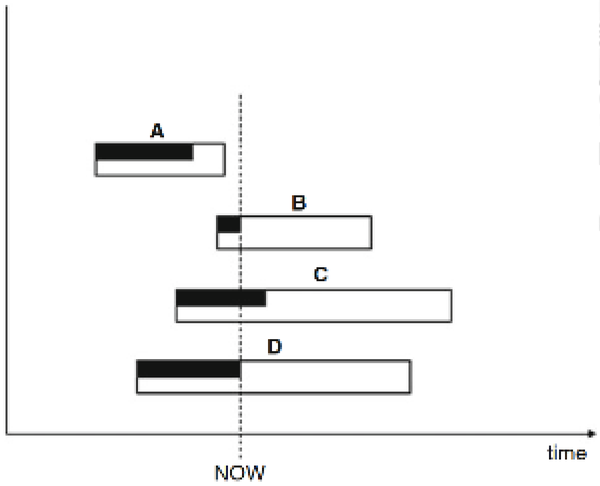


Figure 5 Example of Gantt chart (Tonchia, 2018)

Tonchia (2018) also points out three disadvantages of the original Gantt chart that first, it is not considering the priority amongst each task. Second, though the tasks are put in sequences, the reasons behind them may not be because of the sequential but by other rationales such as lack of resources. Lastly, the diagram should have arrows showing sequences, however, complex project can lead to complication in chart.

Baldwin & Bordoli (2014) describe further that later in 1958, the Program Evaluation Review Technique (PERT) was introduced by the U.S. Navy Special Projects Office and it was used in the Fleet Ballistic Missiles Programme. The PERT was used in that complicated and complex project to determine the longest incompressible sequence of work.

The PERT analysis comprises three types of durations required to estimate an individual task time consumption which are the optimistic, the pessimistic and the most likely durations. After the three have been gathered, the weight average will be applied and the expected duration can be obtained. Stacking up all the tasks and align them well whether they are related to each other in series or in parallel, the total project timeline with critical path can be estimated. The PERT analysis is appropriate for the new task or new project timeline estimation.

At that time, the Critical Path Method was also developed by the DuPont company and was later on proved success. The general term Critical Path Analysis (CPA) (or substitutable, Critical Path Method (CPM)) was therefore used to determine the sequence of works that form the longest time consumption to the project. Two techniques are embedded there, the tasks on arrow and the order of precedence of each task. Figure 6 shows example of CPA (or CPM) analysis.

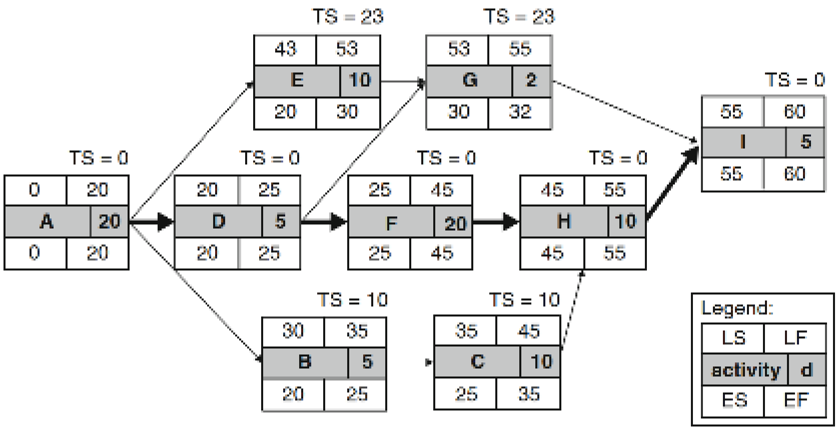


Figure 6 Example of CPA chart showing critical path in bold (Tonchia, 2018)

Later on, however, with reference to the NEDO report in 1983, Baldwin & Bordoli (2014) mention that the CPA techniques did not guarantee the success of the projects and there was no interconnection shown between the use of CPA technique and those successful projects, on the other hand, though the project was using the well contemplated CPA technique, it can be failed by many other factors such as low-quality project management.

The utilization of the project management tools became popular again with the aid of the computer software which provided the local project site team with an access to the up-to-date and linkable bar chart in the CPA software. This makes the CPA not outdated compared to the actual progress at job site. After utilization of the effective computer software, relevant people realized that there must be other rationales to think about other than tools that were available. This was because the successes of many projects were still volatile (Baldwin and Bordoli, 2014).

In 1990s, the Critical Chain Project Management (CCPM) was introduced. The tool concept is to focus on the overall project's buffer rather than individual task buffer, revisit the project schedule time to time and allocate suitable effort including additional workforce to deal with the critical path occurring. With reference to Baldwin & Bordoli (2014), another debate by Ballard and Howell (1992) was that though the project critical path was well analysed, there were still other uncontrollable factors such as unavailable of labour which can cause the project delay. They argued that the planning should focus on the actual capability at that time rather than what should be done.

Nowadays, the Building Information Modelling (BIM) system has become popular amongst construction business and proved advantage to the users. The BIM is the virtual 4D system which can extract the detailed information of all related activities such as procurement's requirements to the project management software to visualize the ongoing progress (Baldwin and Bordoli, 2014).

2.3 Risk management in construction and commissioning

In any construction project, risk will still persist though there are well preparation and planning. Hessler (2014) defines that risk can be anything that can affect the project success in dimensions of time, cost, quality and also safety.

To deal with the risks, he depicts that risk management would comprise three elements, the well- prepared contract, the claim process and the insurance coverage. Figure 7 shows visualisation of risk management tools.

Figure 7 Risk management tools (Hessler, 2014)

Moreover, to understand those risks in detail, risk matrix can be generated which risks' description, likelihood and the level of impact can be considered. The multiplication of the likelihood and level of impact can be put in order to see what risk might harm the project mostly. After that, the mitigation measure to encounter those risks can be populated.

2.4 Risk response strategies

Cretu, et al. (2011) argue about the risk response strategies such that prior to the determination of the proper mitigation measures to those risks, the high level response strategies must be first categorized. Cretu, et al. (2011) propose four groups of risk response strategies as discussed in the following sections.

2.4.1 Avoidance

Cretu, et al. (2011) discuss that avoidance is the best way of handling the risk if possible. One of the possible ways is to modify the scope of works in consideration by doing the alternative instead. However, avoidance of the risk may have additional cost in doing its substitutions which the executioner will have to evaluate whether the alternatives are worth for implementation or not (Cretu et al., 2011).

2.4.2 Transference

The risk in doing works can be transferred by engaging the entity which is more prudent or specialized in that work to be in charge which this is normally the contractor. Though the risk can be pass throughed, it can be subjected to a higher cost compared to completing that particular task by the project owner themselves. However, cost impact from failure to do so by the project owner may be worse than that addition cost by incurred by the appointing the contractor (Cretu et al., 2011).

2.4.3 Mitigation

Mitigation is the measure to reduce the impact and/or possibility of the risk in consideration. Cretu, et al. (2011) argue that the earlier the mitigation measure applied, the easier to do so. Moreover, with the late application of the mitigation measure, there will be more costly in applying than commencement mitigation measure since the beginning (Cretu et al., 2011).

2.4.4 Acceptance

Acceptance is the last measure among all which is however viable for the risks with low possibility or low impact or the aforesaid measures are not appropriate to apply. The contingency budget can be set in this case to accommodate those risks if happen. Moreover, as the ultimate case, ignoring those risks can also be the last alternative (Cretu et al., 2011).

2.5 Similar study

Similar study is found in the area of ultra-critical[1] coal-fired power plants in Korea. Lee, et al. (2018) analyze the construction critical path of ultra-critical coal-fired power plants with the examples of existing 4 ultra-critical and 5 super-critical plants as well as comments from 10 experts. He found that the academic study on the area of construction planning has generally been omitted by focusing more on operating performance, engineering challenges, environmental impact and financial outcomes, this therefore presents a literature gap. Lee, et al. (2018) utilized the PERT and CPM together with the Monte Carlo analysis to assess the construction critical path activities of those plants.

Lee, et al. (2018) categorized his research in several steps including define the high-level project activities, define expected timeline of each task using PERT, analyze construction critical path using Microsoft Project, calculate standard deviation and probability, simulate the project construction critical path and lastly, assess the risk by survey with experts in the area.

The result is reported that the project construction is likely to be between 62.6 to 70.7 months with 85% likelihood. Boiler pressure part installation and test run were found having the major impact on the overall construction timeline. Moreover, from expert interview, most likely risks are identified as labor strike and accident at site respectively (Lee et al., 2018).

[1] Ultra-critical is defined as the power plant that operates with the minimum main steam pressure and temperature of 30 MPa and 610 C respectively.

Chapter 3. The Research Methods Used

The methodologies of this research comprise major steps as illustrates in the following Figure 8.

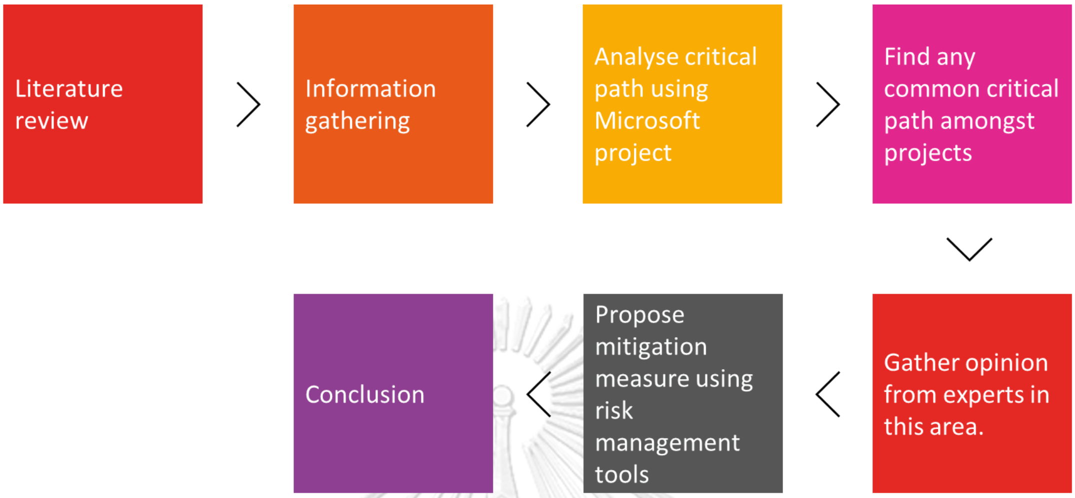


Figure 8 Methodologies major steps

3.1 Literature review

As this research will be analysing the critical path during the power plant project construction, this section's purposes are to review the related journals, papers and research to gain additional knowledges on:

Functional and practical configuration of the CCGT power plant projects;

Tools that are used for the construction project management especially in analysing the project timeline and critical path;

Possible mitigation measures by applying risk management to the area of concerns; and

Any related studies which argue about the critical path of the construction project particularly the power plant of the similar type.

3.2 Information gathering

In this stage, the planned and as-built project schedule of the CCGT power plant construction projects will be gathered. These information in detail will be gathered from at least 3 – 4 CCGT power plant projects. Due to many projects are developed under the confidential basis and not much information is available publicly, all the information will be processed on the anonymous basis (i.e. Project A, Project B, Project C and Project D). Different size of CCGT power plant projects will be taken into consideration whether the large and small CCGT power plants share any common construction critical path or not. The information obtained should have an appropriate in-depth level of detail to conduct the critical path analysis of each project.

3.3 Detailed activities analysis

In the real world, the practical project critical path can be found starting from the work breakdown structure ("WBS"). The WBS will illustrate the work in that project in detail. The better WBS used, the better critical path analysis result (Ramos, 2017). The WBS is a tool to extract the whole project into a smaller task where good WBS determination is linked to the scope of work to be done under such project. It is also necessary for the project manager to be clear on what to be delivered under that project otherwise it will be difficult to control the project in all aspects (Baldwin and Bordoli, 2014). Figure 9 shows the example of the WBS.

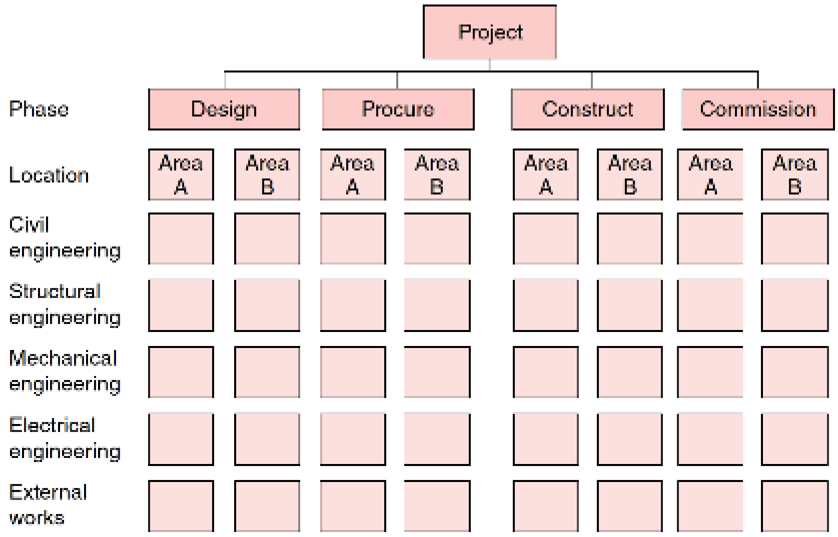


Figure 9 Example of functional WBS (Baldwin and Bordoli, 2014)

Subsequently, it is necessary to arrange the tasks in the WBS in order and link sequences between them. This is crucial to illustrate the interconnections and conditions among those tasks. Those relations will demonstrate whether the particular task can start or not if the precedent task is not yet finished and what is the effect to its dependent task. By putting relations to all the tasks in the project, the overall project steps in sequences can be figured out (Ramos, 2017).

Then, the duration of each task will have to be determined. After that, the longest route of task in sequence forming critical path during construction of each project will be analysed. This will include the near-critical activities analysis as those can potentially become a critical path if any delay to that near-critical task occur (Nagata et al., 2018). The main tools used will be Microsoft Project or equivalent which could help analyse not only the critical path itself but the float available in each activity as well as its early start, early finish, late start and late finish.

3.4 Find common critical path among projects

After the critical path of each project is analysed, they will be compared to other projects whether there is any common critical path or not. Project’s specific conditions will also be taken into considerations such as size, overall construction duration and any other concerns if found strongly related to the project’s overall activities.

3.5 Gather opinions from experts in this area

To evaluate the analysis results with projects in the real industry, opinions from expert or specialist in this area will be gathered. 2 -3 experts will be interviewed and asked for their comment on the analysed results whether the results are in line with their experiences or not.

3.6 Mitigation measures to be recommended

Risk management knowledge will be contemplated to analyse how to practically apply those measures to mitigate or prevent delay that might occur to such area of the critical path found.

For example, Ramos (2017) argue that fast tracking and crashing techniques on the critical path should also be considered. Fast tracking is to find the way to do the critical path in parallel, consequently, shorten the overall project duration. Crashing is to determine the factor that limit that critical path, for example, limited resources, and try to overcome that limit such as adding labour or equipment. However, these techniques may or may not be enforceable as they come with cost which the project manager will have to balance and make a decision to those in the real works because conditions of accelerating the schedule are different project by project.

Chapter 4. Work breakdown structure ("WBS") in CCGT power plant constructions

To create the WBS required for construction of the CCGT power plant projects, the activities in all the gathered projects information have been investigated and grouped into certain levels with in-depth details for further analysis. In this research, the grouped activities are targeted to level 3 of the project construction schedule as the minimum. Sequences of the activities are referenced from the project construction schedules which show interconnection among those.

It should be noted here that prior to start the construction of each project, all the necessary permits and documents have assumably been obtained by the developers. These permits and documents include, but not limited to, the approval of the Environmental Impact Assessment (EIA), the construction permit, the electricity generation license, etc.

The WBS of the CCGT power plant constructions are then created as Figure 10. Their detailed activities and sequences are further descried and explained in the subsequent sections.

The raw data of all the projects have consequently been analyzed and put in order using project scheduling software according to the WBS determined. The project critical paths and float of activities are then automatically calculated. In this research, the near-critical paths shall consider the activities which have the total float of less than 20 percent (noted that 20 percent is opined from the expert interviewed to be adequate in consideration of the near-critical path for this type of project construction).

For clarity, the total float is defined in this research as the duration that each particular task can be delayed compared to its duration. For example, if the duration to complete task X is 100 days and it can be completed within 120 days as the maximum in order not to impact the overall project schedule, therefore, total float of task X is 20 days or 20%. On the other hand, if task X delays more than the total float period, the end date of the project would be shifted.

Section 5.2 to Section 5.5 show the summarized results of the critical paths and near-critical paths of both the planned and actual construction schedules found. Appendix A to Appendix D show the detailed results of construction schedules analyzed from the raw data of planned and actual timeline of Project A to Project D respectively.

Moreover, it is recognized during the information gathering that the planned schedules are linked to the payment milestone of all the projects which will directly affect the cash flow of all. Therefore, the planned schedules are considered generated with certain level of credibility for implementations as the baseline for all the projects.

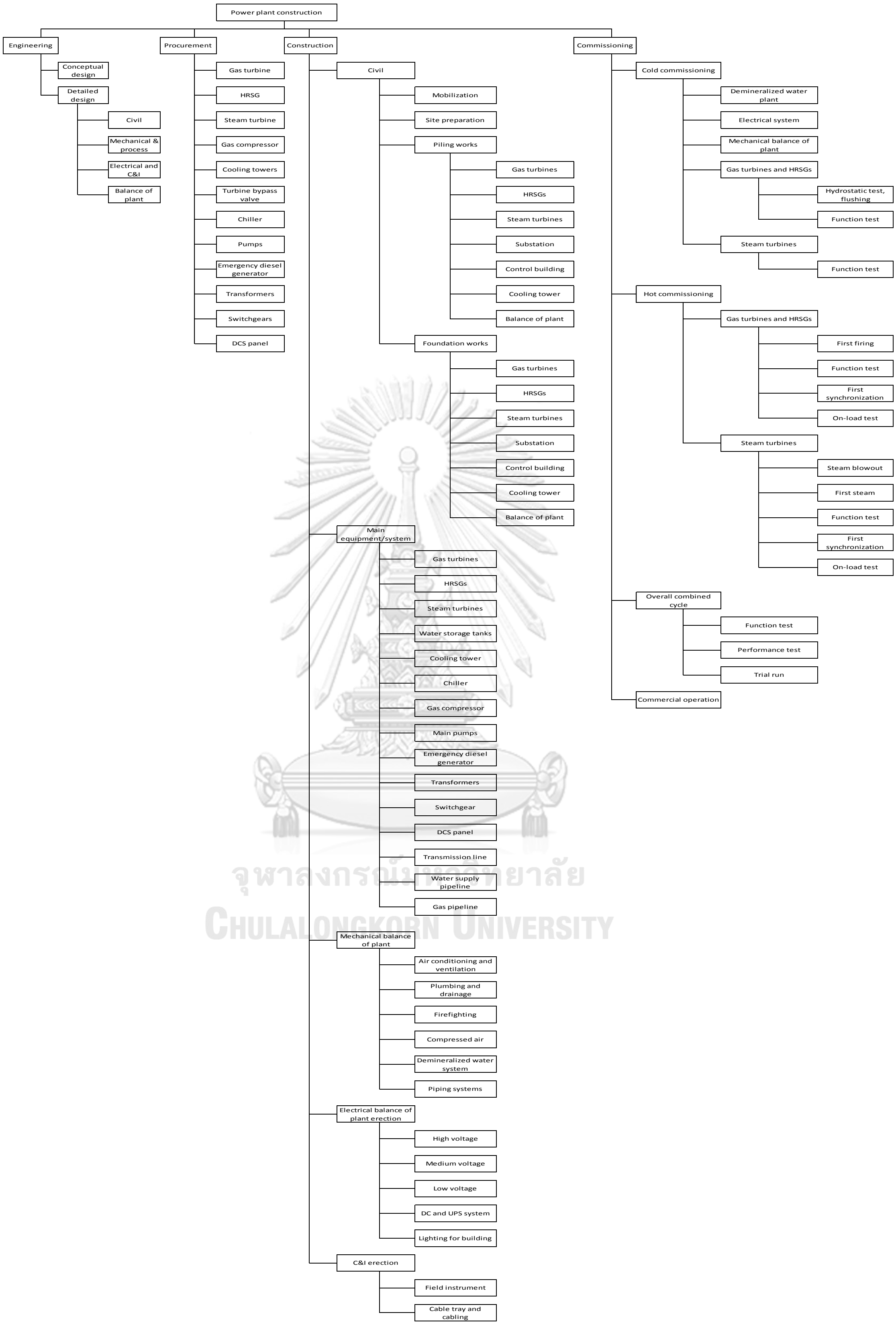


Figure 10 Work breakdown structure of the CCGT power plant construction projects in this research

4.1 Contractual key milestone

4.1.1 Construction contract signing with the contractors

Prior to commencement in constructions of all projects, the key milestones of the construction contract signing with the contractors are set out and noted in all the projects' planned schedules. The construction contract is the agreement which address various aspects mutually agreed by the project developer and the contractor in construction of the power plant such as scope of works, preliminary design, requirements of service and equipment to be provided, plant's performance guarantees, liquidated damages, legal obligations, payment terms, warranty period, etc.

Normally the developers will contract the Engineering, Procurement and Construction contractor (or the "EPC contractor") to construct the power plant. This is because the EPC contractor is specialized in the construction of the power plant in nature. Moreover, as the construction projects will have to deal with many risks during implementation, this is also the risk allocation by the developer to specialist in this area who should be able to manage those construction risks better and more professionally.

4.1.2 Notice to proceed

Notice to proceed or "NTP" is the key milestone found in all projects such that the project owners issue the official letter to the contractors to officially start the work. This is normally related to the payment milestone and trigger the many obligations under those contracts. Consequently, this will also allow the contractors to commence the work that involve with significant payment such as order confirmation of major equipment, start mobilization and construction at site, etc.

4.2 Engineering work

4.2.1 Conceptual design

The conceptual design is the engineering work to affirm what key requirements of the projects will be at a high level, for example, this includes the design confirmation of:

Capacity;

Efficiency (or heat rate);

Plant configuration (number of gas turbine, HRSGs, steam turbine and other key equipment);

Key equipment arrangement (gas turbine on the single shaft or multi shaft);

Fuel characteristic;

Water consumption;

Fuel consumption;

Emission level;

Plant layout;

Heat balance diagram;

Water balance diagram;

Process flow diagram;

Termination points of interconnection;

Steam main cooling arrangement;

Control system architectural.

These conceptual engineering work can be commenced after the contract signing. However, in some cases, they can be done prior to the contract signing or since the project bidding phase.

The conceptual design is necessary for the procurement of all the main equipment and also the detailed design engineering.

4.2.2 Detailed design

The detailed engineering is the work that describe further the conceptual design and make it constructible. Calculations to support the design will be performed and this is usually subjected to review and approval by the owner of the power plant whether they are in compliance with the required functionality of the project as agreed or not.

As the completion of engineering works in all projects are likely to continue until the end of the projects, for example, the completion of as built drawings and the final documentations, in this research, the detailed design of each category shall refer to the completion of such which allow the dependent works to start. For example, the civil detailed design shall refer to the completion of calculations and drawings which allow the piling works to start. Parallelly to the piling works, the remaining civil detailed engineering works shall continue.

Similar engineering works can be grouped by their functionality and engineering discipline as describe below.

4.2.2.1 Civil detailed engineering

For the civil detailed design, it usually starts from consideration of the load from the equipment and structure then design the support and foundation with consideration of the soil bearing load properties normally obtained from the soil investigation and testing. For good engineering practice, this has to be done in accordance with the acceptable or agreed engineering standard (Black & Veatch, 1996). The agreed design life of all the structures which is normally equal to or more than the power plant life has to be factored into the design as well.

All the underground structures designed must also be able to withstand the corrosion of the soil's chemical properties which can be contaminated by acid, alkali or other chemical contamination which can be different from site by site.

Moreover, local law and regulations have to be taken into account such as seismic load resistance. Other loads in consideration will have to include the static load and the specifically the dynamic load from the rotating heavy equipment such as gas turbine and steam turbine. Natural disaster requirements such as flood level, rainwater level, wind speed will have to be considered as well.

Prior to the civil detailed engineering to be finalized, the key outputs from the conceptual design have to be firmed and fixed, for example, the plant configurations, the plant layout and the termination points.

The output from the civil detailed design would typically include the piling and foundation calculations, piling layout drawings, foundation drawings, structure drawings, architecture drawings, road and paving drawings, site drainage drawings, pond drawings.

4.2.2.2 Process and mechanical detailed engineering

The process and mechanical detailed engineering will have to consider the overall process requirement, in this regard, the combined cycle power generation process. Calculations have to be done to confirm the design of the main system and auxiliary systems to make the plant in achieving its highest efficiency as agreed, at the same time, the contractor has to lowest the cost to make it economically viable as much as possible. These include but not limited to the design of:

The gas turbine system, which is the initial power generation system of the power plant;

The fuel gas heating and gas compression systems (if required);

The steam turbine system;

The HRSGs and feedwater system;

The main steam cooling system;

The flue gas treatment system; and

Interconnection to other miscellaneous balance of plant systems.

Almost all the outputs from the conceptual design will have to be freezed first. These include, but not limited to, the designed plant capacity, efficiency, plant layout, equipment configuration, fuel characteristic, emission level, heat balance diagram, water balance diagram, process flow diagram.

The deliverable from the process and mechanical detailed design would typically include the piping and instrument diagrams (P&ID) of all the processes. Moreover, key equipment detailed specification for the purpose of issuance of the purchasing orders to the suppliers will be required especially for those with long lead delivery time. The detailed calculations and drawings will have to be generated as well to support further site erections.

4.2.2.3 Electrical detailed engineering

In the electrical detailed engineering, many key electrical requirements of the project starting from a conceptual design such as power output (in megawatt), grid connection criteria, grid termination point, number of generators and main local power consumers have to be considered then cascade them to the more detailed design works which are specifically for such power plant.

A couple voltage levels can be utilized to suite them with particular applications in the power plant, for example, power is usually exported from the power plant at the high voltage level in accordance with the grid requirements to minimize the lost in transmission line, the power is usually originated from the generator at the middle voltage level which is typical designed by the turbines’ generator manufacturer and the low power consumption equipment is usually design at the low voltage level to save the equipment cost.

Moreover, to provide the plant’s backup power supply, the uninterrupted power supply (UPS) system is required to support the power to the equipment with essential power requirement for conducting the safe shutdown in case of emergency, for example, in case of the plant trip or blackout (disconnected from the grid and cannot generate the load to supply plant’s minimum self consumption). This power is usually kept in the direct current (DC) battery storage system which will be drawn out during emergency cases.

The site characteristic such as soil electrical resistance will have to be analysed and the calculation of the plant’s earthing system will have to be done based on this analysis to support the plant’s operation.

The deliverables from the electrical design typically include the for-construction of single line diagram, the three-line diagram, electrical operation philosophy, the cable sizing calculation, the cable routing drawings, the equipment rating design, relay protection systems and interfaces, the wiring diagrams, earthing systems calculation and drawings, lightning protection system calculation and drawings, UPS system drawings, etc.

4.2.2.4 Control & Instrument (C&I) detailed engineering

The C&I detailed engineering is mainly to design the control logic and interfaces of all the equipment. This includes the power plant's control philosophy, signal interface among single equipment and main distribution controller system (DCS) in the central control room, programming of sequential operation, control schematic diagram, interlock protection and interface philosophy, control logic diagram, instrument specification, instrument layout, instrument installation detail, control cable routing, control cable wiring diagram, etc.

Some necessary calculations will be needed to support the C&I detailed engineering such as hazardous area determination, island mode operation concept (where the plant is disconnected from the grid and only generate power to maintain the in-house load to keep the plant in continuous operation).

To effectively commence the C&I detailed engineering, all the conceptual design should be firmed in order not to replicate the design work which will result in additional time (and cost) consumption.

4.2.2.5 Balance of plant detailed engineering

The balance of plant systems are the auxiliary systems that support and fulfil the functionality of the main power generation system of the power plant. These systems typically include:

The water treatment system;

The wastewater treatment system;

The cooling water system;

The compressed air system;

The firefighting and fire alarm system;

The close loop cooling system;

The piping systems.

The balance of plant detailed engineering is required prior to commence the construction of the work at site for the above mentioned systems. Its output typically includes the pipeline sizing, the isometric drawings of pipelines, the bill of bulk materials (piping, fitting, small valve, gasket, etc.), the stress analysis for high pressure and high temperature system and the detailed plant arrangement of each system.

4.3 Procurement work

In this research, procurement and manufacturing of the equipment refer to the period starting from issuance of purchase order to the manufacturer or supplier until the equipment is delivered on site.

Particularly for some of the main equipment works, there are some procurement in details noted as follow.

4.3.1 Gas turbine and generator

The procurement of the gas turbine and generator (GTG) is observed including not only the price negotiation of its capital cost but also the spare parts cost and long term service agreement fee (if applicable). As this is the core equipment for the combined cycle power plant and to preliminary accept the equipment performance, factory acceptance test is usually conducted prior to shipment from the factory to the site. This is to ensure that the gas turbine performance at the time of manufacturing completion from a factory meets with the agreed specification.

Gas turbines and generators transported to the site will be erected further on the foundations specifically prepared to ensure that the static and dynamic load from this rotating heavy equipment is properly absorbed.

Figure 11 shows gas turbine manufacturing at factory and Figure 12 shows gas turbine’s generator during transportation.

Figure 11 Gas turbine fabrication in manufacturer workshop (Project C monthly reports)

Figure 12 Generator transportation (Project D monthly reports)

4.3.2 HRSGs

The procurement of the HRSGs includes the price negotiation and also other manufacturing conditions which have to be taken into account such as detailed equipment specification, performance, location of manufacturing, subcontracted fabricator and delivery time, etc.

Prior to shipment of the HRSGs to the site, the foundations of the HRSGs have to be completed first to accommodate the laydown of this equipment which is large in both size and weight.

Figure 13 shows HRSG fabrication at manufacturer's workshop.

Figure 13 HRSGs fabrication in manufacturer workshop (Project C monthly reports)

4.3.3 Steam turbine and generator

The steam turbine and generator (STG) procurement mainly have to negotiate with the price, however, the efficiency is also the key consideration as steam turbine is one of the key power generation equipment other than gas turbines. Different steam turbine manufactures can offer different steam turbine efficiencies at different price so the procurement team will have to make a decision on which manufacturer they will be moving forward with.

Same as gas turbines and HRSGs, the steam turbine foundation has to be made ready first before erection of the steam turbine at the site.

Figure 14 shows steam turbine during transportation to the site.

Figure 14 Steam turbine's lower casing transportation (Project D monthly reports)

4.4 Construction work

4.4.1 Civil work

4.4.1.1 Site preparation

Prior to the site construction work to start, the site preparation work is required to make the site ready for construction activity. This, however, depends much on characteristic of each project site.

Activities under site preparation include site levelling, soil cut and fill, existing facilities removal (if applicable). In this report, completion of site preparation means that the site has been prepared and ready for starting of further site construction activities such as piling, foundations, etc.

Figure 15 illustrate example of site preparation work.

Figure 15 Site preparation works (Project C monthly reports)

4.4.1.2 Piling works

For all the projects in this research, the piling works are required for supporting foundations of equipment, building, structures as required by calculation of the load which depends on site geotechnical conditions.

In this research, the completion of piling works means that the piling works have been done so that the following works of foundations of such equipment or structure can commence.

Figure 16 illustrates an example of pilling activity.

Figure 16 Piling works (Project A monthly reports)

4.4.1.3 Foundations

The foundations are the basement of all equipment and buildings which support both the static and dynamic loads during operation then transfer them further to the pilings.

In this research, the foundations can commence after completion of the piling works of such equipment or buildings. Generally, the foundation works include following sub-activities:

Lean concrete pouring;

Rebar wok;

Formwork; and

Concrete pouring;

The completion of foundations in this research mean that they have been installed, tested and ready for the equipment or building further erection works on such foundations.

Figure 17 to Figure 20 illustrate some foundations works of Project A and Project D

Figure 17 Tanks foundation lean concrete pouring (Project A monthly reports)

Figure 18 Gas turbine foundation rebar works (Project A monthly reports)

Figure 19 Gas turbine foundation formworks removal after concrete pouring (Project D monthly reports)

Figure 20 Transformer foundation after concrete pouring (Project D monthly reports)

4.4.1.4 Buildings

For some equipment which has to be installed indoor, for example, electrical and control equipment, the buildings housing those are therefore required.

As the building finishing works such as lighting and ventilation system installation can be done parallelly with the equipment installation, in this research, completion of building installation means that the particular building is ready for subsequent equipment or systems installation, for example, turbine, pumps, switchgears, control cubicles, motor control panels, cable trays and etc.

Figure 21, Figure 22 and Figure 23 illustrate buildings installed in Project A, Project C and Project D respectively.

Figure 21 Central control building installation (Project A monthly reports)

Figure 22 Water treatment building installation (Project C monthly reports)

Figure 23 Turbine building installation (Project D monthly reports)

4.4.1.5 Pipe racks and pipe bridges

To support the interconnections of piping, power cables, control and communication systems among the sub-systems of the power plant, the pipe rack and pipe bridges are required to support those facilities. Pipe racks and pipe bridges are usually made from steel structures fabricated from the manufacturing workshops then transported and erected at site with some remaining final field assemble joints.

In this research, completion of pipe racks and pipe bridges means that they are partially ready for the piping or cable tray installations although there will be some finishing works remain such as painting works.

Figure 24 illustrate example of pipe rack and pipe bridge erections.

Figure 24 Pipe rack and pipe bridges installation (Project B monthly reports)

4.4.1.6 Wastewater ponds

The wastewater ponds are found the requirements by the authority as part of the environmental impact assessment (EIA) of Project A, Project B and Project C. They are functioned to collect the wastewater from the projects' process prior to discharge them from the power plants. In which, water qualities will be continuously monitored to see whether they are within the allowable qualities limit. The sizes however are found different project by project.

Figure 25 illustrates wastewater pond construction.

Figure 25 Water pond construction (Project B monthly reports)

4.4.1.7 Road and paving

Sequence of constructions of road and paving are found different project by project. Project B for example, roads are constructed along with other civil works since the beginning of the project. However, in other projects, temporary roads were used during construction which can alleviate the damage to the permanent roads however cleanliness of the site need to be well managed.

Figure 26 shows example of road and paving.

Figure 26 Road construction (Project B monthly reports)

4.4.2 Main equipment erection work

4.4.2.1 Gas turbine

In this research, the erection of gas turbine includes the gas turbine core engine itself and also related auxiliary system connecting to the gas turbine, for example, lube oil system, air inlet filter system, etc.

Figure 27 shows example of gas turbine and its generator erection.

Figure 27 Gas turbine and generator erection (Project D monthly reports)

4.4.2.2 HRSG

It is found that normally the HRSGs are transported in fabricated modules from the factory which the modules' sizes are vary depend on allowable specific site constrains, for example, port available, width of access road along the transportation routes. Though the majority can be shop fabricated, there will still need to be the site erection inevitably to integrate the separated HRSG modules together.

In this research, the HRSG erection starts since the first module of HRSG being installed at the project site until the period that the whole HRSG is completed and ready for the hydrostatic test. Moreover, the erection of HRSG also includes its components such as deaerator, economizer coil, evaporator coil, superheater coil, steam drum, HRSG's casing, etc.

Figure 28 and Figure 29 demonstrate HRSG modules being installed.

Figure 28 HRSGs installation (Project A monthly reports)

Figure 29 HRSGs installation (Project D monthly reports)

4.4.2.3 Steam turbine

It is observed that the steam turbine as the heavy rotating equipment will be installed on its own separate foundation from the turbine hall. In this research, the steam turbine installation starts from the steam turbine arrival at site, continue to lifting the steam turbine on base and also erections of its auxiliary systems connecting to the steam turbine such as adjacent steam pipelines, lube oil system, turbine bypass system, condenser, cables termination and local control equipment installation.

Figure 30 and Figure 31 show steam turbines under installation.

Figure 30 Steam turbine installation (Project C monthly reports)

Figure 31 Steam turbine installation (Project D monthly reports)

4.4.2.4 Water tank

The water storage tanks are required to reserve many types of water required for power plant operation. These types of water include raw water (non-treated water from supply source), service water (preliminary treated raw water such as screening through sand filter), tap water (treated water supplied from the local water distributor), demineralized water (treated water by power plant's water treatment system for feeding into boiler and steam system).

The requirements of storing each type of water, storage capacities and materials of tanks (i.e. concrete, steel) however are found vary project by project.

Figure 32 shows steel-type water storage tank erection.

Figure 32 Water tanks installation (Project B monthly reports)

4.4.2.5 Cooling tower (if applicable)

For projects in Thailand where water can potentially be a main source of cooling media (unlike those in the Middle East for example), wet type cooling tower is usually designed as the heat exchanger to cool the temperature of the main cooling water down and recirculate it back to the condenser to minimize the water consumption of the projects from natural resource.

Cooling tower has to be installed on the cooling tower basin which will be constructed as part of the civil miscellaneous buildings works.

Figure 33 shows example of cooling tower erection.

Figure 33 Cooling tower installation (Project B monthly reports)

4.4.2.6 Chiller

In Project B of this research, the gas turbine’s air inlet chiller is installed to enhance the overall plant efficiency. Though the chiller increases the internal power consumption, it will lower the gas turbines’ air inlet temperature which will enhance the gas turbine performance and eventually result in the better overall plant performance enhancement.

Installation of chiller in this research includes the chiller itself and the adjacent connection of piping, electrical and control and instrument cable.

4.4.2.7 Pumps

In power plants, various types of pumps are used in many applications, however, in this research, the pumps installation will be focusing on the main process pumps only which are the boiler feedwater pumps and the main cooling water pumps as these pumps are larger than others in terms of capacity and are required for contribution to the main process running. The installation includes mounting the pumps on base, alignment, cable termination and piping connection.

Figure 34 and Figure 35 show installation of main pumps in power plants.

Figure 34 Boiler feedwater pumps installation (Project C monthly reports)

Figure 35 Cooling water pumps installation (Project B monthly reports)

4.4.2.8 Emergency diesel generator

The emergency diesel generator (sometimes called “EDG”) is installed to supply power to the power plant in case that the plant has accidentally shutdown and disconnected from the grid, thus, the back feed of power from outside source is unavailable. In that case, the emergency diesel generator will be in operation to supply the power to plant’s uninterruptable power system (“UPS”) for equipment which require power to support safe shutdown or other essential functionalities of the project, for example, the turbine lube oil system which has to be in operation after plant shutdown to cooldown the turbine and keep the turbine in low speed rotation to avoid turbine shaft sacking.

Erection of emergency diesel generator in this research includes the equipment itself and connection of power and control cable to the emergency diesel generator

4.4.2.9 Turbine bypass valve

The turbine bypass valve is a specific equipment that will bypass the steam from the steam turbine and direct it to the condenser. This functionality is normally used during the start-up, shutdown and emergency cases. The turbine bypass valve has to be supplied with an exceptional quality as malfunction of this equipment could lead to failure of the steam turbine system.

Installation of turbine bypass valve in this research includes installation of the equipment itself and connection with adjacent piping system and control and instrument cables.

4.4.2.10 Transformer

The transformers of the CCGT projects are generally include the generator step up transformer which is the main transformer stepping up the electrical voltage from turbine’s generator to the voltage level required by the grid and the auxiliary transformer which is installed to adjust the electrical voltage from the generator to the level required by the plant’s auxiliary equipment.

Installation of transformer in this research includes putting the transformer on base and connection of the power and control cables to the equipment. Figure 36 illustrates example of transformer installed.

Figure 36 Transformer installation (Project D monthly reports)

4.4.2.11 Switchgear and/or switchyard

Switchyard comprises set of switchgear, relay protections and communication system connecting the power plant to the local electricity grid which is normally at the high voltage level (i.e. 115kV and higher).

Completion of switchgear and/or switchyard in this research means that it is ready for functioning of the incoming/outgoing of the electricity from/to the local grid.

Figure 37 shows power plant switchyard under construction.

Figure 37 Switchyard installation (Project D monthly reports)

4.4.3 Balance of plant mechanical erection works

The balance of plant mechanical erection works comprise installation of the supporting system to the main power generation systems, in this research, they include the air conditioning and ventilation system as required by some equipment; plumbing and drainage system; firefighting system; compressed air system; demineralized water system.

As the nature of construction of these balance of plant system will continue throughout the end of the project to complete the minor remaining works or punchlist items, completion of the balance of plant mechanical erection work in this research covers only the essential supporting systems which can be partially completed and ready for supporting the power plant's cold commissioning works, main focus is on the water treatment system.

Figure 38 shows the demineralized water treatment system as part of the mechanical balance of plant installation.

Figure 38 Demineralized water system installation (Project C monthly reports)

Apart from the essential balance of plant systems discussed above, the piping systems are also the key element which connect various systems together. This include the steam pipeline, boiler feedwater pipeline, cooling water pipeline, compressed air pipeline, etc. Completion of the piping systems in this report means that those main process pipelines have been installed and hydrostatic tested.

Figure 39 to Figure 42 illustrate examples of process piping installations.

Figure 39 Piping system installation (Project B monthly reports)

Figure 40 Piping system installation (Project B monthly reports)

Figure 41 Cooling water pipes installation (Project A monthly reports)

Figure 42 Cooling water pipes installation (Project D monthly reports)

4.4.4 Balance of plant electrical erection works

The balance of plant electrical erection works in this report includes the electrical interconnection system between system and equipment, for example, interconnection cable between the generator and transformer, etc.

The categories of the electrical erection works can be divided further by their voltage levels such as the high voltage system (115kV or above), medium voltage system (11kV - 66kV) and low voltage system (400V and below).

Figure 43 shows example of high voltage cable installation work.

Figure 43 High voltage cable installation (Project B monthly reports)

Other than those mentioned voltage levels which are the Alternating Current (AC) systems, there is the need of the Direct Current (DC) system and Uninterruptable Power System (UPS) to support the power plant as the emergency power backup. These systems are to supply the power to the essential power required equipment, for example, the distributed control system (DCS) which is acting like the brain of the power plant that requires power at all the time even when the power plant accidentally trips and no power generated from the plant's generator nor external back feeding to supply power plant's self-consumption.

Figure 44 shows example of the DC system and UPS installation.

Figure 44 Battery and charger installation as part of the UPS (Project B monthly reports)

Moreover, balance of plant electrical equipment installation comprises miscellaneous erection of supporting equipment such as lighting for building, cable tray and cabling work, etc.

Figure 45 and Figure 46 show example of the cable tray and cable installation work respectively.

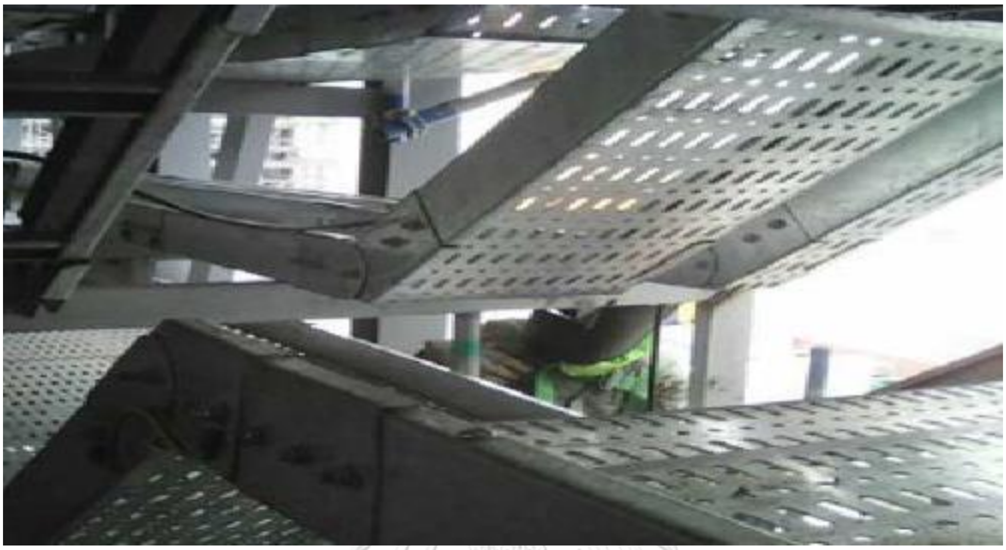


Figure 45 Cable tray installation (Project B monthly reports)

Figure 46 Cabling work (Project B monthly reports)

4.4.5 Balance of plant Control and instrument ("C&I") erection works

The balance of plant C&I erection works mainly comprise installation of Distributed Control System (DCS), field instrument, control cables and communication systems. Cable trays supporting the interconnecting C&I cables among systems can be installed coincidently with the power cable trays but usually those two types of cables are located in different layers of trays to avoid signal interference from power cables.

4.4.6 Transmission line

The transmission line is required to export power to the grid and in some cases, for example, during power plant shutdown or trip, import power back from the grid. In normal case, the completion of the transmission line is required prior to the back energization.

Construction of transmission line however depends much on the local site conditions whether there is difficulty or obstruction in construction along the route or not. Figure 47 shows example of transmission line installation.

Figure 47 Transmission line installation (Project D monthly reports)

4.4.7 Water supply/discharge pipeline

The raw water supply line is required to convey the raw water from the source to the power plant which the type of water used, distance and route line conditions are different project by project.

In this research, the raw water supply line construction starts from the day the notice to proceed of this work has been issued to the water supply pipeline contractor until the water is ready and available for project’s water treatment system.

4.4.8 Gas pipeline

Gas pipeline and metering station is required to receive the gas from gas supplier to the power plant which in Thailand, the natural gas is only distributed by PTT PLC.

Similar to the transmission line, constructions of gas pipelines are different project by projects depending on the route they are going through, moreover, the length, land acquisition, right of way, permit and license required are also the factors which greatly impact the construction schedule of this work.

In this research, the construction duration of the gas pipeline refers to the day since the notice to proceed to this work has been issued up to the date where the pipeline and metering station are completely installed, ready to supply the natural gas to the power plant.

Figure 48 shows example of gas metering installation inside the power plant.

Figure 48 Gas metering installation (Project B monthly reports)

4.5 Commissioning

In all the power plant construction projects, the commissioning is required to test the systems installed whether they are functioning according to the initial requirement and design or not.

Commissioning of the projects can be separated into two main categories, cold commissioning and hot commissioning. The cold commissioning represents the test run of equipment or system which there is still no gas firing in the gas turbine. The power fed into the systems to test run the equipment is usually from the back energization from the grid, the same line the power plant will export its power to.

On the other hand, the hot commissioning represents the equipment or systems being tested after gas turbine firing. In case of the steam turbine, the hot commissioning represents the test run where the steam generated from the HRSGs is in place and fed into the steam turbine.

Individual activities under the cold commissioning and hot commissioning are described below.

4.5.1 Cold commissioning

4.5.1.1 Back energization

The back energization is one of the key milestones observed in all projects. It is required prior to the testing of key equipment which need high level of power consumption for their operation. Though can be different project by project, they generally include the boiler feedwater pumps, condenser extraction pumps and main cooling water pumps. Moreover, the electrical equipment soak test also require the power at certain voltage level to complete the testing.

In this research, the back energization refers to the duration since the power plant has been back energized and the power from the grid is ready for individual equipment testing according to the planned cold commissioning.

4.5.1.2 Demineralization water system testing

After completion of the water treatment system installation, one of the key products is the demineralized water which will be fed into the steam cycle. The demineralized water has to have the conditions which in line with the HRSG and steam turbine requirements otherwise it can harm those equipment in long term operation and guarantees of reliability and availability from those suppliers can be invalid which expose the risk to the project.

Commissioning of the demineralized water system in this research refer to the duration after the water has been first entered into the power plant and the water treatment system installation has been completed, ready to produce the demineralized water, until the first demineralized water has been produced.

4.5.1.3 Electrical system

The cold commissioning of the electrical systems refers to testing after completion of the installation which the quality check and quality assurance process are assumed completed as part of the construction. Testing of these electrical systems refers to the soak test of the main equipment and cable, for example, main switchyard, switchgears and transformers where the power in most case is usually fed from the back energization from the local grid.

4.5.1.4 Mechanical balance of plant system

The cold commissioning of mechanical balance of plant system includes all the individual balance of plant equipment and subsystems performance test and function test to confirm their capability in supporting the main power generation system such as the testing of boiler feedwater pumps, main cooling water pumps, cooling tower fans, compressed air system, firefighting system, gas compressor system (if installed), air inlet chiller system (if installed), etc.

4.5.1.5 Gas turbine and HRSG

The cold commissioning of gas turbine and HRSG refers to period beginning with the hydrostatic test of those equipment and the interconnection steam piping, subsequently, the cleaning and functioning test of their subsystems, for example in case of gas turbine, the lube oil flushing, enclosure leakage test and rotor turning operation test. For the HRSG, this includes the chemical cleaning (if apply) and pipe flushing. Moreover, in this research, the interlock protection tests among the gas turbine and HRSG are also included as part of the cold commissioning.

4.5.1.6 Steam turbine

Similar to the gas turbine and HRSG, the cold commissioning of steam turbine includes hydrostatic test of internal piping and the cleaning and functioning test of its subsystems such as lube oil flushing, steam turbine bypass testing, steam turbine and condenser vacuum pulling test.

4.5.2 Hot commissioning

4.5.2.1 Gas turbine and HRSG

The hot commissioning of the gas turbine and also for the whole power plant in this research is considered starting with the gas turbine first firing. After that, the equipment function test with power originated from the gas turbine will be conducted. The gas turbine hot commissioning includes the gas turbine first firing, start-up and shutdown test, full speed no load test, synchronization of its generator which the power is exported to the local grid via transmission line and afterward various functional tests in response to the grid connection requirement such as part load rejection test and full load rejection test.

Moreover, interlock protection tests and trip tests during hot run of gas turbine and the HRSG are categorized under this gas turbine and HRSG hot commissioning in this research.

4.5.2.2 Steam turbine

During the hot commissioning of the gas turbine and HRSG, the steam blowout can be performed to ensure that the steam quality entering the steam turbine is in line with the manufacturer's requirements. The main activity of the steam turbine hot commissioning in this research starts from that steam blowout and continue to the first steam entering into the steam turbine which, similar to the gas turbine and HRSG, the functioning of equipment under real operating conditions with live steam can be performed, for example, the full speed no load test and load rejection tests.

4.5.3 Overall combined cycle commissioning

4.5.3.1 Combined cycle function test

The completion of the hot commissioning of individual systems is the prior requirements for this overall combined cycle test run. The key activities during the overall combined cycle function test include the plant automatic start up and shut down, part load operation, automatic load control, interlock protection test, trip test, equipment switch over for redundancy test and full plant load rejection test. During this combined cycle function test, the power has to be exported to the grid.

4.5.3.2 Performance test

The performance test is to demonstrate the design and guaranteed performances of the power plant in comparison with the contracts or any agreed terms. General tests include power generation capacity, steam production capacity, plant's efficiency in terms of gas consumption. Other than the thermal performance tests, other performances can be included as part of the performance test such as the air emission guarantees, the effluent guarantees and the noise level guarantees as the near field noise (normally 1 metre from the equipment) and the far field noise (normally at plant's boundary).

Prior to the performance test, the plants are observed performing fully automatic mode without any forced control or any bypass signal allowed which means that the plant has to be a hundred percent complete.

4.5.3.3 Trial run

As the power plant will have to sell electricity to the grid, the trial run is therefore a requirement from the local grid to demonstrate that the power plant will be able to run in compliance with grid requirements without any harm or damage to the grid at any load dominated. The trial run with the grid in Thailand usually takes at least 5 days in case that there is no any interruption found.

4.5.3.4 Commercial operation

The commercial operation is the date that the combined cycle power plant officially sells power to the grid which is the beginning of the project to generate revenue. Moreover, the obligations under the power purchase agreement will start, for example, guarantees of minimum power supply in a year, annual availability, etc. The plant has to be tested and commissioned in good conditions because there can be a penalty if the plat is incompliance with the grid requirements under the power purchase agreement with the authority.

Chapter 5. Results

5.1 Information gathered

To illustrate the general characteristic and nature of the case study projects, Section 5.1.1 to Section 5.1.4 are the general description of the projects which have been studied in this research.

5.1.1 Project A

Project A is a 140MW CCGT power plant project located in Eastern area of Thailand. Its configuration comprises 2 gas turbines, 2 HRSGs, 1 steam turbine and auxiliary balance of plant equipment on a 2 x 2 x 1 scheme. The main cooling arrangement of this project utilizes the raw water supply from the industrial estate.

The planned schedule of Project A is 25 months from NTP to commercial operation.

5.1.2 Project B

Project B is a 132MW CCGT power plant project located in Central of Thailand. Same as project A, its configuration of the main equipment is on the 2 x 2 x 1 basis. The main cooling water for this project is the raw water supplied by the industrial estate.

The planned schedule of Project B is 28 months from NTP to commercial operation.

5.1.3 Project C

Project C is a 240MW CCGT power plant located in Central of Thailand. It comprises 2 identical blocks of 120MW power plants located adjacent to each other. The arrangement of main equipment is on the 2 x 2 x 1 scheme for each block, some balance of plant facilities are shared such as control building, raw water storage tank, wastewater pond, etc. The main cooling water for this project utilizes the recycle water from the industrial estate.

The planned schedule for Project C is 25 months from NTP to commercial operation for both blocks collectively.

5.1.4 Project D

Project D is a 940MW CCGT power plant located in South of Thailand. Its arrangement comprises 2 trains of 1 gas turbine, 1 HRSG, 1 steam turbine and auxiliary equipment on a 1 x 1 x 1 configuration.

For this project, the gas turbine and the steam turbine share the same generator which is the single shaft arrangement. The main cooling system of this project is the seawater once through cooling.

The planned schedule of project D is 34 months from NTP to commercial operation in total for both trains.

Project A, Project B and Project C are defined as the Small Power Producer (SPP) type of CCGT power plants while Project D is categorized as the Independent Power Producer (IPP) according to the definition by the Electricity Generating Authority of Thailand (Electricity Generating Authority of Thailand, 2018).

Summary of projects' key information including their capacities, plant configurations, main cooling arrangements and contractors arrangement are illustrated in Table 1.

Table 1 Summary of projects' key information

Project	Capacity (MW)	Plant configuration				Main cooling arrangement		Contractors arrangement			
		No. of gas turbine	No. of HRSG	No. of steam turbine	Gas turbine - steam turbine arrangement	Method	Media	Main power plant	Gas pipeline	Transmission line	Water supply/discharge
Project A	140	2	2	1	Multi shaft	Wet cooling tower	Raw water	Main EPC contractor	Separate contractor	Separate contractor	Separate contractor
Project B	132	2	2	1	Multi shaft	Wet cooling tower	Raw water	Main EPC contractor	Under main EPC contractor	Separate contractor	Separate contractor
Project C	2 x 120	2 x 2	2 x 2	2 x 1	Multi shaft	Wet cooling tower	Raw water	Main EPC contractor	Separate contractor	Separate contractor	Separate contractor
Project D	2 x 470	2 x 1	2 x 1	2 x 1	Single shaft	Once through	Seawater	Main EPC contractor	Separate contractor	Separate contractor	Under main EPC contractor

5.2 Project A results

5.2.1 Critical path

The critical paths of the planned schedule, their durations and adjacent precedent activities can be summarized in Table 2.

Table 2 Project A planned critical path

Activity	Duration (days)	Adjacent precedent activities
Notice to proceed (NTP)	0	Contract signing
Steam turbine order confirmation	31	NTP Conceptual design
Steam turbine manufacturing and transportation	456	Steam turbine order confirmation
Steam turbine erection	160	Steam turbine transportation Steam turbine foundation Steam turbine hall
Steam turbine cold commissioning	44	Steam turbine erection
Steam turbine first steam	1	Overall mechanical completion Steam turbine cold commissioning Main steam header blowout
Steam turbine hot commissioning and function test	5	Steam turbine first steam
Steam turbine first synchronization	1	Steam turbine hot commissioning and function test
Combined cycle function test	45	GTG1 first synchronization GTG2 first synchronization STG first synchronization
Plant performance test	4	Combined cycle function test
Plant trial run	15	Plant performance test
Commercial operation	0	Plant trial run
Total	762	

The critical paths of the actual schedule, their durations and adjacent precedent activities can be summarized in Table 3.

Table 3 Project A actual critical path

Activity	Duration (days)	Adjacent precedent activities
Notice to proceed (NTP)	0	Contract signing
Steam turbine order confirmation	62	NTP Conceptual design
Steam turbine manufacturing and transportation	399	Steam turbine order confirmation
Steam turbine erection	192	Steam turbine transportation Steam turbine foundation Steam turbine hall
Steam turbine cold commissioning	47	Steam turbine erection
Overall mechanical completion	0	Cold commissioning of electrical system Cold commissioning of balance of plant equipment Cold commissioning of GTG1 and HRSG1 Cold commissioning of GTG2 and HRSG2 Cold commissioning of steam turbine
Steam turbine first steam	2	Overall mechanical completion Steam turbine cold commissioning Main steam header blowout
Steam turbine hot commissioning and function test	1	Steam turbine first steam
Steam turbine first synchronization	1	Steam turbine hot commissioning and function test
Combined cycle function test	36	GTG1 first synchronization GTG2 first synchronization STG first synchronization
Plant performance test	2	Combined cycle function test
Plant trial run	14	Plant performance test
Commercial operation	0	Plant trial run
Total	756	

5.2.2 Near-critical path

The near-critical paths of the planned schedule, their durations, total floats and percentage of floats can be summarized in Table 4.

Table 4 Project A planned near-critical path

Activity	Duration (days)	Total float (days)	% float
GTG1 procurement and manufacturing	457	55	12.0%
Cooling tower procurement and manufacturing	320	44	13.8%
GTG2 procurement and manufacturing	472	71	15.0%
HRSG1 procurement and manufacturing	425	72	16.9%

The near-critical paths of the actual schedule, their durations, total floats and percentage of floats can be summarized in Table 5.

Table 5 Project A actual near-critical path

Activity	Duration (days)	Total float (days)	% float
GTG1 procurement and manufacturing	446	50	11.2%
GTG2 procurement and manufacturing	485	76	15.7%
Transformer procurement and manufacturing	378	65	17.2%
Pipe rack and pipe bridge foundation	226	44	19.5%

5.3 Project B results

5.3.1 Critical path

The critical paths of the planned schedule, their durations and adjacent precedent activities can be summarized in Table 6.

Table 6 Project B planned critical path

Activity	Duration (days)	Adjacent precedent activities
Notice to proceed (NTP)	0	Contract signing
GTG2 order confirmation	0	NTP Conceptual design
GTG2 manufacturing and transportation	530	GTG2 order confirmation
GTG2 erection	127	GTG2 procurement and manufacturing
GTG2 and HRSG2 function test during cold commissioning	75	GTG2 erection; HRSG2 erection; Piping and auxiliary equipment installation; Demineralized water ready; Cold commissioning of balance of plant equipment
Steam turbine function test (interlock test, trip test) during steam turbine cold commissioning	45	Erection of steam turbine; Function test of GTG1 and HRSG1; Function test of GTG2 and HRSG2;
Steam turbine first steam	8	Steam turbine function test; Main steam header blowout;
Steam turbine first synchronization	7	First steam to steam turbine
Combined cycle function test	49	GTG1 and HRSG1 first synchronization; GTG2 and HRSG2 first synchronization; Steam turbine first synchronization;
Plant performance test	3	Combined cycle function test
Plant trial run	7	Plant performance test
Commercial operation	1	Plant trial run
Total	852	

The critical paths of the actual schedule, their durations and adjacent precedent activities can be summarized in Table 7.

Table 7 Project B actual critical path

Activity	Duration (days)	Adjacent precedent activities
Notice to proceed (NTP)	0	Contract signing
GTG1 order confirmation	18	NTP Conceptual design
GTG1 manufacturing and transportation	429	GTG1 order confirmation
GTG1 erection	289	GTG1 procurement and manufacturing
GTG1 and HRSG1 cold commissioning including function test	11	GTG1 erection HRSG1 erection Piping system installation
GTG1 and HRSG1 hot commissioning	39	GTG1 and HRSG1 cold commissioning
Main steam header blowout	5	GTG1 hot commissioning
Steam turbine function test	48	Main steam header blowout
Steam turbine first steam	5	Main steam header blowout
Steam turbine first synchronization	1	Steam turbine first steam
Combined cycle function test	20	GTG1 first synchronization GTG2 first synchronization STG first synchronization
Plant performance test	2	Combined cycle function test
Plant trial run	6	Plant performance test
Remaining plant's function test	8	
Commercial operation	0	Plant trial run
Total	881	
Remaining plant's function test	21	

5.3.2 Near-critical path

The near-critical paths of the planned schedule, their durations, total floats and percentage of floats can be summarized in Table 8.

Table 8 Project B planned near-critical path

Activity	Duration (days)	Total float (days)	% float
Balance of detailed plant engineering	365	1	0.3%
Emergency diesel generator procurement and manufacturing	250	1	0.4%
HRSG1 procurement and manufacturing	501	7	1.4%
GTG1 procurement and manufacturing	500	8	1.6%
GTG1 and HRSG1 function test with DCS in cold commissioning	60	1	1.7%
Main steam header blowout	45	1	2.2%
HRSG2 procurement and manufacturing	516	14	2.7%
Emergency diesel generator erection	30	1	3.3%
Cold commissioning of balance of plant equipment	19	1	5.3%
HRSG1 erection	127	7	5.5%
Transmission line	639	37	5.8%
GTG1 erection	127	8	6.3%
Cold commissioning of GTG and HRSG1	96	7	7.3%
C&I detailed engineering	285	26	9.1%
HRSG2 erection	127	14	11.0%
DCS panel procurement and manufacturing	215	27	12.4%
Demineralization water system erection	250	31	12.4%
Hot commissioning of GTG1 and HRSG1	7	1	14.3%
Steam turbine procurement and manufacturing	536	87	16.2%
Piping and auxiliary equipment	270	48	17.8%
Gas compressor procurement and manufacturing	493	93	18.9%

The near-critical paths of the actual schedule, their durations, total floats and percentage of floats can be summarized in Table 9.

Table 9 Project B actual near-critical path

Activity	Duration (days)	Total float (days)	% float
Cable tray and cabling	407	7	1.7%
Switchgear procurement and manufacturing	397	7	1.8%
Pipe rack and pipe bridge foundation	230	7	3.0%
High voltage system installation	227	7	3.1%
Medium voltage system installation	227	7	3.1%
Electrical detailed engineering	128	7	5.5%
Balance of plant detailed engineering	128	7	5.5%
GTG2 procurement and manufacturing	476	27	5.7%
GTG2 erection	264	27	10.2%
Demineralization water system erection	283	29	10.2%
HRSG2 procurement and manufacturing	524	54	10.3%
Gas pipeline	702	72	10.3%
Transmission line	699	94	13.4%
Field instrument installation	216	29	13.4%
Tank foundation and miscellaneous balance of plant	200	29	14.5%
Pipe rack and pipe bridge piling	45	7	15.6%
Piping system erection	184	29	15.8%
Civil detailed engineering	43	7	16.3%
HRSG1 procurement and manufacturing	508	86	16.9%
Control building construction	180	31	17.2%
Low voltage system installation	195	39	20.0%

5.4 Project C results

5.4.1 Critical path

The critical paths of the planned schedule, their durations and adjacent precedent activities can be summarized in Table 10.

Table 10 Project C planned critical path

Activity	Duration (days)	Adjacent precedent activities
Notice to proceed (NTP)	0	Contract signing
Steam turbine 2 order confirmation	0	NTP Conceptual design
Steam turbine 2 manufacturing and transportation	413	Steam turbine 2 order confirmation
Erection of STG2	197	Steam turbine manufacturing and transportation STG2 foundation Steam turbine hall
Cold commissioning of STG2, including function test	90	Erection of STG2 Piping system erection Cold commissioning of electrical system
Steam turbine 2 first steam	1	Cold commissioning of STG2, including function test Overall mechanical completion of balance of plant Main steam header blowout
Steam turbine 2 function test	34	Steam turbine first steam
Steam turbine 2 first synchronization	1	Steam turbine function test
Combined cycle function test of block 2	24	Steam turbine first synchronization
Plant performance test of block 2	4	Combined cycle function test of block 2
Plant trial run of block 2	6	Plant performance test of block 2
Commercial operation	1	Plant trial run of block 2
Total	771	

The critical paths of the actual schedule, their durations and adjacent precedent activities can be summarized in Table 11.

Table 11 Project C actual critical path

Activity	Duration (days)	Precedent activities
Notice to proceed (NTP)	0	Contract signing
Site preparation, clearing and levelling work	85	Notice to proceed (NTP)
Piling of GTG1 2	20	Civil detailed engineering Permit to start civil work Site preparation, clearing and levelling work
Piling of control building	25	Piling of GTG1 2
Control building foundation	217	Piling of control building
Control building construction	64	Control building foundation
Medium voltage system installation	320	Control building construction
Cable tray and cabling work	320	Control building construction
Transmission line	197	
Back energization	23	Electrical work installation Transmission line
Cold commissioning of electrical system	4	Back energization Electrical work installation
Function test in cold commissioning of GTG1 and HRSG1	7	GTG1 erection HRSG1 hydrostatic test, flush and cleaning Cold commissioning of electrical system
Function test in cold commissioning of GTG2 and HRSG2	7	GTG2 erection HRSG2 hydrostatic test, flush and cleaning Cold commissioning of electrical system
GTG1 first firing	2	Gas compressor erection Pre commissioning of demineralization water plant Function test in cold commissioning of GTG1 and HRSG1
GTG1 function test with DCS (No-load test)	3	GTG1 first firing
GTG1 first synchronization	95	GTG1 function test with DCS (No-load test)
GTG1 on load test	8	GTG1 first synchronization
GTG2 first firing	2	Gas compressor erection Pre commissioning of demineralization

Activity	Duration (days)	Precedent activities
		water plant Function test in cold commissioning of GTG2 and HRSG2
GTG2 function test with DCS (No-load test)	4	GTG2 first firing
GTG2 first synchronization	94	GTG2 function test with DCS (No-load test)
GTG2 on load test	8	GTG2 first synchronization
STG1 main steam header blowout	6	GTG1 on load test GTG2 on load test
STG1 first steam	33	STG1 function test Overall mechanical completion of balance of plant STG1 main steam header blowout
STG1 function test	1	STG1 first steam
STG1 first synchronization	1	STG1 function test
Combined cycle function test of block 1	79	STG1 first synchronization
Plant trial run of block 1	6	Combined cycle function test of block 1
Commercial operation	5	Plant trial run of block 1
Total	1,003	

5.4.2 Near-critical path

The near-critical paths of the planned schedule, their durations, total floats and percentage of floats can be summarized in Table 12.

Table 12 Project C planned near-critical path

Activity	Duration (days)	Total float (days)	% float
STG1 erection	192	11	5.7%
Substation piling	166	12	7.2%
GTG1 2 piling	150	11	7.3%
Cold commissioning of STG1	122	11	9.0%
Steam turbine 1 procurement and manufacturing	350	36	10.3%
HRSG4 procurement and manufacturing	353	38	10.8%
STG1 foundation	100	11	11.0%
Cooling tower piling	147	22	15.0%
Substation of block 1 erection	147	24	16.3%
HRSG3 procurement and manufacturing	353	59	16.7%
Steam turbine hall erection	63	11	17.5%
HRSG2 procurement and manufacturing	306	55	18.0%
Pipe rack and pipe bridge erection	122	22	18.0%
STG2 piling	65	12	18.5%
Transmission line	366	70	19.1%
Tank foundation and miscellaneous balance of plant	110	22	20.0%
HRSG1 procurement and manufacturing	306	63	20.6%

The near-critical paths of the actual schedule, their durations, total floats and percentage of floats can be summarized in Table 13.

Table 13 Project C actual near-critical path

Activity	Duration (days)	Total float (days)	% float
Gas pipeline	756	10	1.3%
Raw water pipeline	497	32	6.4%
GTG4 procurement and manufacturing	516	75	14.5%
GTG3 procurement and manufacturing	501	74	14.8%

5.5 Project D results

5.5.1 Critical path

The critical paths of the planned schedule, their durations and adjacent precedent activities can be summarized in Table 14.

Table 14 Project D planned critical path

Activity	Duration (days)	Adjacent precedent activities
Notice to proceed (NTP)	1	Contract signing
GTG2 order confirmation	13	NTP Conceptual design
GTG2 manufacturing and transportation	625	GTG2 order confirmation
GTG2 erection	134	GTG2 manufacturing and transportation GT2 and ST2 foundation
Cold commissioning of GTG2 and HRSG2, including function test	111	GTG2 erection Cold commissioning of electrical system HRSG2 hydrostatic test, flush and cleaning
GTG2 first firing	1	Gas compressor erection Gas heater erection Pre commissioning of demineralization water plant Cold commissioning of GTG2 and HRSG2, including function test Gas pipeline completion
Function test with DCS (No-load test)	30	GTG2 first firing
GTG2 first synchronization	2	Function test with DCS (No-load test)
GTG2 on load test	30	GTG2 first synchronization
ST2 main steam header blowout	5	GTG2 on load test
Steam turbine first steam	5	Cold commissioning of ST2 Overall mechanical completion of balance of plant ST2 main steam header blowout
Steam turbine function test	30	Steam turbine first steam
Steam turbine first synchronization	2	Steam turbine function test
Combined cycle function test of train 2	30	Steam turbine first synchronization
Plant performance test of train 2	2	Combined cycle function test of train 2
Plant trial run of train 2	14	Plant performance test of train 2
Commercial operation	1	Plant trial run of train 2
Total	1,035	

The critical paths of the actual schedule, their durations and adjacent precedent activities can be summarized in Table 15.

Table 15 Project D actual critical path

Activity	Duration (days)	Precedent activities
EPC contract signing	1	-
Conceptual design	11	Contract signing
Notice to proceed (NTP)	1	Contract signing
GTG2 order confirmation	12	Notice to proceed (NTP) Conceptual design
GTG2 manufacturing and transportation	625	GTG2 order confirmation
ST2 order confirmation	15	Contract signing
ST2 manufacturing and transportation	703	ST2 order confirmation
GTG2 erection	180	GTG2 and ST2 foundation GTG2 manufacturing and transportation
ST2 erection	246	GTG2 and ST2 foundation ST2 manufacturing and transportation
GTG2 and HRSG2 cold commissioning, including function test	69	GTG2 erection Cold commissioning of electrical system HRSG2 hydrostatic test, flushing and cleaning
ST2 cold commissioning, including function test	33	ST2 erection Piping system installation Cold commissioning of electrical system
GTG2 first firing	1	Gas compressor erection Gas heater erection Pre commissioning of demineralization water plant GTG2 and HRSG2 cold commissioning Gas pipeline completion
GTG2 function test with DCS (no-load test)	25	GTG2 first firing
GTG2 first synchronization	1	GTG2 function test with DCS (no-load test)
GTG2 on load test	3	GTG2 first synchronization
ST2 first steam	1	ST2 cold commissioning Overall mechanical completion of balance of plant GTG2 on load test Main steam header blowout
ST2 function test	5	ST2 first steam
ST2 first synchronization	1	ST2 function test
Combined cycle function test of	76	Steam turbine first synchronization

Activity	Duration (days)	Precedent activities
train 2		
Plant performance test of train 2	2	Combined cycle function test of train 2
Plant trial run of train 2	15	Plant performance test of train 2
Commercial operation of train 2	1	Plant trial run of train 2
Total	1,017	

5.5.2 Near-critical path

The near-critical paths of the planned schedule, their durations, total floats and percentage of floats can be summarized in Table 16.

Table 16 Project D planned near-critical path

Activity	Duration (days)	Total float (days)	% float
HRSG2 procurement and manufacturing	580	25	4.3%
Transmission line	517	31	6.0%
GTG1 procurement and manufacturing	577	36	6.2%
HRSG1 procurement and manufacturing	483	31	6.4%
Steam turbine 2 procurement and manufacturing	719	68	9.5%
Control building foundation	230	31	13.5%
HRSG1 erection	227	31	13.7%
HRSG2 erection	162	25	15.4%
Steam turbine 1 procurement and manufacturing	658	104	15.8%
Cable tray and cabling erection	192	31	16.1%
Condenser procurement and transportation	521	100	19.2%

The near-critical paths of the actual schedule, their durations, total floats and percentage of floats can be summarized in Table 17.

Table 17 Project D actual near-critical path

Activity	Duration (days)	Total float (days)	% float
Steam turbine 1 procurement and manufacturing	649	10	1.5%
GTG1 procurement and manufacturing	577	10	1.7%
Balance of plant mechanical system	392	8	2.0%
Control building foundation	280	8	2.9%
HRSG1 procurement and manufacturing	502	17	3.4%
ST1 erection	284	10	3.5%
Control building construction	150	8	5.3%
GTG1 erection	180	10	5.6%
HRSG2 procurement and manufacturing	581	38	6.5%
HRSG1 erection	227	17	7.5%
Condenser procurement and manufacturing	521	42	8.1%
Combined cycle commissioning work of train 1	114	10	8.8%
GT2 and ST2 piling	91	8	8.8%
Emergency diesel generator procurement and manufacturing	537	52	9.7%
GTG1 and HRSG1 function test in cold commissioning	96	10	10.4%
Switchgear procurement and manufacturing	460	74	16.1%
Site preparation, clearing and levelling work	42	8	19.0%
GT1 and ST1 piling	40	8	20.0%

Chapter 6. Analysis of individual project

6.1 Project A analysis

6.1.1 Critical path

The planned critical paths of Project A are found mostly related with the steam turbine since its procurement, manufacturing, erection, cold commissioning, hot commissioning and combined cycle commissioning until commercial operation.

The two longest activities in the critical path were planned as the steam turbine manufacturing & transportation and the steam turbine erection with the durations of 456 days and 160 days respectively. The total duration of the planned critical path is found at 762 days or 25 months from NTP to commercial operation. The two longest activities are calculated consuming 59.8% and 21.0% of the entire planned critical path respectively.

Activities in the actual critical paths are found exactly align with the plan. The two longest activities in the critical path are steam turbine manufacturing and transportation; and steam turbine erection which took 399 days and 174 days (52.8% and 25.4% of the entire critical paths) respectively. However, the manufacturing took 57 days or 12.5% shorter than plan while the erection took 32 days or 20% longer than plan. The total construction critical path is found at 755 days or 25 months, 6 days earlier than the original schedule which is considered fully align with plan.

Amongst all the activities, the GTG2 procurement and manufacturing consumed the longest duration of 485 days (around 16 months) starting from order confirmation to delivery at site, however, it has the total float of 15.7% (76 days) which is considered one of the near-critical paths discussed in the next section.

6.1.2 Near-critical path

The planned near-critical paths of Project A are all found related to the procurement and manufacturing activities which consist of GTG1, cooling tower, GTG2 and HRSG1 with the float of 12.0% (55 days), 13.8% (44 days), 15.0% (71 days) and 16.9% (72 days) respectively.

For the actual near-critical paths, the procurement and manufacturing of both GTG1 and GTG2 are found align with the plan with the total float of 11.2% (50 days) and 15.7% (76 days) respectively while the procurement of cooling tower and HRSG1 are found outrange from the actual near-critical path activities.

Two unplanned near-critical paths comprise procurement and manufacturing of transformer and foundation of pipe rack and pipe bridge with the total float of 17.2% (65 days) and 19.5% (44 days) respectively.

6.2 Project B analysis

6.2.1 Critical path

The planned critical path for Project B is found related to the gas turbine 2 procurement, manufacturing, erection and cold commissioning then moves to the steam turbine cold commissioning, hot commissioning and finally the overall combined cycle commissioning, performance test and trial run. In total, these would take 852 days or approximately 28 months from NTP to commercial operation.

The two longest activities in the planned critical path are found to be GTG2 procurement and manufacturing; and GTG2 erection which consume 530 days and 127 days (or 62.2% and 14.9% of the entire critical path) respectively.

The actual critical path is found quite different compared to the plan. It starts from the GTG1 procurement and manufacturing; GTG1 erection; GTG1 and HRSG1 function test in cold commissioning; and GTG unit 1 hot commissioning. The critical path is then switch to steam turbine related activities including main steam header blowout; steam turbine function test; steam turbine first steam; steam turbine first synchronization. Finally, the critical path moves to the overall combined cycle commissioning and function test, overall plant performance test, trial run until commercial operation. The total duration from NTP to commercial operation of Project B is 881 days or circa 29 months, a month delay from the original plan.

Table 18 illustrates the actual critical paths durations compared to their plans of Project B.

Table 18 Comparison of actual critical paths duration of Project B to their plan

Critical activities	Actual duration (days)	Planned duration (days)	Difference (days)
Notice to proceed (NTP)	0	0	0
GTG1 order confirmation	18	0	-18
GTG1 manufacturing and transportation	429	500	71
GTG1 erection	289	127	-162
GTG1 and HRSG1 cold commissioning including function test	11	60	49
GTG1 and HRSG1 hot commissioning	39	7	-32
Main steam header blowout	5	45	-8
Steam turbine function test	48		
Steam turbine first steam	5	8	3

Critical activities	Actual duration (days)	Planned duration (days)	Difference (days)
Steam turbine first synchronization	1	7	6
Combined cycle function test	20	49	29
Plant performance test	2	3	1
Plant trial run	6	7	1
Remaining plant's function test	8	0	-8
Commercial operation	0	1	1

The two longest activities in the actual critical paths are GTG1 procurement and manufacturing; and GTG1 erection which took 429 days and 289 days or 48.7% and 32.8% respectively.

It is found that the GTG1 erection work took much longer than the plan, 289 days compared to 127 days plan or 127.5% longer. Moreover, the actual hot commissioning work of GTG1 also took longer duration than plan, 39 days compared to its plan of only 7 days. The hot commissioning work of GTG1 is also found longer than that of the GTG2 of only 10 days.

Combination of those delay in GTG1 erection work and commissioning work make the critical path alter to the GTG1 route instead of the GTG2 although the GTG2 had started the installation later.

It is observed from the actual critical path of Project B that many proper logics of CCGT power plant construction have been omitted. For example, the gas turbine 1 commenced the first firing before the plant had been back energized which is very unlikely. This can be done but may require additional resources such as another source of power supply to feed in the entire plant's electrical load consumption and control system for commissioning which may result in additional cost to the project. Moreover, there were plant's function tests which have been done after plant trail run and the others remain to be completed after the commercial operation which is not according to the plan nor standard sequences.

With those non-sequential activities and the late commercial operation compared to the plan, it can be implied that during the construction, there could be the omission of some standard sequences to expedite the construction progress to be completed on time, as shown in the project actual schedule for example, omission of function tests of some equipment. This could raise the risk of plant's non-functionality or failure after commercial operation due to supporting or auxiliary systems are not properly installed in place. The worst case impact of this circumstance could be the project has low availability during commercial operation subsequently loss of revenue and penalty from the authority in case that the plant cannot achieve the guaranteed level of availability under the power purchase agreement.

Amongst all the activities, the gas pipeline construction and the transmission line construction are the two longest tasks with the duration of 702 days and 699 days respectively (both around 23 months), starting from construction commencement date to availability of each facility, however, they have the total float of 10.3% (72 days) and 13.4% (94 days) which are part of the near-critical paths discussed in the next section.

6.2.2 Near-critical path

The planned near-critical paths of Project B are found with many activities and routes. The path with most less float includes the balance of plant detailed engineering which is the precedence activity of the emergency diesel procurement and erection then the cold commissioning of the balance of plant equipment. This path is found with only 0.3% float (1 day) while the longest activity of balance of plant detailed engineering consume a year to complete.

Another planned near-critical path which could potentially transfer into the critical path is the HRSG1 manufacturing and transportation, HRSG1 erection and hydrostatic test of HRSG1 which has the total float of 7 days. The longest activity is the HRSG1 procurement and manufacturing which take 501 days to complete while its float is only 1.4% (7 days).

The next near-critical path which should be in consideration is the gas turbine 1 related activities. This starts from gas turbine 1 procurement, manufacturing, transportation and then erection. The manufacturing work is planned with 500 days duration. The total float for these activities is only 1.6% (8 days).

Moreover, HRSG2 procurement, manufacturing and erection are also the planned near-critical path with only 2.7% float (14 days) on the HRSG2 procurement and manufacturing task with its planned duration of 516 days.

Last but not least, the transmission line is the near-critical path with float of 5.8% (37 days) from the planned construction duration of 639 days. This is the key activity to be completed prior to the back energization which is the key milestone before plant cold commissioning.

Regarding the Project B, it can be noted that there were many planned near-critical paths which some of those are considered not necessary compared to other projects and could be eliminate or shorten their durations for better management and minimize the risk of delay during construction.

The actual near-critical paths can explain further why the project was delay as there are several near-critical paths found compared to Project A which had been completed within schedule. The first near-critical path is found related to the electrical system installation starting since electrical detailed engineering; balance of plant detailed engineering; switchgear procurement and manufacturing; high voltage system installation; medium voltage system installation; and cable tray and cabling installation. The task with the shortest float is the cable tray and cabling installation with total float of 1.7% (7 days) compared to its actual duration of 407 days.

The civil activities which are required to support those electrical tasks are civil detailed engineering; pipe rack and pipe bridge piling; and pipe rack and pipe bridge foundation. The civil near-critical path with shortest float is the pipe rack and pipe bridge foundation with the total float of 3.0% (7 days) compared to its duration of 230 days.

The next actual near-critical path is found with the GTG2 procurement and manufacturing; and GTG2 erection where the first activity has a total float of only 5.7% (27 days) compared to its duration of 476 days.

Demineralized water system erection is also the near-critical path for this project with a total float of 10.2% (29 days) compared to its duration of 283 days.

The HRSG1 and HRSG2 procurement and manufacturing are the next critical path with low float of 16.9% and 10.3% respectively.

Finally, the gas pipeline and electricity transmission line are considered the near-critical paths as well with the total float of 10.3% and 13.4% compared to its construction period of 702 days and 699 days respectively.

6.3 Project C analysis

6.3.1 Critical path

As Project C comprises 2 blocks of power generation, the planned critical paths are found embedded within block 2 which was scheduled to complete sequentially after block 1. Starting with notice to proceed, the planned critical paths go through the steam turbine 2 procurement and manufacturing; steam turbine 2 erection; steam turbine 2 cold commissioning including function test; steam turbine 2 first steam; and steam turbine 2 first synchronization. After that, the planned critical paths continue to block 2 combined cycle function test; block 2 overall plant performance test; block 2 trial run; and block 2 commercial operation. The total duration of the planned critical path for this project is 771 days or approximately 25 months from notice to proceed to commercial operation of both blocks.

The two longest activities in the planned critical path were the steam turbine 2 procurement and manufacturing; and the steam turbine 2 erection with the durations of 413 days and 197 days respectively. These are calculated at 53.6% and 25.6% of the entire planned critical path respectively.

The actual critical paths however are found much different and much longer than the plan, many unplanned critical activities became issues of concern. It is found that there is a bottleneck at the key milestone of back energization where there are two routes of precedent critical paths prior to this activity. The first route starts with the civil work and the electrical system installation. The civil work comprises activities related to construction of control building beginning with site preparation; piling of the control building (commenced after piling of gas turbines); control building foundation; and control building construction. All of those are required to support the electrical system installation subsequently.

The second route solely came from the delay in transmission line construction which was, for this Project C, in the responsibility of the authority.

Table 19 compares the actual critical paths durations to their plans of Project C.

Table 19 Critical paths of Project C that different from plan

Critical activities	Actual duration (days)	Planned duration (days)	Difference (days)
Notice to proceed (NTP)	0	0	0
Site preparation, clearing and levelling work	85	52	-33
Piling of GTG1 2	20	150	130
Piling of control building	25	20	-5
Control building foundation	217	58	-159

Critical activities	Actual duration (days)	Planned duration (days)	Difference (days)
Control building construction	64	89	25
Medium voltage system installation	320	13	-307
Cable tray and cabling work	320	46	-274
Transmission line	197	366	169
Back energization	23	1	-22
Cold commissioning of electrical system	4	79	75
Function test in cold commissioning of GTG1 and HRSG1	7	34	27
Function test in cold commissioning of GTG2 and HRSG2	7	26	19
GTG1 first firing	2	6	4
GTG1 function test with DCS (No-load test)	3	10	7
GTG1 first synchronization	95	2	-93
GTG1 on load test	8	18	10
GTG2 first firing	2	21	19
GTG2 function test with DCS (No-load test)	4	6	2
GTG2 first synchronization	94	1	-93
GTG2 on load test	8	1	-7
STG1 main steam header blowout	6	10	4
STG1 first steam	33	1	-32
STG1 function test	1	18	17
STG1 first synchronization	1	1	0
Combined cycle function test of block 1	79	24	-55
Plant trial run of block 1	6	5	-1
Commercial operation	5	1	-4

Particularly for the Project C, the control building foundation is found consuming much longer time than plan, 217 days compared to the plan of only 58 days (or approximately 7 months compared to 2 months). So as the medium voltage system installation and the cable works, they are also found much longer than the plan, 320 days or approximately 10 months compared to the plan of only around 3 months in total. With consideration that other critical paths were expedited and shorten from plan, these civil and electrical erections delays greatly push the readiness of the power plant back energization delay by around 9 months.

The back energization itself is also reported with significant magnitude of delay, 23 days to complete compared to the plan of only 1 day.

The critical paths after the back energization are found to be the electrical system cold commissioning; GTG1 and HRSG1 cold commissioning, GTG2 and HRSG2 cold commissioning; GTG1 and HRSG1 hot commissioning; and GTG2 and HRSG2 hot commissioning. All the aforesaid activities were unplanned and became critical due to the delay of back energization. After that, the sequences of critical path ran as plan but move from block 2 to block 1 due to delay in block 1's combined cycle commissioning. The critical paths in this later stage comprise the steam turbine 1 first steam; steam turbine 1 hot commissioning; combined cycle function test of block 1; plant trial run of block 1; then commercial operation.

Both the GTG1 and GTG2 first synchronization which are part of the hot commissioning of GTGs and HRSGs of Project C are found much longer than usual, they took around 3 months compared to the plan of only 2 days. This is found related to the requirement from the authority prior to connect the generators to the grid which the completeness of power plant electrical system was also related to the relay coordination and protection system of the transmission line in responsible by another authority.

Due to the complicated causes of the delayed critical milestone of the back energization and the first synchronization, it is noted from the project information that these issues would be in the process of arbitration afterward for the route cause analysis and to seek for the actual time and also the commercial impact to the affected parties.

It is also noted for Project C that the planned performance test of 4 days had been omitted from the critical path and had been done after the commercial operation instead.

In total, the Project C took 1,003 days to complete (approximately 33 months) compared to the original schedule of 771 days (or around 25 months) from notice to proceed to commercial operation, this is around 8 months delay.

6.3.2 Near-critical path

The construction schedule of Project C was planned with too many near-critical paths unnecessarily. First of all, the shortest planned near-critical path is found on the steam turbine 1 related activities. Starting with steam turbine 1 procurement and manufacturing which has 10.3% total float (36 days compared to 350 days procurement duration) and parallelly the steam turbine 1 foundation with total float of only 11.0%. Subsequently, the steam turbine 1 erection which has only 5.7% total float, the shortest planned near-critical activity amongst all. Continue to the steam turbine cold commissioning, this is found with 9.0% total float. It can be assessed that this steam turbine 1 related activities have a very high potential to become a critical path.

Moreover, the commencement of the first piling of Project C should be scheduled with more margin as they could begin immediately after completion of site preparation and once the permit to start to civil work is obtained. According to the plan, they have been prolonged for more than 4 months resulting in the float of approximately 7% only prior to start piling works which created the near-critical path unnecessarily.

The next category of activities which has low planned float is the HRSGs procurement and manufacturing. The shortest planned float in this category is found on the HRSG4 with only 10.8% float (38 floating days compared to the plan of 353 days), other HRSGs procurement and manufacturing have planned float ranging from 16.7% - 20.6%.

Last but not least, the transmission line had been originally planned with 19.1% float (70 days compared to 366 days plan), however, there were many obstructions occurred during completing this task and made it one of the actual critical activity of this project eventually.

Regarding the actual near-critical path of Project C, due to the vast delay in civil foundation work, back energization and first synchronization as mentioned in the above critical path section which those activities spread throughout the entire construction timeline of the project, the actual near-critical path of Project C are found with less number of activities.

Gas pipeline construction is found with significantly low margin of only 1.3% (10 days) from the entire duration of 756 days from commencement date to mechanical completion of the gas pipeline which is the date that gas is ready for the power plant. This could potentially become the critical path and should be closely monitored during the actual construction of this project.

Raw water pipeline construction is also observed with low actual margin of 6.4% (32 days out of 497 days)

The last two near-critical paths observed are the GTG4 procurement and manufacturing; and GTG3 procurement and manufacturing which have total float of 14.5% and 14.8% from the duration of 516 and 501 days respectively.

6.4 Project D analysis

6.4.1 Critical path

Project D is found planned with critical paths that laid within train 2 construction. Starting with notice to proceed, the critical paths went through GTG2 procurement and manufacturing; GTG2 erection; GTG2 and HRSG2 cold commissioning; GTG2 first firing; GTG2 function test (no-load test) in hot commissioning; GTG2 first synchronization; GTG2 on-load test; ST2 main steam header blowout; ST2 first steam; ST2 function test; ST2 first synchronization; combined cycle function test of train 2; plant performance test of train 2; plant trail run of train 2; and commercial operation. In total, the overall construction schedule had been planned to take 1,035 days or approximately 34 months.

The two longest activities among the planned critical paths are the GTG2 manufacturing and transportation; and GTG2 erection which took 638 days and 134 days or around 61.6% and 12.9% of the entire planned critical path respectively.

The actual critical paths are found similar to the plan with some slight differences at the beginning of the project. Instead of the single line of activities, the critical paths comprise both gas turbines and steam turbines related activities which ran in parallel. This can be explained due to the nature of the single shaft configuration of this type of power plant where the gas turbine and steam turbine are connected to a single generator, as described in section 5.1.4 of this dissertation, therefore, the construction and erection of both gas turbine and steam turbine had been done in the same area resulting in two parallel critical paths before the steam turbine first steam.

The first critical route comes from the steam turbine 2 procurement and manufacturing which had been brought earlier before the notice to proceed issuance, therefore, the EPC contract signing and conceptual design which are activities necessary before the procurement of all main equipment also become those of the critical paths. Activities downstream of this route comprise steam turbine 2 erection and cold commissioning of the steam turbine 2.

Parallelly, the second route is the gas turbine and generators of train 2 related works. Similar to the steam turbine's activities, this route starts with procurement and manufacturing of GTG2; GTG2 erection work; GTG2 cold commissioning including function test; GTG2 first firing; GTG2 no-load test; GTG2 first synchronization; and GTG2 on-load test.

The critical paths are then convergent toward the steam turbine 2 first steam which require both cold commissioning of steam turbine 2 itself and the GTG2 completion of its hot commissioning. The critical activities after ST2 first steam includes ST2 first synchronization; combined cycle function test of train 2; performance test of train 2; plant trial run; then the commercial operation of train 2.

The actual construction duration of Project D took 1,017 days or approximately 33.5 months, two weeks ahead of the schedule which is considered fully align with the plan.

The two longest activities in the critical path of Project D are found to be ST2 manufacturing and transportation; and GTG2 manufacturing and transportation which took 703 days and 625 days or 69.1% and 61.5% of the entire critical path respectively, noted that they were running parallelly.

The ST2 was not initially planned as the critical path, however, it was actually the first key activity that had been commenced. This can be explained because it had been forecasted with the longest duration amongst all which starting the task the earliest could provide more margin to the project during construction.

6.4.2 Near-critical path

The planned near-critical paths are mostly found with main equipment procurement and manufacturing, these include HRSG2; GTG1; HRSG1; ST2; and ST1 with the total float ranging from 4.3%; 6.2%; 6.4% 9.5%; and 15.8% respectively.

The transmission line construction is also planned with low total float of 6.0%, 31 days compared to the construction duration of 517 days.

Control building foundation is found planned with the total float of 13.5%. This is the upstream activity for the cable tray and cable installation work which has the total float of 16.1%.

HRSG1 and HRSG2 are considered the planned near-critical paths as well with the total float of 13.7% and 15.4% respectively.

The actual near-critical paths of Project D are found with more varieties than plan. The actual near-critical path which found with the lowest total float is the ST1 procurement and manufacturing with the actual duration of 649 days. Though the duration aligns with plan of 658 days, its total float reduces to only 1.5% compared to the plan of 15.8% (10 days compared to 104 days). Its subsequent activity of ST1 erection is found with low total float as well (3.5% or 10 days compared to 284 days erection).

So as the GTG1 procurement and manufacturing which have the actual total float of only 1.7% compared to the plan of 6.2% (10 days compared to 36 days). This contributes to the GTG1 erection lower float of 5.6% compared to the plan of 27.1%.

The unexpected near-critical path of the balance of plant mechanical system is observed. It had not been planned as the near-critical path but found with low total float as the outcome from the actual construction with quite low actual total float of 2.0% or 8 days from the construction duration of 392 days, noted according to the plan that it should have the total float of 31.6%.

The control building foundation is another activity which found with much lower actual total float compared to the plan, 2.9% compared to 13.5% or 8 days compared to 31 days from the actual duration of 280 days. Its downstream activity of control building construction is therefore the near-critical path with total float of 5.3%, 8 days from the actual duration of 150 days.

The HRSG1 procurement and manufacturing together with its subsequent activity of erection are other near-critical paths, each with total float of 3.4% and 7.5% from the actual duration of 502 days and 227 days respectively. Similarly, HRSG2 procurement and manufacturing is considered the near-critical path with total float of 6.5% or 38 days from its actual duration of 581 days.

Condenser procurement and manufacturing is equipment which actually has the lower total float of 8.1% (42 days from the actual duration of 521 days), note that it had been planned with the total float of 19.2%.

Last activity which should be discussed here is the combined cycle commissioning work of train 1. It had been planned with the duration of 30 days with float of 31 days or 103.3%. However, the actual commissioning duration took 114 days resulting in only 10 days or 8.8% float.

Chapter 7. Analysis of actual common critical paths and near-critical paths

7.1 Actual common critical paths and near-critical paths in all projects

To determine preventive measures for project schedule control of combined cycle gas turbine power plant, the actual common critical paths and near-critical paths for all the case studies found are analysed to see their recurrences, moreover, they are categorized into groups according to the work breakdown structure. List of all those activities can be found in Table 20. The magnitudes of each near-critical path are also shown, in the percentage of its total float compared to its duration, to evaluate their potential of becoming the critical paths.

Table 20 Summary of the critical paths and near-critical paths found in all projects

Activity	Critical paths of project:	Near-critical paths of project:
Contractual process		
Construction contract signing	D	
Notice to proceed	A B C D	
Engineering work		
Conceptual design	D	
Electrical detailed engineering		B (5.5%)
Balance of plant detailed engineering		B (5.5%)
Civil detailed engineering		B (16.3%)
Procurement work		
GTG1 procurement and manufacturing	B	A (11.2%) D (1.7%)
GTG2 procurement and manufacturing	D	A (15.7%) B (5.7%)
Steam turbine procurement and manufacturing	A D	D[2] (1.5%)
GTG4 procurement and manufacturing		C (14.5%)
GTG3 procurement and manufacturing		C (14.8%)
HRSG1 procurement and manufacturing		B (16.9%) D (3.4%)
HRSG2 procurement and manufacturing		B (10.3%) D (6.5%)
Switchgear procurement and manufacturing		B (1.8%) D (16.1%)
Condenser procurement and manufacturing		D (8.1%)
Emergency diesel generator procurement and manufacturing		D (9.7%)

[2] Train 2 is critical path. Train 1 is near-critical path.

Activity	Critical paths of project:	Near-critical paths of project:
Transformer procurement and manufacturing		A (17.2%)
Construction work		
Civil work		
Site preparation, clearing and levelling work	C	D (19.0%)
Piling of GTG1 and GTG2	C	D (20.0%)
Piling of control building	C	
Pilling of ST1 and ST2		D (8.8%)
Piling of pipe rack and pipe bridge		B (15.6%)
Foundation of pipe rack and pipe bridge		A (19.5%) B (3.0%)
Foundation of control building	C	D (2.9%)
Foundation of tank and miscellaneous balance of plant		B (14.5%)
Control building construction	C	B (17.2%) D (5.3%)
Main equipment erection work		
GTG1 erection	B	D (5.6%)
GTG2 erection	D	B (10.2%)
Steam turbine erection	A D	D[2] (3.5%)
HRSG1 erection		D (7.5%)
Balance of plant and miscellaneous erection work		
Cable tray and cabling	C	B (1.7%)
Medium voltage system installation	C	B (3.1%)
Transmission line	C	B (13.4%)
Back energization	C	
Gas pipeline		B (10.3%) C (1.3%)
Balance of plant mechanical system		D (2.0%)
High voltage system installation		B (3.1%)
Raw water pipeline		C (6.4%)
Demineralization water system erection		B (10.2%)
Field instrument installation		B (13.4%)
Piping system erection		B (15.8%)
Low voltage system installation		B (20.0%)
Commissioning work		
Cold commissioning		
GTG1 and HRSG1 cold commissioning, including function test	B C	D (10.4%)
GTG2 and HRSG2 cold commissioning, including function test	C D	
Cold commissioning of electrical system	C	
Steam turbine cold commissioning	A B D	

Activity	Critical paths of project:	Near-critical paths of project:
Hot commissioning		
GTG1 first firing	B C	
GTG1 function test (no-load test)	B C	
GTG1 first synchronization	B C	
GTG1 on-load test	B C	
GTG2 first firing	C D	
GTG2 function test with DCS (No-load test)	C D	
GTG2 first synchronization	C D	
GTG2 on load test	C D	
Main steam header blowout	B C	
Steam turbine first steam	A B C D	
Steam turbine hot commissioning and function test	A B C D	
Steam turbine first synchronization	A B C D	
Combined cycle function test	A B C D	D^2 (8.8%)
Plant performance test	A B D	
Plant trial run	A B C D	
Commercial operation	A B C D	
Remaining plant’s function test after trial run	B	
Remaining plant’s function test after commercial operation	B	

7.2 Contractual process analysis

First of all, issuances of notice to proceed to the main power plant EPC contractors to start their works are found as the critical milestone for all the projects.

The contract signing however is found only the critical path of Project D where the procurement of steam turbine, the longest activities amongst all in that project, has been shifted earlier before the notice to proceed.

7.3 Engineering work analysis

Similar to the contractual process, the conceptual design is found to be the critical path of only Project D due to early steam turbine procurement. Other engineering works however are found only the near-critical paths for Project B while for the remaining projects, certain quantities of margin for engineering works are observed.

7.4 Procurement work analysis

It is found that the procurement and manufacturing of gas turbines are the critical paths of Project B and Project D while the procurement and manufacturing of steam turbines are the critical paths of Project A and Project D. Those procurement and manufacturing activities have significant contributions to the critical paths ranging from 48.7% to 69.1% from only a single activity (please see section 6.2.1 and 6.4.1 for details).

With reference to the results analysed, procurement of turbines, in general, is found to be the common critical path of 3 projects. This is because they are costly, moreover in some cases, they are made to order thus manufacturing of these equipment usually takes long time.

Regarding Project D, it is noted that the procurement and manufacturing of both gas turbines and steam turbines took longer than others in term of durations. Comparison of procurement and manufacturing of gas turbines and steam turbines of all projects are summarized in Table 21 for further analysis.

Table 21 Comparison of duration for procurement and manufacturing of gas turbines and steam turbines

	SPP scale power plants				IPP scale power plant
	Project A	Project B	Project C	Project A B C Average	Project D
	(days)	(days)	(days)	(days)	(days)
Gas turbines					
Gas turbine 1	446	447	441		577
Gas turbine 2	485	476	444		637
Gas turbine 3	-	-	501		-
Gas turbine 4	-	-	516		-
Average of gas turbines				**470**	**607**
Steam turbines					
Steam turbine 1	461	542	350		649
Steam turbine 2	-	-	466		718
Average of steam turbines				**455**	**684**

Note: Red text refer to activity which is critical path.

Difference in manufacturing durations of the main equipment of Project D compared to others can be explained due to their size which Project D has larger generation capacity than Project A, Project B and Project C which are at the same size but much smaller (Project D can generate 470 MW per train compared to around 120 MW of others projects' power generation capacity per each block). Approximately 30% and 50% longer duration for manufacturing durations of gas turbines and steam turbines are calculated from Project D actual record compared to the average of others respectively.

In some projects, the procurement and manufacturing schedules of miscellaneous balance of plant equipment such as switchgear; transformer; emergency diesel generator; and condenser are found as the near-critical path while they are not observed from others. These are considered the unnecessary near-critical paths that were done with too late delivery schedule. However, the real reasons behind will need further investigation as this may not result from the technical reason such as long manufacturing period but may result from other factors such as the financial concern or other limitations. For example, the delivery of transformer may have to wait for the certain period to be delivered to the site because of cash flow of the project which the project management team may not want to spend the money in the early date against equipment delivery. On the other hand, late delivery may be due to limitation of space to store that equipment at site. Balancing of margin over project schedule and other factors would require proper judgement of the project management team which may differ from project to project.

In summary, though different in sizes, 3 out of 4 projects have their critical paths including procurement activities of the turbines. Moreover, procurement of the turbines other than those critical paths are found to be the near-critical path in all of the projects.

Regarding the SPP scale power plants, to determine the recommended durations of each common critical paths found in this research for further reference, as the project implementation schedules are project detailed specific and individual project factors can influence those timelines significantly in detailed level, it is therefore recommended to consider the “average actual” durations as the general guideline with a range of plus or minus 20% as a margin for general references, similar criteria to the percent total float considered for the near-critical path in this research.

7.5 Construction work analysis

First of all, the civil works starting from site preparation, piling and control building related works are found as the critical path of only Project C. However, as discussed in section 6.3.1 of this research, the foundation work of control building took around 3.7 times longer than plan and also around 2.3 times longer than the average of Project A and Project B which have the same capacity of power generation. Thus, this is considered outrange and unusual timeline compared to other projects.

Next, the main equipment erections of gas turbines and steam turbines are found as the dependent critical paths of Project A, Project B, and Project D which have the procurement as the precedent critical tasks.

Balance of plant erection work is found as the critical paths of only Project C, subsequent to the control building work. The critical paths in this area are related to the electrical activities such as cable installation and medium voltage installation which have to be completed before the back energization.

Regarding the electrical works erection, Project B is also found as the near-critical with relatively low margin of only 1.7% for cable installation and 3.1% for medium voltage installation. It is noticed that both Project B and Project C are those subjected to construction delay. This can be considered as the area where further construction of this type of projects may have to be aware of.

Duration of construction works that are critical paths compared to others is shown in Table 22.

Table 22 Duration of construction work that are critical paths compared to others

	SPP scale power plants				IPP scale power plant
	Project A	Project B	Project C	Project A B C Average	Project D
	(days)	(days)	(days)	(days)	(days)
Site preparation, clearing and levelling work	60	35	85	60	42
Piling of GTG1 and GTG2	32	30	20	27	40
Piling of control building	7	15	25	16	14
Foundation of control building	41	150	217	136	280
Control building construction	206	180	64	150	150
GTG1 erection	107	289	140	179	180
GTG2 erection	105	264	218	196	180
Steam turbine erection	160	124	297	194	265
Cable tray and cabling	175	407	320	301	93
Medium voltage system installation	18	227	320	188	93
Transmission line	298	699	197	398	396
Back energization	1	1	23	8	1

Note: Red text refer to activity which is critical path.

Considering the different size of projects between Project D and others, it is noted from

Table 22 that the gas turbines erection durations are within the same range while the steam turbine erections take slightly longer than average but still shorter than that of Project C. The electrical balance of plant installation, on the other hand, takes shorter than the average of Project A, Project B and Project C. The transmission line, however, is unable to compare because this depends largely on site conditions which are different project by project, for example, length of transmission line, right of way of areas the transmission line pass through and etc. Last but not least, the back energizations take the same duration of only 1 day among Project A, Project B and Project D which can be implied that the constructions of all related systems are done properly resulting in a day to complete. It is noted for Project C that there were some technical problems at the electrical system during back energization which made this activity much longer than others.

Similar to the procurement, guidance for the appropriate timeline of each critical path of the SPP scale power plants can apply the same concept of actual average as general reference except the transmission line which is absolutely project specific and the back energization which Project C duration is explicitly odd compared to other projects and should be ignored regarding this consideration.

7.6 Commissioning work analysis

The cold commissioning works are found as the common critical paths for all projects. The gas turbines and HRSGs cold commissioning are found as the critical paths of Project B, Project C, and Project D while the steam turbine cold commissioning is found as the critical paths of Project A, Project B and Project D.

Similar to the cold commissioning, the hot commissioning works are found with critical paths for all projects. The gas turbine hot commissioning, starting from first firing, it is found as the critical paths of Project B, Project C and Project D while for the steam turbine hot commissioning activities, starting from steam turbine first steam up until the commercial operation, are explicitly found as the common critical paths for all projects.

Summary of commissioning works that are critical paths of all projects is shown in Table 23.

Table 23 Summary of commissioning works that are critical paths of all projects

	SPP scale power plants				IPP scale power plant
	Project A	Project B	Project C	Project A B C Average	Project D
	(days)	(days)	(days)	(days)	(days)
Cold commissioning					
GTG1 and HRSG1 cold commissioning, including function test	42	11	7	20	96
GTG2 and HRSG2 cold commissioning, including function test	43	9	18	23	69
Cold commissioning of electrical system	16	4	4	8	4
Steam turbine cold commissioning	44	59	53	52	33
Hot commissioning					
GTG1 first firing	1	1	2	1	1
GTG1 function test	9	37	11	19	29
GTG1 first synchronization	1	1	95	32	1
GTG2 first firing	1	1	2	1	1
GTG2 function test	5	8	12	8	28
GTG2 first synchronization	1	1	94	32	1
Main steam header blowout	20	5	6	10	14
Steam turbine first steam	1	5	36	14	1
Steam turbine hot commissioning and function test	5	48	1	18	5
Steam turbine first synchronization	1	1	1	1	1
Combined cycle function test	45	20	79	48	76
Plant performance test	4	2	0	2	2
Plant trial run	15	6	6	9	15
Commercial operation	0	0	5	2	1

Note: Red text refer to activity which is critical path.

The function test of gas turbines and HRSGs during both cold commissioning and hot commissioning of Project D are found longer than the average of the other three projects, on the other hand, the steam turbines function tests are found shorter. This is due to the configuration of equipment which Project D has the steam turbines connecting to the same generators as the gas turbines, referred to as the single shaft configuration, therefore, eliminate the function test of common auxiliary systems such as lube oil and generators related equipment, resulted in reduction of the inter-equipment function test duration.

The rest of the commissioning activities are observed with similar durations despite difference in project size except for the first synchronization of Project C which took much longer than others. Cause of delay has been discussed in section 6.3.1 of this research.

In summary, though difference in project size, commissioning works are the critical paths of all projects when looking at the high-level particularly when considering the steam turbine first steam afterward. This is because it is necessary to test run the plants to ensure that the installed components are working properly with high reliability, ready to support the plants in the long term electricity generation, subsequently, reliable revenue generation to the projects.

Similar to the procurement and construction, guidance for the appropriate timeline of each critical path of the SPP scale power plants can apply the same concept of actual average as general reference for future timeline prediction except for the first synchronization and steam turbine first steam which Project C duration is explicitly odd compared to other projects and should be ignored in this regard.

Chapter 8. Discussion and preventive measures

Findings, observations and preventive measures for project schedule control of combined cycle gas turbine power plant are discussed in the below sections.

8.1 General findings and observations

8.1.1 Project durations of different project sizes

Table 24 summarizes all projects' actual critical paths by grouping into major categories according to the work breakdown structure.

Table 24 Summary of all projects' actual critical paths in major categories

	Duration (days)			
	Project A	Project B	Project C	Project D
Engineering	-	-	-	11
Procurement	461	447	-	718
Construction	239	300	765	279
Commissioning	56	134	239	101
Overall duration	756	881	1,004	1,109

Considering the overall project duration of Project D which is larger than others in term of capacity, it is found that Project D consumes the longest construction duration (1,109 days compared to 756 days and 881 days of Project A and Project B respectively). It should be noted that comparison of the overall duration of Project D to Project C can lead to misunderstanding because Project C is much delay from the plan.

The major contributions to those of Project D are the procurement works, this is also longer than others (718 days compared to 461 days and 447 days of Project A and Project B respectively). However, both the construction and commissioning durations are found within the same range of Project A and Project B though the Project D's capacity and size are larger.

8.1.2 Quantity of the planned near-critical paths in the delayed projects

Similarity is found in the delay projects (i.e. Project B and Project C) such that they were planned with many near-critical paths unnecessarily. For example, Project B and Project C were planned with 21 and 17 activities of near-critical paths respectively while the on-time projects (i.e. Project A and Project D) were planned with only 4 and 10 near-critical path activities respectively.

Causes of improper planning could be because lack of experience of scheduler which can result in erroneous in critical path planning. Moreover, another constrain could be that the scheduling planner and the implementor may be different person therefore lack of communication between them can lead to inconsistency between planning and practical implementation in the real works.

8.2 Preventive measures categorization

According to recommendations by Cretu, et al. (2011), prior to the identification of the appropriate preventive measures to the risk analysed in section 7.1 (in this case, the delay risks of the common critical paths), the high level response strategies of those measures should be first determined including avoidance, transference, mitigation and acceptance.

As this research is focusing on the preventive mitigation measures, only this type of strategy will be further discussed. Table 25 summarizes the delay risk response strategies categorized into groups as recommended by Cretu, et al. (2011) by focusing on the mitigation strategy and applying it to the main groups of activities under the work breakdown structures of the combined cycle gas turbine power plant construction which have been discussed in Chapter 4 and Chapter 7. The detailed recommendations of preventive measures to avoid delay by Hessler (2014) and Chartered Institute of Building (CIOB) (2014) are also considered which the summaries of those are also incorporated in Table 25.

Table 25 Delay risk response strategies and possible preventive measures

Strategies Activities	Avoidance	Transference	Mitigation	Acceptance
Contractual process	-	-	- Avoid deferring the contractual milestone which will affect the project timeline inevitably	-
Engineering work	-	-	- Precise on requirements and scopes (Hessler, 2014) (Chartered Institute of Building (CIOB), 2014)	-
Procurement work	-	-	- Commence the procurement work at the earliest	-
Construction work	-	-	- Maintain construction commencement date and sequences (Hessler, 2014) - Maintain proper level of communication between parties (Hessler, 2014) - Continually monitoring project progress and chasing area of concern (Chartered Institute of Building (CIOB), 2014) - Robust contractual obligations determining liquidated damages (Hessler, 2014) - Time contingency can be set (Chartered Institute of Building (CIOB), 2014)	-
Commissioning work	-	-	- Good quality management since engineering and construction phases (Chartered Institute of Building (CIOB), 2014) - Robust contractual documents determining commissioning requirements (Chartered Institute of Building (CIOB), 2014) - Insurance coverage (Hessler, 2014)	-

Details of the delay risk preventive measures are discussed further in the below sections.

8.3 Preventive measures for schedule control during engineering phase

Though the engineering work is found only the critical paths of Project D, preventive measures in this area should also be considered. Hessler (2014) discuss some of those regarding the project's requirements in the way that determination of the project requirements should be clear whether it is based on the general requirements or the detailed basis. For example, if the requirements of the project are for the contractors to meet the international standard for piping, the pipeline sizing should not be fixed, on the other hand, it should allow the contractor to design and also responsible for the consequences of those design themselves.

8.4 Preventive measures for schedule control during procurement phase

According to the results and analysis of this research, it is found that the procurement works especially those of the main equipment (i.e. gas turbines and steam turbines) are the critical paths for most of the projects or at least the near-critical paths for the remaining projects. Therefore, expediting the procurement of main equipment should be done where possible. One of the possible methods is to shift all the long lead time equipment to be procured before the notice to proceed issuance.

The example has been found effectively shorten the project overall duration in case of Project D where the steam turbine procurement, the longest lead time equipment in the project, had been shifted earlier prior to the notice to proceed issuance. While for other projects, the procurement of all equipment had been done after issuance of notice to proceed due to obligations to undertake the risk of the contracting parties.

Figure 49 illustrates the shifting earlier of the start date of major long lead equipment procurement.

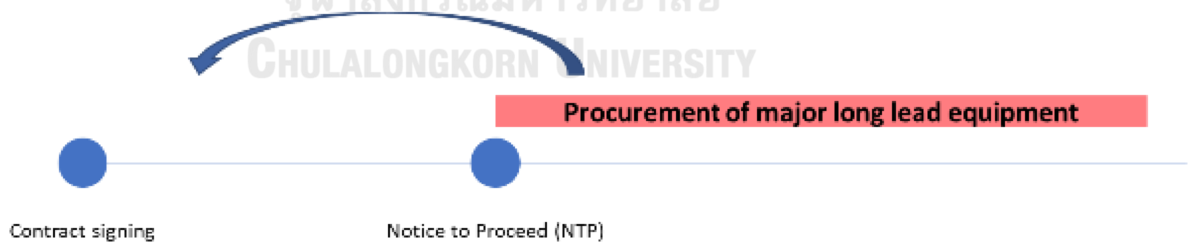


Figure 49 Shifting in start date of major long lead equipment procurement

This however would need the contractual languages agreed by all related parties to support which is found in line with the risk management tools recommended by Hessler (2014). The contractual obligations to encourage those should be mutually agreed and clearly mention all other aspects impacting to the related parties such as the financial and legal obligations.

8.5 Preventive measures for schedule control during construction phase

As all the projects are found with the equipment erections embedded as part of the critical paths, delay scheduling protection originating from erection works is therefore worth considered. Hessler (2014) argues some of the frequent originators of the delay in this area which should be avoided. Moreover, preventive measures to construction delay by Chartered Institute of Building (CIOB) (2014) are also discussed. Those preventive measures and applications found in the studied projects are shown in Table 26.

Table 26 Recommendations to avoid construction delay and application of case study projects

Recommendation on avoidance	Observation found on case study projects			
	Project A	Project B	Project C	Project D
Construction commencement date shifting	No	No	No	No
Sequence of work changes	No	Yes	Yes	No
Improper level of project governance	Information not available	Information not available	Information not available	Information not available
Progress monitoring	Yes	Yes	Yes	Yes
Robust contractual obligations including liquidated damages	Yes	Yes	Yes	Yes
Time contingency build-in	Yes	Yes	Yes	Yes

8.5.1 Shifting in construction commencement date

Shifting the start date in some cases can lead to the delay, for example, revision of plan which result in starting of the project site construction during rainy season. This could potentially delay the civil work which some of the activities of the civil work are found as the critical path of Project C and the near-critical paths of all other projects in this research.

8.5.2 Sequence of work changes

Necessity to change the sequences of work can also case the delay. This may be resulted from unforeseen restrictions which may come from the working parties themselves or limitations from the third party.

This is in line with the results observed from this research where the abnormal sequences are found in the delayed projects such that the actual project activities had been done with many confusing sequences and without proper logic according to the original plan. For example, the back energization of Project B was done after the gas turbine first firing which is not a normal practice as found in other projects. Ignoring of standard sequences could potentially lead to catastrophe because without the back energization, for example, the balance of plant equipment including the backup power system; the redundant equipment switching capability; and many interlocks protections would not be properly tested and integrated into the overall control and protection systems, thus, the supporting systems and failure prevention systems would not be in place in case any accident happen. Regarding Project B, it is noted from the actual project schedule that the balance of plant equipment had been partially tested after plant trial run before the commercial operation, and some omitted tests were even completed after the commercial operation

This situation could happen due to many causes and can be originated by many parties, for example, the expedition of the work progress by the contractor to complete the project on time which can result in omission of appropriate sequences according to good industrial practice during construction and commissioning, on the other hand, can be the impact from external parties, for example, additional requirement by the government authority to install particular protection equipment in the power plant electrical system prior to connecting the power plant to the national grid. The actual root cause however needs further analysis and study.

8.5.3 Improper level of project governances by the owners

Hessler (2014) argues that excessive management by the project owners toward contractors, manufacturers and subcontractors could lead to delay. This is because the construction companies will have their own organization charts, communication structures and lines of commands, moreover in many cases, there will be a number of subcontractors subcontracting works from the main one. Interfering those workflows and communications will result in confusion eventually result in negative impact to the project progress.

On the other hand, lack of involvement by the stakeholders can result in the convergence. Generally during project implementation, there will be some ambiguous areas which require judgements by the project owners that usually relate to the commercial and the time impacts. Late response can drag the problem out unnecessarily which will potentially delay the project progress. Therefore, it is recommended to maintain appropriate level of communication to avoid the gap amongst parties which can result in delay of the project completion.

8.5.4 Progress monitoring

Whilst the projects are being developed, unforeseen problems or accidents can happen which will affect the project progress. Continually monitor the progresses of the contractors, manufacturers and subcontractors including the construction at site and also the shop fabrication of the key equipment are recommended. This is to keep tracking on the actual works on progress and chasing the delayed critical areas or any areas of concern in order to recover back the progress and keep the all activities on track, avoiding accumulated delay which will be more difficult to expedite as the time passed (Chartered Institute of Building (CIOB), 2014).

8.5.5 Determining robust contractual obligations

As the quality of power plant obtained from the contractor, subcontractors and manufacturers plays an important role not only during project construction but throughout the operation phase, selecting reputable contractors, manufacturers and subcontractors with good track records would help lower the risk of non-performing party which could potentially lead to delay in construction. In this area according to Hessler (2014), contractual obligations incorporating liquidated damages could help encourage all the parties to perform well and to complete the project within the agreed timeframe. The contract should allow for the tracking of the actual progresses by the owner toward all the parties as well. It is further recommended that communication is crucial in order to prevent mismatch things amongst parties to happen.

8.5.6 Time contingency build-in

Appropriate time contingency is necessary to provide margin to the overall project schedule caused by foreseeable potential risks during the project planning such as divergence of individual planning or coordination risk among parties (Chartered Institute of Building (CIOB), 2014). This will allow the project to have buffer in case that such risk happens and the actual working schedule will be better manageable. Time contingency can be estimated as the likely duration consumed due to those interventions happen.

8.6 Preventive measures for schedule control during commissioning phase

As the commissioning works comprise critical activities commonly found on all the projects in this research and they inevitably have been sequenced at the last part of the projects, prior preventive measures to avoid problems occur during commissioning period should be considered.

Quality Assurance and Quality Control (QA/QC) since engineering and construction phases are necessary (Chartered Institute of Building (CIOB), 2014). This is to ensure that the quality of the equipment and works installed are align with good industrial standards which could help alleviate the problem of individual equipment functioning during the test run and commissioning. Figure 50 shows example of a QA/QC activity during erection. Moreover, the contract between parties should also determine the requirements of the commissioning explicitly on which parts of the works will be tested and how will the test procedure be (Chartered Institute of Building (CIOB), 2014).

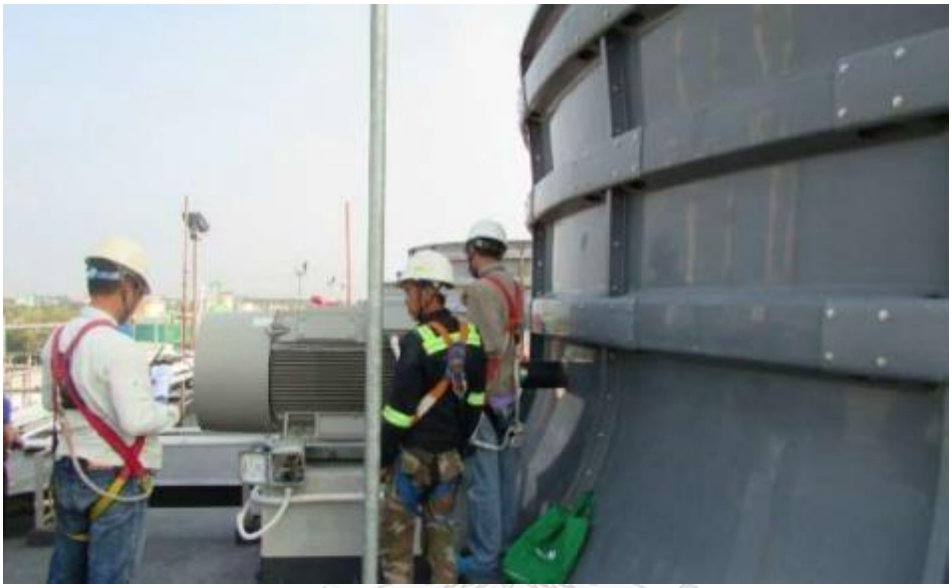


Figure 50 Example of QA/QC activity during erection

Last but not least, Hessler (2014) recommends that insurance should be in place to provide protections to the projects as the comprehensive tools. There are many types of insurance which can be assured, for example, there can be a surety bond in place throughout the construction and commissioning of the project by the contractors to provide guarantee that they will implement the project according to what have been agreed. Moreover, typical types of insurance for construction projects are recommended including:

Marine cargo insurance;

Construction all risk;

Third-party liability;

Worker’s compensation;

Mobile equipment insurance; and

Loss of revenue insurance;

It is also noted that though plenty of insurances have been made, there can be some exceptions remain. For example, some insurance policy may exclude failure from poor in design which risk in the omission areas of insurance will require further consideration by the responsible parties.

Moreover in some cases, the project owner may execute the overall project insurance themselves which the contractor may have to assure their own additional insurance for the first damage coverage to fulfil the gap prior to the insurance by the owner trigger. This will require a well communication amongst the parties to bring all the detailed understandings on the same page.

8.7 Benefit from successful applying of the preventive mitigation measures

In the real CCGT power plant construction projects, the construction delay can occur which in this research are found on Project B and Project C. To estimate how much the delay recovering is worth in value, let's consider the delay penalty under the power purchase agreement with the authority of 0.33 percent of the performance bond per day of delay (Electricity Generating Authority of Thailand, 2011), this delay penalty is then calculated at approximately THB 1,000,000 per day for this type of power plants. Therefore, the delay preventive measures are quite worth applying to those projects to avoid the delay in construction which eventually will result in the late commercial operation of the projects.

Chapter 9. Opinion from experts in this area

Interviews have been made with two experts in this area. The first expert has experience in the CCGT construction projects for more than 30 years. She is currently working in the international consultant company and holding a position of technical director – thermal power plant. Her backgrounds in education are bachelor’s degree in engineering and master’s degree in business management. She is now holding the professional license of Senior Professional Engineer (Mechanical) from the Council of Engineers, Thailand. She involved in more than 30 CCGTs both local and international construction projects in various roles during her working experiences including contractor, owner’s engineer and lender’s technical advisor.

The second expert interviewed is the senior management in the Thai conglomerate which is the developer of many electricity generation projects. He holds the bachelor’s degree in engineering and currently has the position of executive vice president – project management. His responsibility is directly in charge of all the construction projects under his company’s portfolio.

9.1 First expert’s opinions

According to the interview with the first expert, she provides her view that, though the procurement contributes to the critical paths as the longest activities, in her experiences, she found that the procurements of the main equipment are rarely to delay. This is because they are manufactured in the fabrication shops in which the qualities and resources can be controlled. Also, the main equipment manufacturers are specialized in their equipment with many reproductive of the equipment in their production line, moreover, there were always firm procurement contracts made with these manufacturers thus ensuring the guaranteed performance and delivery time of these main equipment.

On the other hand, the causes that make most the projects delay in her experience are the construction and erection works at site especially the balance of plant erection works which many uncontrolled factors could be found, for example, unpredictable weather conditions, unavailability of resources and uncontrolled quality of site installation works.

Next, the commissioning works are found as the single line of activities which testing of particular equipment has to be done in proper sequences after the precedent one. This inevitably makes the commissioning works the critical paths in all the projects in her experience. So, there will usually be the embedded margin in each planned activity in this commissioning phase as the implementors of this task know that this set of activities has no float.

Moreover, she opines that the criteria of the near-critical path with 20% total float is more than comprehensive to consider the near-critical activity which can potentially become the critical one.

Lastly, she opines that with more detailed levels of activities breakdown, the project critical paths analysis will be more accurate.

9.2 Second expert's opinions

The second expert opines that he agrees with the assumption in this research that the contractors in responsible of the power plant constructions should assumably have adequate and similar project experiences in power plant construction as different contractors will have their own areas of strength.

Moreover, he opines that the hardness of the plant location should be taken into account as this can differentiate the difficulties of construction activities, therefore, the time required to complete the same tasks in different site locations will be different from construction perspective.

Last but not least, he opines that different contractors' arrangement can result in different construction timeline. This is because the fluency in project management will be different between the single contractor arrangement compared to the multiple contractors arrangement, not only from the project owners' perspective but also from the contractors' point of view as they are the party who will have to coordinate and manage the interconnection works among many complicated systems and integrate them into the power plant.

Chapter 10. Conclusions

In this research, construction schedules of 4 combined cycle gas turbine power plant projects have been analysed. The common work breakdown structures have been set out to group the detailed construction activities of those projects into pre-determined categories. After that the analysis of each project to find out the construction critical paths has been carried out which some set of activities are found common.

3 out of 4 projects are found with the critical paths beginning with the issuance of notice to proceed then the procurement and erection of the main equipment (either gas turbine or steam turbine). 1 out of 4 is found with the critical paths starting with the civil works, balance of plant electrical equipment erection and back energization.

After that, all the projects are found with the common critical paths in commissioning works of both cold and hot commissioning. The cold commissioning comprises individual equipment or subsystem test run using power supply which has been back fed from the local electrical grid while the hot commissioning is determined in this research as the starting of the gas turbine first firing onward. Particularly after the steam turbine first steam (as part of the hot commissioning), the subsequent activities have been found as the common critical paths for all projects, those activities include the steam turbine first steam itself following with the overall combined cycle commissioning works, overall plant performance test and up to the commercial operation at the end of the projects.

In the projects which found delay from the planned schedule (i.e. Project B and Project C), it is observed that they were planned with too many near-critical paths unnecessarily, moreover, according to the critical paths analysis results, the major activities contributing to the delay duration are found relating to the site erection works.

Preventive measures to control those construction critical paths for the combined cycle gas turbine power plant projects are then determined based on the recommendations from the published papers by Hessler (2014) then applied to the common critical paths observed. Those preventive measures, at a high level, comprise measures to be implemented during the engineering, procurement, construction and commissioning phase. It can be found that among the two projects that found delay, lacks of some practices according to Hessler's recommendation are observed.

2 experts' comments and opinions are gathered through interviews. All those experts are professionals who currently work in the area of the power plant constructions with abundant experiences. Opinions on the analysed results and preventive mitigation measures in this research from them show that the analysis results are in line with their experiences. Apart from their opinions, some advises on further studies are suggested.

Analysis results of the construction critical paths and near-critical paths together with the recommended preventive mitigation measures to control project schedule in this research are hopefully beneficial to those who will develop, construct or participate in the combined cycle gas turbine power plant projects in the near future.

Chapter 11. Future Work

According to this research's assumptions and comments from experts, the studies in more details of the following areas can be conducted which are believed to be beneficial to the related parties.

11.1 More detailed level of activities

As recommended by Ramos (2017) and also the interview results from the experts in this area, the more detailed work breakdown structures would result in the more accurate of the critical paths of the particular projects. Therefore, investigating deeper into the project details is interesting and would be beneficial for those who will have to do the project planning for this type of combined cycle gas turbine power plants.

11.2 Manpower planning and labour availability in consideration

It is possible that the durations to complete some activities are limited by the lack of labour. This can be the root causes other than the normal durations required to complete that works themselves. The rationales behind are usually not shown in the project construction schedules. Therefore, further study in this area would provide more understanding on the limitations of this type during project construction.

11.3 Financial performance in consideration

As the components of good project management comprise not only the timeline but also the cost incurred, the cash flow of management during construction would directly affect the schedule planning. For example, it is possible that the delay in construction may be not because the project is technically delay but the contractor may have to wait for the payment to progress things further.

Further study on the financial performance of the projects relating to the project schedule could be the area of interest to see the relation among those key project success factors.

11.4 Difficulties of site conditions in consideration

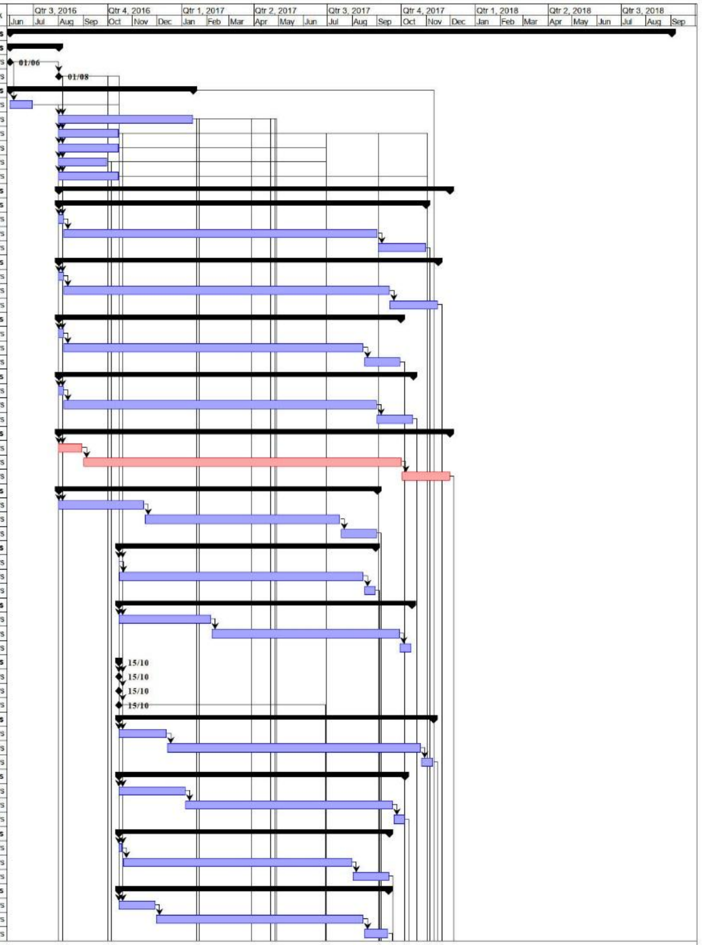
As recommended by one of the experts, different site conditions can result in different timeline to complete the construction of those projects. Therefore, analysis on the impact of different site conditions (for example, soil conditions, altitudes, remote or urban areas, etc) toward the time required to complete the subtasks of the similar type of projects could be the area of interest.

11.5 Environmental and safety

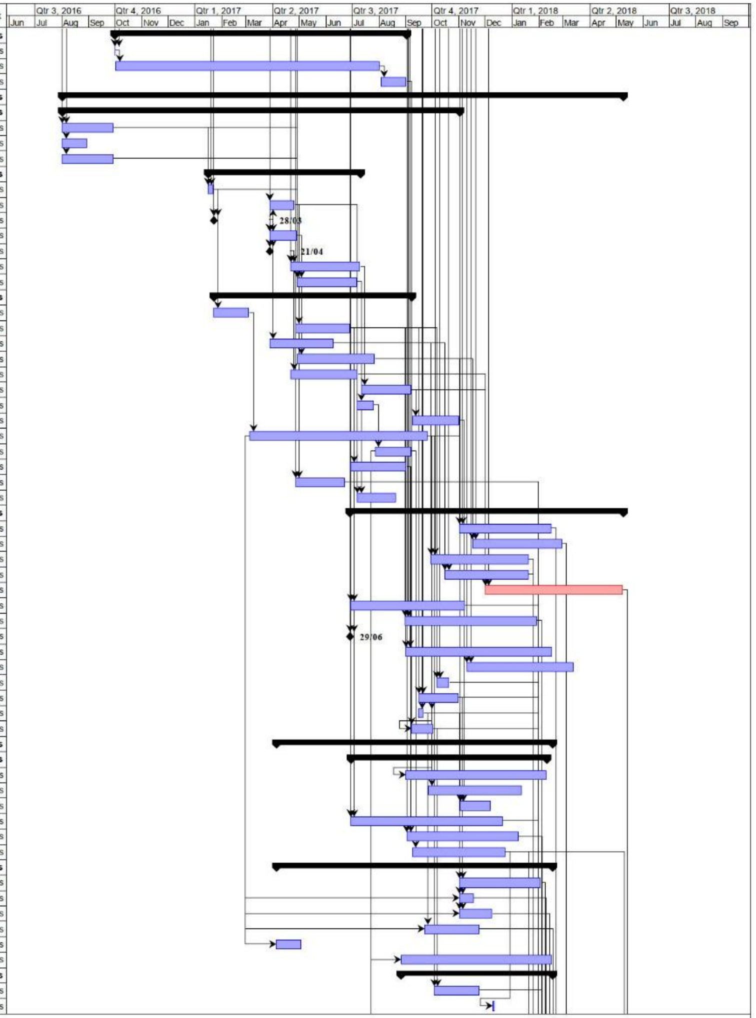
Nowadays, many construction projects consider the safety at the highest priority amongst all. The more robust in safety aspect however could have an effect to the construction schedule. For example, the safety officer at site may request for activity suspension in case that current construction activity is not in compliance with the standard safety practice or even the project site's specific restrictions. This can be considered as part of the quality control of the overall project construction, however, it will inevitably affect the construction progress. More analysis on the relation between site safety regulations and the project progress can be an area for further study to evaluate the appropriate level of safety measurements at site which should be applied to push the project forward timely and safely.

Appendix A Detailed results of construction schedules analysis of Project A

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project A**	**823 days**	**01/06/16...**	**01/09/18...**		**0 days**
2		**Key milestone**	**61 days**	**01/06/16...**	**01/08/16...**		**0 days**
3	01/06/16 ...	EPC Contract signing	0 days	01/06/16 ...	01/06/16 ...		0 days
4	01/08/16 ...	Notice to proceed	0 days	01/08/16 ...	01/08/16 ...	3	0 days
5		**Detailed Engineering work**	**229 days**	**01/06/16...**	**15/01/17...**		**81 days**
6		Conceptual design	30 days	01/06/16 ...	30/06/16 ...	3	31 days
7		Civil detialed engineering	168 days	01/08/16 ...	15/01/17 ...	4;6	0 days
8		Mechanical and process detailed engineering	75 days	01/08/16 ...	14/10/16 ...	4;6	0 days
9		Electrical detailed engineering	75 days	01/08/16 ...	14/10/16 ...	4;6	0 days
10		C&I detailed engineering	61 days	01/08/16 ...	30/09/16 ...	4;6	0 days
11		Balance of plant detailed engineering	75 days	01/08/16 ...	14/10/16 ...	4;6	0 days
12		**Procurement**	**487 days**	**01/08/16...**	**30/11/17...**		**275 days**
13		**GTG1**	**457 days**	**01/08/16...**	**31/10/17...**		**55 days**
14		Confirm order to GTG	7 days	01/08/16 ...	07/08/16 ...	4;6	0 days
15		Manufacturing	390 days	08/08/16 ...	01/09/17 ...	14	0 days
16		Transportation	60 days	02/09/17 ...	31/10/17 ...	15	0 days
17		**GTG2**	**472 days**	**01/08/16...**	**15/11/17...**		**71 days**
18		Confirm order to GTG	7 days	01/08/16 ...	07/08/16 ...	4;6	0 days
19		Manufacturing	405 days	08/08/16 ...	16/09/17 ...	18	0 days
20		Transportation	60 days	17/09/17 ...	15/11/17 ...	19	0 days
21		**HRSG1**	**425 days**	**01/08/16...**	**29/09/17...**		**72 days**
22		Confirm order to HRSG	7 days	01/08/16 ...	07/08/16 ...	4;6	0 days
23		Manufacturing	373 days	08/08/16 ...	15/08/17 ...	22	0 days
24		Transportation	45 days	16/08/17 ...	29/09/17 ...	23	0 days
25		**HRSG2**	**441 days**	**01/08/16...**	**15/10/17...**		**94 days**
26		Confirm order to HRSG	7 days	01/08/16 ...	07/08/16 ...	4;6	0 days
27		Manufacturing	389 days	08/08/16 ...	31/08/17 ...	26	0 days
28		Transportation	45 days	01/09/17 ...	15/10/17 ...	27	0 days
29		**Steam turbine**	**487 days**	**01/08/16...**	**30/11/17...**		**0 days**
30		Confirm order to STG	31 days	01/08/16 ...	31/08/16 ...	4;6	0 days
31		Manufacturing	396 days	01/09/16 ...	01/10/17 ...	30	0 days
32		Transportation	60 days	02/10/17 ...	30/11/17 ...	31	0 days
33		**Gas heater**	**396 days**	**01/08/16...**	**31/08/17...**		**197 days**
34		Confirm order to gas compressor	107 days	01/08/16 ...	15/11/16 ...	4;6	0 days
35		Manufacturing	244 days	16/11/16 ...	17/07/17 ...	34	0 days
36		Transportation	45 days	18/07/17 ...	31/08/17 ...	35	0 days
37		**Cooling tower**	**320 days**	**15/10/16...**	**30/08/17...**		**44 days**
38		Confirm order to cooling tower	1 day	15/10/16 ...	15/10/16 ...	4;8;6	0 days
39		Manufacturing	304 days	16/10/16 ...	15/08/17 ...	38	0 days
40		Transportation	15 days	16/08/17 ...	30/08/17 ...	39	0 days
41		**Turbine bypass valve**	**364 days**	**15/10/16...**	**13/10/17...**		**323 days**
42		Confirm order to turbine bypass valve	115 days	15/10/16 ...	06/02/17 ...	4;6;8;11	0 days
43		Manufacturing	234 days	07/02/17 ...	28/09/17 ...	42	0 days
44		Transportation	15 days	29/09/17 ...	13/10/17 ...	43	323 days
45		**Chiller**	**0 days**	**14/10/16...**	**14/10/16...**		**687 days**
46		Confirm order to chiller	0 days	14/10/16 ...	14/10/16 ...	4;8;11;6	0 days
47		Manufacturing	0 days	14/10/16 ...	14/10/16 ...	46	0 days
48		Transportation	0 days	14/10/16 ...	14/10/16 ...	47	257 days
49		**Pump**	**391 days**	**15/10/16...**	**09/11/17...**		**172 days**
50		Confirm order to pumps	60 days	15/10/16 ...	13/12/16 ...	4;6;8	0 days
51		Manufacturing	316 days	14/12/16 ...	25/10/17 ...	50	0 days
52		Transportation	15 days	26/10/17 ...	09/11/17 ...	51	0 days
53		**Emergency diesel generator**	**356 days**	**15/10/16...**	**05/10/17...**		**145 days**
54		Confirm order to energency diesel generator	83 days	15/10/16 ...	05/01/17 ...	4;8;9;11;6	0 days
55		Manufacturing	258 days	06/01/17 ...	20/09/17 ...	54	0 days
56		Transportation	15 days	21/09/17 ...	05/10/17 ...	55	0 days
57		**Transformer**	**336 days**	**15/10/16...**	**15/09/17...**		**78 days**
58		Confirm order to transformers	5 days	15/10/16 ...	19/10/16 ...	4;9;11;6	0 days
59		Manufacturing	286 days	20/10/16 ...	01/08/17 ...	58	0 days
60		Transportation	45 days	02/08/17 ...	15/09/17 ...	59	0 days
61		**Switchgear**	**335 days**	**15/10/16...**	**14/09/17...**		**118 days**
62		Confirm order to switchgear	46 days	15/10/16 ...	29/11/16 ...	4;9;11;6	0 days
63		Manufacturing	259 days	30/11/16 ...	15/08/17 ...	62	0 days
64		Transportation	30 days	16/08/17 ...	14/09/17 ...	63	0 days

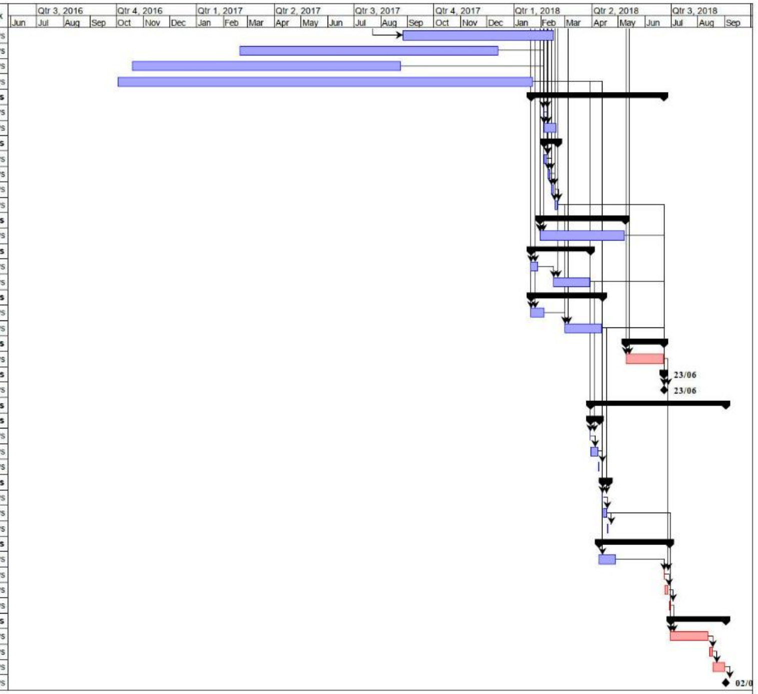


	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
65		**DCS panel**	**336 days**	**01/10/16...**	**01/09/17...**		**154 days**
66		Confirm order to DCS	1 day	01/10/16 ...	01/10/16 ...	4;6;10	0 days
67		Manufacturing	305 days	02/10/16 ...	02/08/17 ...	66	0 days
68		Transportation	30 days	03/08/17 ...	01/09/17 ...	67	5 days
69		**Construction work**	**647 days**	**01/08/16...**	**09/05/18...**		**115 days**
70		**Civil work**	**458 days**	**01/08/16...**	**01/11/17...**		**304 days**
71		Permit to start civil work	60 days	01/08/16 ...	29/09/16 ...	4;6	108 days
72		Site mobilization and site temporary office	30 days	01/08/16 ...	30/08/16 ...	4	732 days
73		Site preparation, clearing and levelling work	60 days	01/08/16 ...	29/09/16 ...	4	108 days
74		**Piling works**	**176 days**	**16/01/17...**	**10/07/17...**		**84 days**
75		Control building piling	7 days	16/01/17 ...	22/01/17 ...	73;7;71	0 days
76		Tank piling and miscellaneous balance of plant	30 days	28/03/17 ...	26/04/17 ...	73;71;7;77	0 days
77		HRSG piling	64 days	23/01/17 ...	27/03/17 ...	7;71;73;75	0 days
78		GTG piling	32 days	28/03/17 ...	28/04/17 ...	7;71;73;77	0 days
79		STG piling	24 days	28/03/17 ...	20/04/17 ...	7;71;73;77	0 days
80		Steam turbine hall piling	81 days	21/04/17 ...	10/07/17 ...	7;71;73;79	0 days
81		Pipe rack and pipe bridge piling	69 days	29/04/17 ...	06/07/17 ...	7;71;73;78;75	0 days
82		**Foundations**	**228 days**	**23/01/17...**	**07/09/17...**		**109 days**
83		Control building	41 days	23/01/17 ...	04/03/17 ...	75	0 days
84		Tank foundation and miscellaneous balance of plant	63 days	27/04/17 ...	28/06/17 ...	76	0 days
85		HRSG foundation	74 days	28/03/17 ...	09/06/17 ...	77	112 days
86		GTG foundation	90 days	29/04/17 ...	27/07/17 ...	78	96 days
87		STG founndation	78 days	21/04/17 ...	07/07/17 ...	79	146 days
88		Steam turbine hall	59 days	11/07/17 ...	07/09/17 ...	80	0 days
89		Pipe rack and pipe bridge foundation	20 days	07/07/17 ...	26/07/17 ...	81	0 days
90		Steam turbine hall	55 days	08/09/17 ...	01/11/17 ...	88	0 days
91		Control building	206 days	05/03/17 ...	26/09/17 ...	83	0 days
92		Pipe rack and pipe bridge steel structure erection	43 days	27/07/17 ...	07/09/17 ...	89	0 days
93		Miscellaneous buildings	65 days	29/06/17 ...	01/09/17 ...	84	0 days
94		Water/wastewater pond	57 days	27/04/17 ...	22/06/17 ...	7;73;76	222 days
95		Road and paving	45 days	07/07/17 ...	20/08/17 ...	81;76	377 days
96		**Main equipment erection work**	**315 days**	**28/06/17...**	**09/05/18...**		**115 days**
97		GTG1	107 days	01/11/17 ...	15/02/18 ...	16;86	0 days
98		GTG2	105 days	16/11/17 ...	28/02/18 ...	20;86	0 days
99		HRSG1	113 days	30/09/17 ...	20/01/18 ...	24;85	0 days
100		HRSG2	97 days	16/10/17 ...	20/01/18 ...	28;85	0 days
101		STG	160 days	01/12/17 ...	09/05/18 ...	32;87;88	0 days
102		Service water tank	133 days	29/06/17 ...	08/11/17 ...	8;84	83 days
103		Cooling tower	153 days	31/08/17 ...	30/01/18 ...	40;84	0 days
104		Chiller	0 days	28/06/17 ...	28/06/17 ...	48;84	430 days
105		Gas heater	169 days	01/09/17 ...	16/02/18 ...	36;84	197 days
106		Pump	124 days	10/11/17 ...	13/03/18 ...	5;52	172 days
107		Emergency diesel generator	16 days	06/10/17 ...	21/10/17 ...	56;84	101 days
108		Transformer	46 days	16/09/17 ...	31/10/17 ...	60;84	0 days
109		Switchgear	7 days	15/09/17 ...	21/09/17 ...	64;91FS-40 days	0 days
110		DCS panel	26 days	07/09/17 ...	02/10/17 ...	68;91FS-20 days	0 days
111		**Balance of plant erection work**	**319 days**	**04/04/17...**	**16/02/18...**		**197 days**
112		**Mechanical work**	**227 days**	**29/06/17...**	**10/02/18...**		**203 days**
113		Air conditioning and ventilation system	163 days	01/09/17 ...	10/02/18 ...	91FS-26 days	203 days
114		Plumbing and drainage	108 days	27/09/17 ...	12/01/18 ...	91	232 days
115		Firefighting	36 days	02/11/17 ...	07/12/17 ...	8;11;90;91	268 days
116		Compressed air system	176 days	29/06/17 ...	21/12/17 ...	8;9;10;11;84	40 days
117		Demineralization water system	129 days	02/09/17 ...	08/01/18 ...	8;11;93	27 days
118		Piping system	108 days	08/09/17 ...	24/12/17 ...	92	0 days
119		**Electrical work**	**319 days**	**04/04/17...**	**16/02/18...**		**197 days**
120		High voltage system installation	95 days	01/11/17 ...	03/02/18 ...	108;109	0 days
121		Medium voltage system installation	18 days	01/11/17 ...	18/11/17 ...	91SS+30 days;108;109	82 days
122		Low voltage system installation	39 days	01/11/17 ...	09/12/17 ...	91SS+30 days;108;109	65 days
123		DC and UPS system installation	64 days	22/09/17 ...	24/11/17 ...	91SS+30 days;109	84 days
124		Lighting for building	30 days	04/04/17 ...	03/05/17 ...	91SS+30 days	486 days
125		Cable tray and cabling	175 days	26/08/17 ...	16/02/18 ...	92SS+30 days	197 days
126		**Control and Instrument work**	**175 days**	**26/08/17...**	**16/02/18...**		**197 days**
127		DCS system installation	53 days	03/10/17 ...	24/11/17 ...	91;110	71 days
128		Field instrument installation	3 days	10/12/17 ...	12/12/17 ...	118FS-15 days	263 days

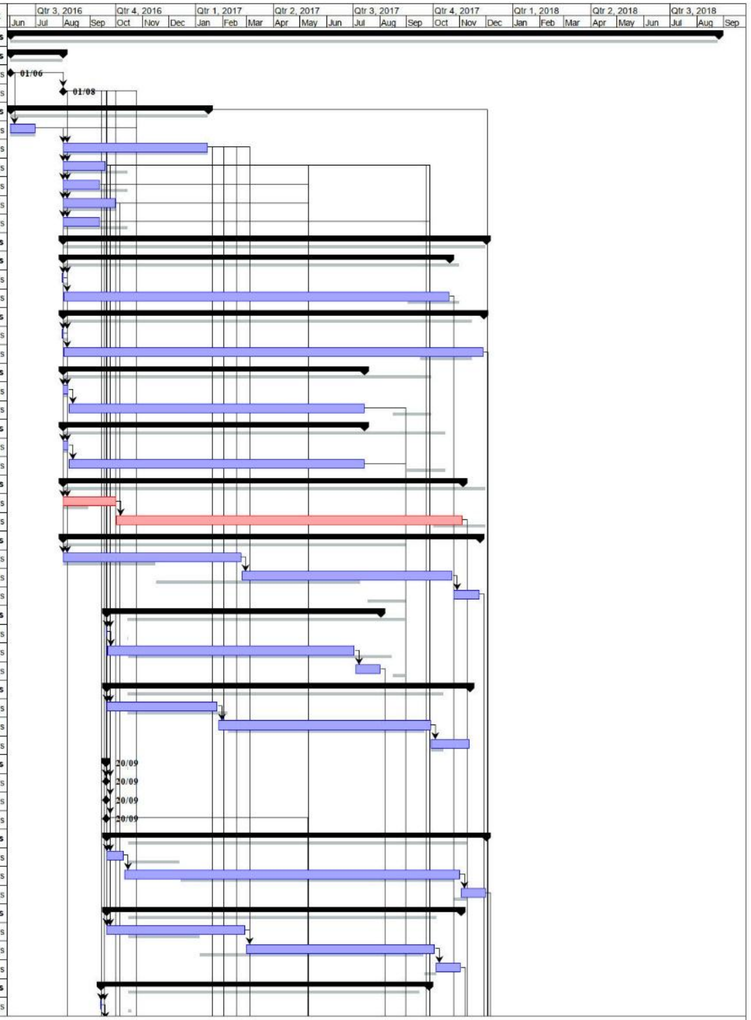


Project A Schedule (Plan) - page2

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
129		Cable tray and cabling work	175 days	26/08/17 ...	16/02/18 ...	92SS+30 days	197 days
130	20/02/17 ...	Transmission line	298 days	20/02/17 ...	14/12/17 ...		51 days
131	19/10/16 ...	Raw water available	310 days	19/10/16 ...	24/08/17 ...		164 days
132	03/10/16 ...	Gas available	478 days	03/10/16 ...	23/01/18 ...		65 days
133		**Cold commissioning**	**153 days**	**21/01/18...**	**22/06/18...**		**71 days**
134		Back energization	1 day	04/02/18 ...	04/02/18 ...	120;127;130	0 days
135		Pre commissioning of demineralization water plant	15 days	05/02/18 ...	19/02/18 ...	117;118;134;131	194 days
136		**Cold commissioning of electrical system**	**16 days**	**05/02/18...**	**20/02/18...**		**78 days**
137		HV system	4 days	05/02/18 ...	08/02/18 ...	120;134	0 days
138		MV system	4 days	09/02/18 ...	12/02/18 ...	121;137	0 days
139		LV system	4 days	13/02/18 ...	16/02/18 ...	122;138	0 days
140		DC and UPS system	4 days	17/02/18 ...	20/02/18 ...	123;139	8 days
141		**Cold commissioning of mechanical system**	**99 days**	**31/01/18...**	**09/05/18...**		**44 days**
142		Cold commissioning of balance of plant equipment	99 days	31/01/18 ...	09/05/18 ...	94;102;103;107;108;109;110;116;118	44 days
143		**Cold commissioning of GTG and HRSG1**	**68 days**	**21/01/18...**	**29/03/18...**		**55 days**
144		Hydrostatic test, flush and cleaning	9 days	21/01/18 ...	29/01/18 ...	99;118	17 days
145		Function test	42 days	16/02/18 ...	29/03/18 ...	97;144	0 days
146		**Cold commissioning of GTG and HRSG2**	**82 days**	**21/01/18...**	**12/04/18...**		**71 days**
147		Hydrostatic test, flush and cleaning	16 days	21/01/18 ...	05/02/18 ...	100;118	23 days
148		Function test	43 days	01/03/18 ...	12/04/18 ...	98;140;147	0 days
149		**Cold commissioning of STG**	**44 days**	**10/05/18...**	**22/06/18...**		**0 days**
150		Function test	44 days	10/05/18 ...	22/06/18 ...	101;118;140	0 days
151		**Overall mechanical completion**	**0 days**	**22/06/18...**	**22/06/18...**		**0 days**
152		Overall mechanical completion	0 days	22/06/18 ...	22/06/18 ...	140;142;145;148;150	0 days
153		**Hot commissioning work**	**156 days**	**30/03/18...**	**01/09/18...**		**0 days**
154		**Commissioning of GTG unit 1**	**11 days**	**30/03/18...**	**09/04/18...**		**145 days**
155		GTG1 first firing	1 day	30/03/18 ...	30/03/18 ...	145;132	0 days
156		Function test with DCS	9 days	31/03/18 ...	08/04/18 ...	155	0 days
157		GTG1 first synchronization	1 day	09/04/18 ...	09/04/18 ...	156	145 days
158		**Commissioning of GTG unit 2**	**7 days**	**13/04/18...**	**19/04/18...**		**135 days**
159		GTG2 first firing	1 day	13/04/18 ...	13/04/18 ...	148;132	0 days
160		Function test with DCS	5 days	14/04/18 ...	18/04/18 ...	159	0 days
161		GTG2 first synchronization	1 day	19/04/18 ...	19/04/18 ...	160	135 days
162		**Commissioning of STG**	**82 days**	**09/04/18...**	**29/06/18...**		**0 days**
163		Main steam header blowout	20 days	09/04/18 ...	28/04/18 ...	156	55 days
164		STG first steam	1 day	23/06/18 ...	23/06/18 ...	150;152;163	0 days
165		Function test	5 days	24/06/18 ...	28/06/18 ...	164	0 days
166		STG first synchronization	1 day	29/06/18 ...	29/06/18 ...	165	0 days
167		**Overall commissioning work**	**64 days**	**30/06/18...**	**01/09/18...**		**0 days**
168		Combined cycle function test	45 days	30/06/18 ...	13/08/18 ...	166;160	0 days
169		Plant performance test	4 days	14/08/18 ...	17/08/18 ...	168	0 days
170		Plant trial run	15 days	18/08/18 ...	01/09/18 ...	169	0 days
171		COD	0 days	01/09/18 ...	01/09/18 ...	170	0 days

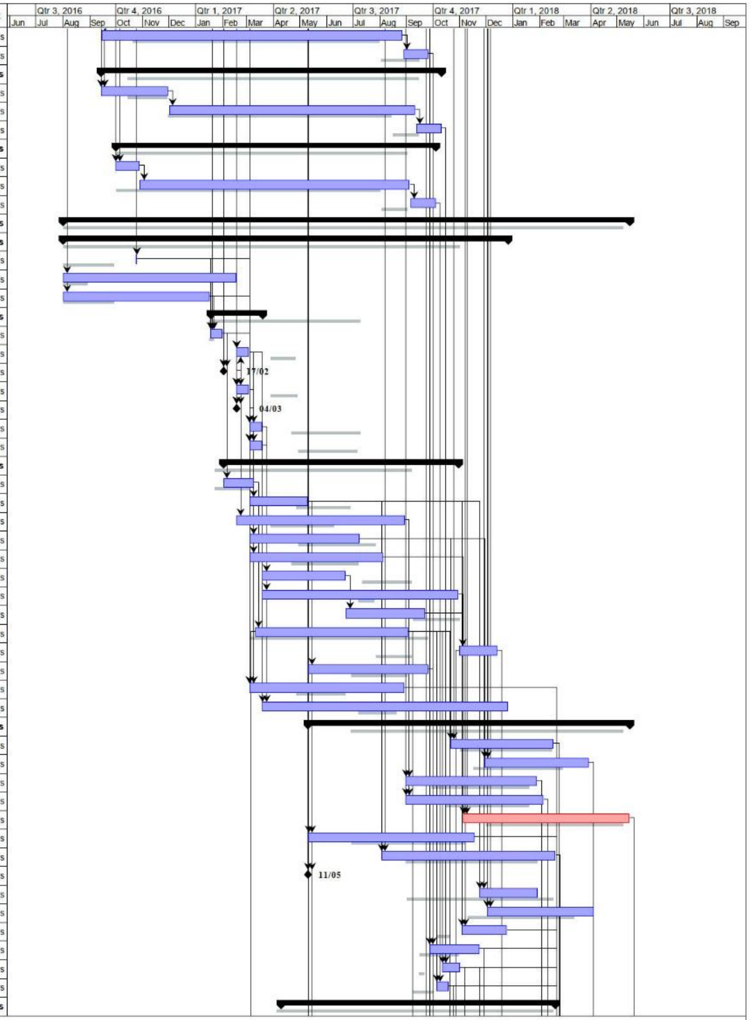


	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project A**	**817 days**	**01/06/16...**	**26/08/18...**		**0 days**
2		**Key milestone**	**61 days**	**01/06/16...**	**01/08/16...**		**0 days**
3	01/06/16 ...	EPC Contract signing	0 days	01/06/16 ...	01/06/16 ...		0 days
4	01/08/16 ...	Notice to proceed	0 days	01/08/16 ...	01/08/16 ...	3	0 days
5		**Detailed Engineering work**	**229 days**	**01/06/16...**	**15/01/17...**		**51 days**
6		Conceptual design	30 days	01/06/16 ...	30/06/16 ...	3	31 days
7		Civil detailed engineering	168 days	01/08/16 ...	15/01/17 ...	4;6	2 days
8		Mechanical and process detailed engineering	50 days	01/08/16 ...	19/09/16 ...	4;6	0 days
9		Electrical detailed engineering	44 days	01/08/16 ...	13/09/16 ...	4;6	0 days
10		C&I detailed engineering	61 days	01/08/16 ...	30/09/16 ...	4;6	0 days
11		Balance of plant detailed engineering	44 days	01/08/16 ...	13/09/16 ...	4;6	0 days
12		**Procurement**	**488 days**	**01/08/16...**	**01/12/17...**		**268 days**
13		**GTG1**	**446 days**	**01/08/16...**	**20/10/17...**		**50 days**
14		Confirm order to GTG	1 day	01/08/16 ...	01/08/16 ...	4;6	0 days
15		GTG1 manufacturing and transportation	445 days	02/08/16 ...	20/10/17 ...	14	0 days
16		**GTG2**	**485 days**	**01/08/16...**	**28/11/17...**		**76 days**
17		Confirm order to GTG	1 day	01/08/16 ...	01/08/16 ...	4;6	0 days
18		GTG2 manufacturing and transportation	484 days	02/08/16 ...	28/11/17 ...	17	0 days
19		**HRSG1**	**348 days**	**01/08/16...**	**14/07/17...**		**113 days**
20		Confirm order to HRSG	7 days	01/08/16 ...	07/08/16 ...	4;6	0 days
21		HRSG1 manufacturing and transportation	341 days	08/08/16 ...	14/07/17 ...	20	47 days
22		**HRSG2**	**348 days**	**01/08/16...**	**14/07/17...**		**173 days**
23		Confirm order to HRSG	7 days	01/08/16 ...	07/08/16 ...	4;6	0 days
24		HRSG2 manufacturing and transmporation	341 days	08/08/16 ...	14/07/17 ...	23	47 days
25		**Steam turbine**	**461 days**	**01/08/16...**	**04/11/17...**		**0 days**
26		Confirm order to STG	62 days	01/08/16 ...	01/10/16 ...	4;6	0 days
27		STG manufacturing and transportation	399 days	02/10/16 ...	04/11/17 ...	26	0 days
28		**Gas heater**	**480 days**	**01/08/16...**	**23/11/17...**		**208 days**
29		Confirm order to gas compressor	206 days	01/08/16 ...	22/02/17 ...	4;6	0 days
30		Manufacturing	244 days	23/02/17 ...	24/10/17 ...	29	0 days
31		Transportation	30 days	25/10/17 ...	23/11/17 ...	30	0 days
32		**Cooling tower**	**317 days**	**20/09/16...**	**02/08/17...**		**88 days**
33		Confirm order to cooling tower	1 day	20/09/16 ...	20/09/16 ...	4;8;6	0 days
34		Manufacturing	286 days	21/09/16 ...	03/07/17 ...	33	0 days
35		Transportation	30 days	04/07/17 ...	02/08/17 ...	34	0 days
36		**Turbine bypass valve**	**419 days**	**20/09/16...**	**12/11/17...**		**287 days**
37		Confirm order to turbine bypass valve	129 days	20/09/16 ...	26/01/17 ...	4;6;8;11	0 days
38		Manufacturing	245 days	27/01/17 ...	28/09/17 ...	37	0 days
39		Transportation	45 days	29/09/17 ...	12/11/17 ...	38	287 days
40		**Chiller**	**0 days**	**19/09/16...**	**19/09/16...**		**706 days**
41		Confirm order to chiller	0 days	19/09/16 ...	19/09/16 ...	4;8;11;6	0 days
42		Manufacturing	0 days	19/09/16 ...	19/09/16 ...	41	0 days
43		Transportation	0 days	19/09/16 ...	19/09/16 ...	42	233 days
44		**Pump**	**438 days**	**20/09/16...**	**01/12/17...**		**144 days**
45		Confirm order to pumps	21 days	20/09/16 ...	10/10/16 ...	4;6;8	0 days
46		Manufacturing	387 days	11/10/16 ...	01/11/17 ...	45	0 days
47		Transportation	30 days	02/11/17 ...	01/12/17 ...	46	0 days
48		**Emergency diesel generator**	**409 days**	**20/09/16...**	**02/11/17...**		**144 days**
49		Confirm order to energency diesel generator	161 days	20/09/16 ...	27/02/17 ...	4;8;9;11;6	0 days
50		Manufacturing	218 days	28/02/17 ...	03/10/17 ...	49	0 days
51		Transportation	30 days	04/10/17 ...	02/11/17 ...	50	0 days
52		**Transformer**	**378 days**	**14/09/16...**	**26/09/17...**		**65 days**
53		Confirm order to transformers	1 day	14/09/16 ...	14/09/16 ...	4;6;9	0 days



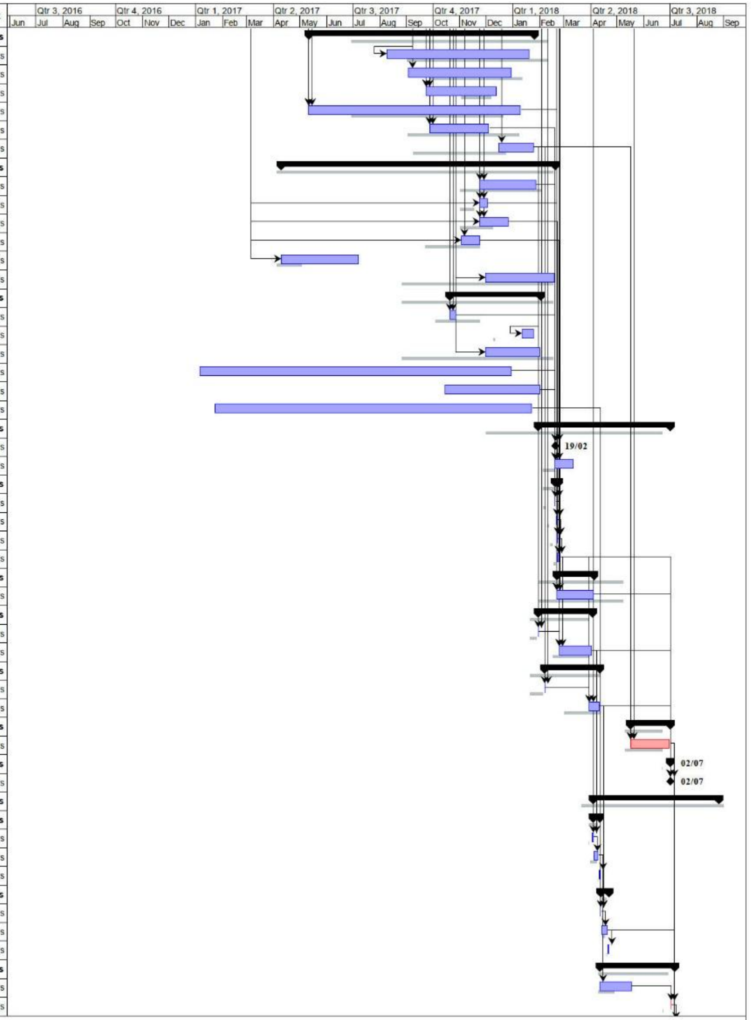
Project A Actual - page1

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
54		Manufacturing	347 days	15/09/16 ...	27/08/17 ...	53	0 days
55		Transportation	30 days	28/08/17 ...	26/09/17 ...	54	0 days
56		**Switchgear**	**393 days**	**14/09/16...**	**11/10/17...**		**87 days**
57		Confirm order to switchgear	78 days	14/09/16 ...	30/11/16 ...	4;9;11;6	0 days
58		Manufacturing	285 days	01/12/16 ...	11/09/17 ...	57	0 days
59		Transportation	30 days	12/09/17 ...	11/10/17 ...	58	0 days
60		**DCS panel**	**369 days**	**01/10/16...**	**04/10/17...**		**158 days**
61		Confirm order to DCS	28 days	01/10/16 ...	28/10/16 ...	4;6;10	0 days
62		Manufacturing	311 days	29/10/16 ...	04/09/17 ...	61	0 days
63		Transportation	30 days	05/09/17 ...	04/10/17 ...	62	0 days
64		**Construction work**	**653 days**	**01/08/16...**	**15/05/18...**		**103 days**
65		**Civil work**	**513 days**	**01/08/16...**	**26/12/17...**		**243 days**
66	25/10/16 ...	Permit to start civil work	1 day	25/10/16 ...	25/10/16 ...	4;6	84 days
67		Site mobilization and site temporary office	200 days	01/08/16 ...	16/02/17 ...	4	556 days
68		Site preparation, clearing and levelling work	170 days	01/08/16 ...	17/01/17 ...	4	0 days
69		**Piling works**	**60 days**	**18/01/17...**	**18/03/17...**		**113 days**
70		Control building piling	15 days	18/01/17 ...	01/02/17 ...	68;7;66	0 days
71		Tank piling and miscellaneous balance of plant	15 days	17/02/17 ...	03/03/17 ...	68;66;7;72	0 days
72		HRSG piling	15 days	02/02/17 ...	16/02/17 ...	7;66;68;70	0 days
73		GTG piling	15 days	17/02/17 ...	03/03/17 ...	7;66;68;72	0 days
74		STG piling	15 days	17/02/17 ...	03/03/17 ...	7;66;68;72	0 days
75		Steam turbine hall piling	15 days	04/03/17 ...	18/03/17 ...	7;66;68;74	0 days
76		Pipe rack and pipe bridge piling	15 days	04/03/17 ...	18/03/17 ...	7;66;68;73;70	0 days
77		**Foundations**	**271 days**	**02/02/17...**	**30/10/17...**		**44 days**
78		Control building	36 days	02/02/17 ...	09/03/17 ...	70	0 days
79		Tank foundation and miscellaneous balance of plant	68 days	04/03/17 ...	10/05/17 ...	71	0 days
80		HRSG foundation	195 days	17/02/17 ...	30/08/17 ...	72	0 days
81		GTG foundation	127 days	04/03/17 ...	08/07/17 ...	73	104 days
82		STG founndation	154 days	04/03/17 ...	04/08/17 ...	74	92 days
83		Steam turbine hall	96 days	19/03/17 ...	22/06/17 ...	75	0 days
84		Pipe rack and pipe bridge foundation	226 days	19/03/17 ...	30/10/17 ...	76	0 days
85		Steam turbine hall	92 days	23/06/17 ...	22/09/17 ...	83	0 days
86		Control building	177 days	10/03/17 ...	02/09/17 ...	78	0 days
87		Pipe rack and pipe bridge steel structure erection	45 days	31/10/17 ...	14/12/17 ...	84	0 days
88		Miscellaneous buildings	139 days	11/05/17 ...	26/09/17 ...	79	0 days
89		Water/wastewater pond	179 days	04/03/17 ...	29/08/17 ...	7;68;71	174 days
90		Road and paving	283 days	19/03/17 ...	26/12/17 ...	76;71	243 days
91		**Main equipment erection work**	**370 days**	**10/05/17...**	**15/05/18...**		**103 days**
92		GTG1	119 days	21/10/17 ...	16/02/18 ...	15;81	6 days
93		GTG2	121 days	29/11/17 ...	29/03/18 ...	18;81	0 days
94		HRSG1	152 days	31/08/17 ...	29/01/18 ...	21;80	0 days
95		HRSG2	159 days	31/08/17 ...	05/02/18 ...	24;80	0 days
96		STG	192 days	05/11/17 ...	15/05/18 ...	27;82;85	0 days
97		Service water tank	192 days	11/05/17 ...	18/11/17 ...	8;79	93 days
98		Cooling tower	201 days	03/08/17 ...	19/02/18 ...	35;79	0 days
99		Chiller	0 days	10/05/17 ...	10/05/17 ...	43;79	473 days
100		Gas heater	68 days	24/11/17 ...	30/01/18 ...	31;79	208 days
101		Pump	124 days	02/12/17 ...	04/04/18 ...	5;47	144 days
102		Emergency diesel generator	53 days	03/11/17 ...	25/12/17 ...	51;79	56 days
103		Transformer	58 days	27/09/17 ...	23/11/17 ...	55;79	0 days
104		Switchgear	21 days	12/10/17 ...	01/11/17 ...	59;86FS-40 days	0 days
105		DCS panel	15 days	05/10/17 ...	19/10/17 ...	63;86FS-20 days	0 days
106		**Balance of plant erection work**	**316 days**	**09/04/17...**	**18/02/18...**		**189 days**



Project A Actual - page2

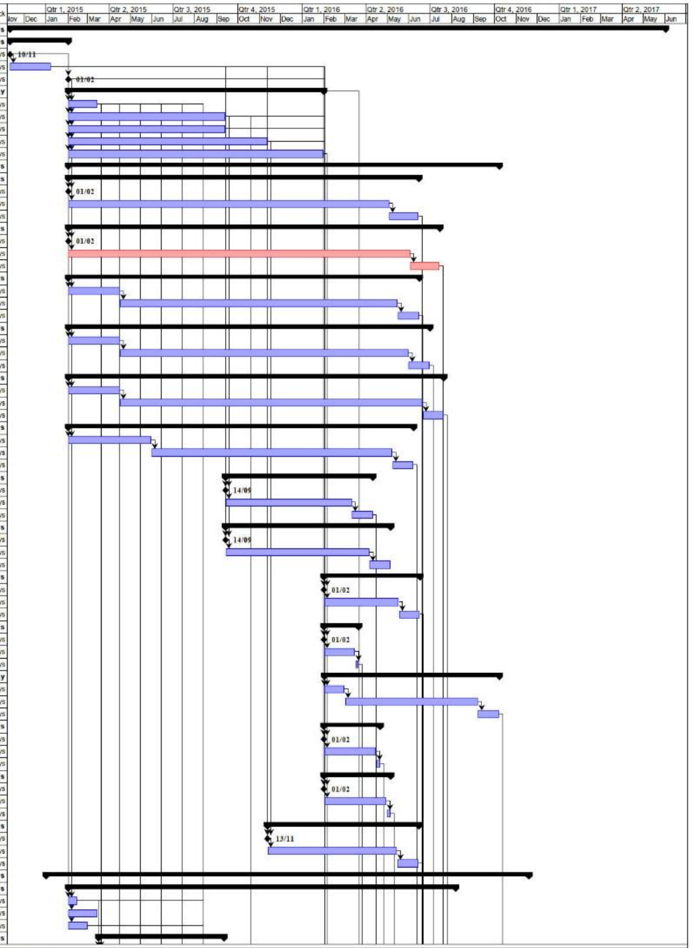
	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
107		**Mechanical work**	**260 days**	**11/05/17...**	**25/01/18...**		**213 days**
108		Air conditioning and ventilation system	166 days	08/08/17 ...	20/01/18 ...	86FS-26 days	218 days
109		Plumbing and drainage	120 days	03/09/17 ...	31/12/17 ...	86	238 days
110		Firefighting	82 days	23/09/17 ...	13/12/17 ...	8;11;85;86	256 days
111		Compressed air system	245 days	11/05/17 ...	10/01/18 ...	8;9;10;11;79	40 days
112		Demineralization water system	70 days	27/09/17 ...	05/12/17 ...	8;11;88	75 days
113		Piping system	42 days	15/12/17 ...	25/01/18 ...	87	0 days
114		**Electrical work**	**316 days**	**09/04/17...**	**18/02/18...**		**0 days**
115		High voltage system installation	66 days	24/11/17 ...	28/01/18 ...	103;104	21 days
116		Medium voltage system installation	10 days	24/11/17 ...	03/12/17 ...	86SS+30 days;103;104	78 days
117		Low voltage system installation	34 days	24/11/17 ...	27/12/17 ...	86SS+30 days;103;104	55 days
118		DC and UPS system installation	23 days	02/11/17 ...	24/11/17 ...	86SS+30 days;104	89 days
119		Lighting for building	90 days	09/04/17 ...	07/07/17 ...	86SS+30 days	270 days
120		Cable tray and cabling	81 days	30/11/17 ...	18/02/18 ...	87SS+30 days	44 days
121		**Control and instrument work**	**105 days**	**20/10/17...**	**01/02/18...**		**206 days**
122		DCS system installation	8 days	20/10/17 ...	27/10/17 ...	86;105	114 days
123		Field instrument installation	15 days	11/01/18 ...	25/01/18 ...	113FS-15 days	213 days
124		Cable tray and cabling work	64 days	30/11/17 ...	01/02/18 ...	87SS+30 days	206 days
125	06/01/17 ...	Transmission line	360 days	06/01/17 ...	31/12/17 ...		49 days
126	15/10/17 ...	Raw water available	110 days	15/10/17 ...	01/02/18 ...		17 days
127	23/01/17 ...	Gas available	366 days	23/01/17 ...	23/01/18 ...		69 days
128		**Cold commissioning**	**153 days**	**30/01/18...**	**01/07/18...**		**56 days**
129		Back energization	0 days	18/02/18 ...	18/02/18 ...	114;122;125	0 days
130		Pre commissioning of demineralization water plant	22 days	19/02/18 ...	12/03/18 ...	112;113;129;126	167 days
131		**Cold commissioning of electrical system**	**4 days**	**19/02/18...**	**22/02/18...**		**44 days**
132		HV system	1 day	19/02/18 ...	19/02/18 ...	115;129	0 days
133		MV system	1 day	20/02/18 ...	20/02/18 ...	116;132	0 days
134		LV system	1 day	21/02/18 ...	21/02/18 ...	117;133	0 days
135		DC and UPS system	1 day	22/02/18 ...	22/02/18 ...	118;134	0 days
136		**Cold commissioning of mechanical system**	**44 days**	**20/02/18...**	**04/04/18...**		**88 days**
137		Cold commissioning of balance of plant equipment	44 days	20/02/18 ...	04/04/18 ...	89;97;98;102;103;104;105;111;113	88 days
138		**Cold commissioning of GTG and HRSG1**	**63 days**	**30/01/18...**	**02/04/18...**		**44 days**
139		Hydrostatic test, flush and cleaning	2 days	30/01/18 ...	31/01/18 ...	94;113	22 days
140		Function test	39 days	23/02/18 ...	02/04/18 ...	92;135;139	0 days
141		**Cold commissioning of GTG and HRSG2**	**65 days**	**06/02/18...**	**11/04/18...**		**76 days**
142		Hydrostatic test, flush and cleaning	2 days	06/02/18 ...	07/02/18 ...	95;113	50 days
143		Function test	13 days	30/03/18 ...	11/04/18 ...	93;135;142	0 days
144		**Cold commissioning of STG**	**47 days**	**16/05/18...**	**01/07/18...**		**0 days**
145		Function test	47 days	16/05/18 ...	01/07/18 ...	96;113;135	0 days
146		**Overall mechanical completion**	**0 days**	**01/07/18...**	**01/07/18...**		**0 days**
147		Overall mechanical completion	0 days	01/07/18 ...	01/07/18 ...	135;137;140;143;145	0 days
148		**Hot commissioning work**	**146 days**	**03/04/18...**	**26/08/18...**		**0 days**
149		**Commissioning of GTG unit 1**	**9 days**	**03/04/18...**	**11/04/18...**		**137 days**
150		GTG1 first firing	1 day	03/04/18 ...	03/04/18 ...	140;127	0 days
151		Function test with DCS	7 days	04/04/18 ...	10/04/18 ...	150	0 days
152		GTG1 first synchronization	1 day	11/04/18 ...	11/04/18 ...	151	137 days
153		**Commissioning of GTG unit 2**	**10 days**	**12/04/18...**	**21/04/18...**		**127 days**
154		GTG2 first firing	1 day	12/04/18 ...	12/04/18 ...	143;127	0 days
155		Function test with DCS	8 days	13/04/18 ...	20/04/18 ...	154	0 days
156		GTG2 first synchronization	1 day	21/04/18 ...	21/04/18 ...	155	127 days
157		**Commissioning of STG**	**86 days**	**11/04/18...**	**05/07/18...**		**0 days**
158		Main steam header blowout	38 days	11/04/18 ...	18/05/18 ...	151	44 days
159		STG first steam	2 days	02/07/18 ...	03/07/18 ...	145;147;158	0 days



	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
160		Function test	1 day	04/07/18 ...	04/07/18 ...	159	0 days
161		STG first synchronization	1 day	05/07/18 ...	05/07/18 ...	160	0 days
162		**Overall commissioning work**	**52 days**	**06/07/18...**	**26/08/18...**		**0 days**
163		Combined cycle function test	36 days	06/07/18 ...	10/08/18 ...	155;161	0 days
164		Plant performance test	2 days	11/08/18 ...	12/08/18 ...	163	0 days
165		Plant trial run	14 days	13/08/18 ...	26/08/18 ...	164	0 days
166		COD	0 days	26/08/18 ...	26/08/18 ...	165	0 days

Appendix B Detailed results of construction schedules analysis of Project B

	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project B (Planned)**	**935 days**	**10/11/14...**	**01/06/17...**		**0 days**
2		**Key milestone**	**83 days**	**10/11/14...**	**01/02/15...**		**0 days**
3		EPC Contract signing	0 days	10/11/14 ...	10/11/14 ...		0 days
4		Conceptual design	60 days	10/11/14 ...	08/01/15 ...	3	23 days
5	01/02/15...	Notice to proceed	0 days	01/02/15 ...	01/02/15 ...	3	0 days
6		**Detailed Engineering work**	**365 days**	**01/02/15...**	**31/01/16...**		**1 day**
7		Civil detialed engineering	43 days	01/02/15 ...	15/03/15 ...	4;5	0 days
8		Mechanical engineering	225 days	01/02/15 ...	13/09/15 ...	4;5	0 days
9		Electrical engineering	225 days	01/02/15 ...	13/09/15 ...	4;5	60 days
10		C&I engineering	285 days	01/02/15 ...	12/11/15 ...	4;5	0 days
11		Balance of plant engineering	365 days	01/02/15 ...	31/01/16 ...	4;5	0 days
12		**Procurement**	**615 days**	**01/02/15...**	**07/10/16...**		**237 days**
13		**GTG1**	**500 days**	**01/02/15...**	**14/06/16...**		**8 days**
14		Confirm order to GTG	0 days	01/02/15 ...	01/02/15 ...	4;5	0 days
15		Manufacturing	458 days	01/02/15 ...	03/05/16 ...	14	0 days
16		Transportation	42 days	04/05/16 ...	14/06/16 ...	15	0 days
17		**GTG2**	**530 days**	**01/02/15...**	**14/07/16...**		**0 days**
18		Confirm order to GTG	0 days	01/02/15 ...	01/02/15 ...	4;5	0 days
19		Manufacturing	488 days	01/02/15 ...	02/06/16 ...	18	0 days
20		Transportation	42 days	03/06/16 ...	14/07/16 ...	19	0 days
21		**HRSG1**	**501 days**	**01/02/15...**	**15/06/16...**		**7 days**
22		Confirm order to HRSG	75 days	01/02/15 ...	16/04/15 ...	4;5	0 days
23		Manufacturing	396 days	17/04/15 ...	16/05/16 ...	22	0 days
24		Transportation	30 days	17/05/16 ...	15/06/16 ...	23	0 days
25		**HRSG2**	**516 days**	**01/02/15...**	**30/06/16...**		**14 days**
26		Confirm order to HRSG	75 days	01/02/15 ...	16/04/15 ...	4;5	0 days
27		Manufacturing	411 days	17/04/15 ...	31/05/16 ...	26	0 days
28		Transportation	30 days	01/06/16 ...	30/06/16 ...	27	0 days
29		**Steam turbine**	**536 days**	**01/02/15...**	**20/07/16...**		**87 days**
30		Confirm order to STG	75 days	01/02/15 ...	16/04/15 ...	4;5	0 days
31		Manufacturing	431 days	17/04/15 ...	20/06/16 ...	30	0 days
32		Transportation	30 days	21/06/16 ...	20/07/16 ...	31	0 days
33		**Gas compressor**	**493 days**	**01/02/15...**	**07/06/16...**		**93 days**
34		Confirm order to gas compressor	120 days	01/02/15 ...	31/05/15 ...	4;5	0 days
35		Manufacturing	343 days	01/06/15 ...	08/05/16 ...	34	0 days
36		Transportation	30 days	09/05/16 ...	07/06/16 ...	35	0 days
37		**Cooling tower**	**210 days**	**13/09/15...**	**10/04/16...**		**129 days**
38		Confirm order to cooling tower	0 days	13/09/15 ...	13/09/15 ...	4;5;8	0 days
39		Manufacturing	180 days	14/09/15 ...	11/03/16 ...	38	0 days
40		Transportation	30 days	12/03/16 ...	10/04/16 ...	39	0 days
41		**Turbine bypass valve**	**235 days**	**13/09/15...**	**05/05/16...**		**392 days**
42		Confirm order to turbine bypass valve	0 days	13/09/15 ...	13/09/15 ...	4;5;8	0 days
43		Manufacturing	205 days	14/09/15 ...	05/04/16 ...	42	0 days
44		Transportation	30 days	06/04/16 ...	05/05/16 ...	43	392 days
45		**Chiller**	**137 days**	**31/01/16...**	**16/06/16...**		**114 days**
46		Confirm order to chiller	0 days	31/01/16 ...	31/01/16 ...	4;5;8;11	0 days
47		Manufacturing	107 days	01/02/16 ...	17/05/16 ...	46	0 days
48		Transportation	30 days	18/05/16 ...	16/06/16 ...	47	0 days
49		**Pump**	**50 days**	**31/01/16...**	**21/03/16...**		**171 days**
50		Confirm order to pumps	0 days	31/01/16 ...	31/01/16 ...	4;5;8;11	0 days
51		Manufacturing	45 days	01/02/16 ...	16/03/16 ...	50	0 days
52		Transportation	5 days	17/03/16 ...	21/03/16 ...	51	0 days
53		**Emergency diesel generator**	**250 days**	**01/02/16...**	**07/10/16...**		**1 day**
54		Confirm order to energency diesel generator	30 days	01/02/16 ...	01/03/16 ...	4;5;8;9;11	0 days
55		Manufacturing	190 days	02/03/16 ...	07/09/16 ...	54	0 days
56		Transportation	30 days	08/09/16 ...	07/10/16 ...	55	0 days
57		**Transformer**	**80 days**	**31/01/16...**	**20/04/16...**		**171 days**
58		Confirm order to transformers	0 days	31/01/16 ...	31/01/16 ...	4;5;9;11	0 days
59		Manufacturing	75 days	01/02/16 ...	15/04/16 ...	58	0 days
60		Transportation	5 days	16/04/16 ...	20/04/16 ...	59	0 days
61		**Switchgear**	**95 days**	**31/01/16...**	**05/05/16...**		**35 days**
62		Confirm order to switchgear	0 days	31/01/16 ...	31/01/16 ...	4;5;9;11	0 days
63		Manufacturing	90 days	01/02/16 ...	30/04/16 ...	62	0 days
64		Transportation	5 days	01/05/16 ...	05/05/16 ...	63	0 days
65		**DCS panel**	**215 days**	**12/11/15...**	**14/06/16...**		**25 days**
66		Confirm order to DCS	0 days	12/11/15 ...	12/11/15 ...	4;5;9;10	0 days
67		Manufacturing	185 days	13/11/15 ...	15/05/16 ...	66	0 days
68		Transportation	30 days	16/05/16 ...	14/06/16 ...	67	0 days
69		**Construction work**	**688 days**	**01/01/15...**	**18/11/16...**		**195 days**
70		**Civil work**	**553 days**	**01/02/15...**	**06/08/16...**		**299 days**
71		Permit to start civil work	14 days	01/02/15 ...	14/02/15 ...	4;5	29 days
72		Site mobilization and site temporary office	43 days	01/02/15 ...	15/03/15 ...	5	809 days
73		Site preparation, clearing and levelling work	29 days	01/02/15 ...	01/03/15 ...	5	14 days
74		**Piling works**	**180 days**	**16/03/15...**	**11/09/15...**		**47 days**



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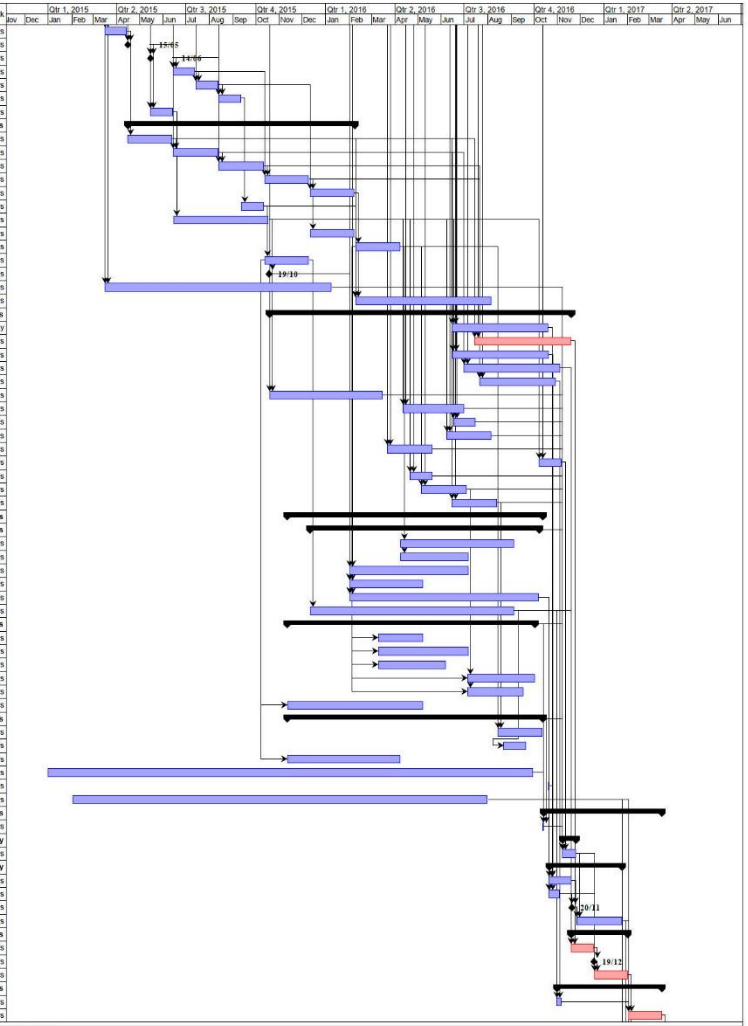
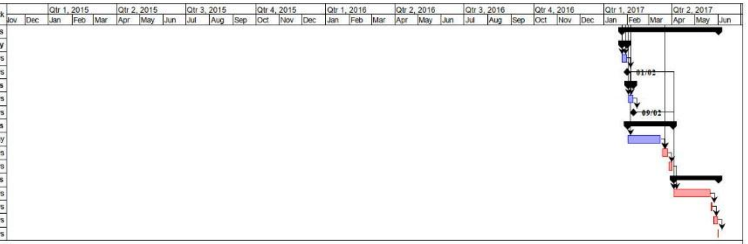
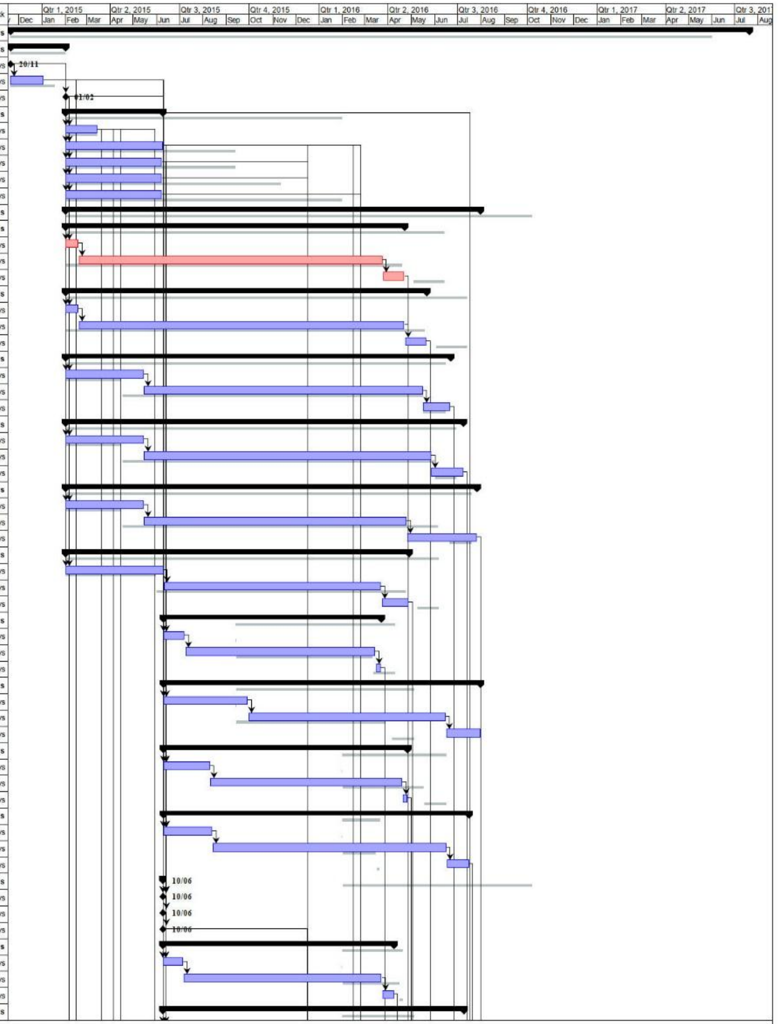
	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
75		GTG piling	30 days	16/03/15 ...	14/04/15 ...	7;71;73	0 days
76		HRSG piling	30 days	15/04/15 ...	14/05/15 ...	7;71;73;75	0 days
77		STG piling	30 days	15/05/15 ...	13/06/15 ...	7;71;73;76	0 days
78		Steam turbine hall piling	30 days	14/06/15 ...	13/07/15 ...	7;71;73;77	0 days
79		Control building piling	30 days	14/07/15 ...	12/08/15 ...	7;71;73;78	0 days
80		Pipe rack and pipe bridge piling	30 days	13/08/15 ...	11/09/15 ...	7;71;73;79	0 days
81		Tank piling and miscellaneous balance of plant	31 days	15/05/15 ...	14/06/15 ...	7;71;73;76	0 days
82		**Foundations**	**300 days**	**15/04/15...**	**08/02/16...**		**62 days**
83		GTG foundation	60 days	15/04/15 ...	13/06/15 ...	75	0 days
84		HRSG foundation	60 days	14/06/15 ...	12/08/15 ...	76;83	0 days
85		STG founndation	60 days	13/08/15 ...	11/10/15 ...	77;84	0 days
86		Steam turbine hall	60 days	12/10/15 ...	10/12/15 ...	78;85	0 days
87		Control building	60 days	11/12/15 ...	08/02/16 ...	79;86	0 days
88		Pipe rack and pipe bridge foundation	30 days	12/09/15 ...	11/10/15 ...	80	0 days
89		Tank foundation and miscellaneous balance of plant	126 days	15/06/15 ...	18/10/15 ...	81	0 days
90		Steam turbine hall	60 days	11/12/15 ...	08/02/16 ...	86	479 days
91		Control building	60 days	09/02/16 ...	08/04/16 ...	87	0 days
92		Pipe rack and pipe bridge steel structure erection	60 days	12/10/15 ...	10/12/15 ...	88	0 days
93		Miscellaneous buildings	0 days	18/10/15 ...	18/10/15 ...	89	105 days
94		Water/wastewater pond	300 days	16/03/15 ...	09/01/16 ...	7;73	30 days
95		Road and paving	180 days	09/02/16 ...	06/08/16 ...	83;84;85;86;87;88;89;94	299 days
96		**Mainl equipment erection work**	**397 days**	**19/10/15...**	**18/11/16...**		**68 days**
97		GTG1	127 days	15/06/16 ...	19/10/16 ...	16;83	1 day
98		GTG2	127 days	15/07/16 ...	18/11/16 ...	20;83	0 days
99		HRSG1	127 days	16/06/16 ...	20/10/16 ...	24;84	0 days
100		HRSG2	127 days	01/07/16 ...	04/11/16 ...	28;84	14 days
101		STG	102 days	21/07/16 ...	30/10/16 ...	32;85;86	0 days
102		Service water tank	150 days	19/10/15 ...	16/03/16 ...	8;89	235 days
103		Cooling tower	82 days	11/04/16 ...	01/07/16 ...	40;89	128 days
104		Chiller	30 days	17/06/16 ...	16/07/16 ...	48;89	113 days
105		Gas compressor	60 days	08/06/16 ...	06/08/16 ...	36;89	92 days
106		Pump	60 days	22/03/16 ...	20/05/16 ...	6;52	170 days
107		Emergency diesel generator	30 days	08/10/16 ...	06/11/16 ...	56;89	0 days
108		Transformer	30 days	21/04/16 ...	20/05/16 ...	60;89	170 days
109		Switchgear	60 days	06/05/16 ...	04/07/16 ...	64;91	0 days
110		DCS panel	60 days	15/06/16 ...	13/08/16 ...	68;91	0 days
111		**Balance of plant erection work**	**337 days**	**11/11/15...**	**12/10/16...**		**26 days**
112		**Mechanical work**	**302 days**	**11/12/15...**	**07/10/16...**		**30 days**
113		Air conditioning and ventilation system	150 days	09/04/16 ...	05/09/16 ...	91	63 days
114		Plumbing and drainage	90 days	09/04/16 ...	07/07/16 ...	91	123 days
115		Firefighting	158 days	01/02/16 ...	07/07/16 ...	8;11	123 days
116		Compressed air system	98 days	01/02/16 ...	08/05/16 ...	8;9;10;11;89	183 days
117		Demineralization water system	250 days	01/02/16 ...	07/10/16 ...	8;11;93	13 days
118		Piping and auxiliary equipment	270 days	11/12/15 ...	05/09/16 ...	92	0 days
119		**Electrical work**	**327 days**	**11/11/15...**	**02/10/16...**		**10 days**
120		DC and UPS system installation	60 days	10/03/16 ...	08/05/16 ...	91SS+30 days	182 days
121		Low voltage system installation	120 days	10/03/16 ...	07/07/16 ...	91SS+30 days	122 days
122		Lighting for building	90 days	10/03/16 ...	07/06/16 ...	91SS+30 days	152 days
123		Medium voltage system installation	90 days	05/07/16 ...	02/10/16 ...	91SS+30 days;109	35 days
124		High voltage system installation	75 days	05/07/16 ...	17/09/16 ...	91SS+30 days;109	50 days
125		Cable tray and cabling	180 days	11/11/15 ...	08/05/16 ...	92SS+30 days	182 days
126		**Control and Instrument work**	**337 days**	**11/11/15...**	**12/10/16...**		**0 days**
127		DCS system installation	60 days	14/08/16 ...	12/10/16 ...	91;110	25 days
128		Field instrument installation	30 days	22/08/16 ...	20/09/16 ...	118FS-15 days	47 days
129		Cable tray and cabling work	150 days	11/11/15 ...	08/04/16 ...	92SS+30 days	212 days
130	01/01/15...	Transmission line	639 days	01/01/15 ...	30/09/16 ...		12 days
131	20/10/16...	Raw water available	1 day	20/10/16 ...	20/10/16 ...		0 days
132	01/02/15...	Gas available	548 days	01/02/15 ...	01/08/16 ...		176 days
133		**Cold commissioning**	**157 days**	**13/10/16...**	**18/03/17...**		**0 days**
134		Back energization	1 day	13/10/16 ...	13/10/16 ...	119;126;130	7 days
135		**Cold commissioning of balance of plant equipment**	**19 days**	**07/11/16...**	**25/11/16...**		**1 day**
136		Cold commissioning of balance of plant equipment	19 days	07/11/16 ...	25/11/16 ...	94;102;103;104;105;106;107;108;109;110;112;119;126;134	0 days
137		**Cold commissioning of GTG and HRSG1**	**96 days**	**21/10/16...**	**24/01/17...**		**1 day**
138		Hydrostatic test, flush and cleaning	30 days	21/10/16 ...	19/11/16 ...	97;99;118	0 days
139		Pre commissioning of demineralization water	14 days	21/10/16 ...	03/11/16 ...	117;118;134;131	16 days
140		Mechanical completion of unit 1	0 days	19/11/16 ...	19/11/16 ...	138;139	6 days
141		Function test with DCS (trip test, interlock test)	60 days	26/11/16 ...	24/01/17 ...	140;136	0 days
142		**Cold commissioning of GTG and HRSG2**	**75 days**	**19/11/16...**	**01/02/17...**		**0 days**
143		Hydrostatic test, flush and cleaning	30 days	19/11/16 ...	18/12/16 ...	98;100;118	0 days
144		Mechanical completion of unit 2	0 days	18/12/16 ...	18/12/16 ...	143	0 days
145		Function test with DCS (trip test, interlock test)	45 days	19/12/16 ...	01/02/17 ...	136;139;144	0 days
146		**Cold commissioning of STG**	**139 days**	**31/10/16...**	**18/03/17...**		**0 days**
147		Mechanical completion of steam turbine	7 days	31/10/16 ...	06/11/16 ...	101;118	87 days
148		Function test with DCS (trip test, interlock test)	45 days	02/02/17 ...	18/03/17 ...	141;145;147	0 days



	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
149		**Hot commissionoing work**	**127 days**	**25/01/17...**	**31/05/17...**		**0 days**
150		**Commissioning of GTG1 and HRSG1**	**7 days**	**25/01/17...**	**31/01/17...**		**1 day**
151		GTG1 first firing	7 days	25/01/17 ...	31/01/17 ...	141;132	0 days
152		GTG1 first synchronization	0 days	31/01/17 ...	31/01/17 ...	151	0 days
153		**Commissioning of GTG2 and HRSG2**	**7 days**	**02/02/17...**	**08/02/17...**		**53 days**
154		GTG2 first firing	7 days	02/02/17 ...	08/02/17 ...	145;132	0 days
155		GTG2 first synchronization	0 days	08/02/17 ...	08/02/17 ...	154	53 days
156		**Commissioning of STG**	**61 days**	**01/02/17...**	**02/04/17...**		**0 days**
157		Main steam header blowout	45 days	01/02/17 ...	17/03/17 ...	152	1 day
158		STG first steam	8 days	19/03/17 ...	26/03/17 ...	148;157	0 days
159		STG first synchronization	7 days	27/03/17 ...	02/04/17 ...	158	0 days
160		**Overall commissioning work**	**59 days**	**03/04/17...**	**31/05/17...**		**0 days**
161		Combined cycle function test and tuning	49 days	03/04/17 ...	21/05/17 ...	152;155;159	0 days
162		Plant performance test	3 days	22/05/17 ...	24/05/17 ...	161	0 days
163		Plant trial run	7 days	25/05/17 ...	31/05/17 ...	162	0 days
164		COD	1 day	01/06/17 ...	01/06/17 ...	163	0 days

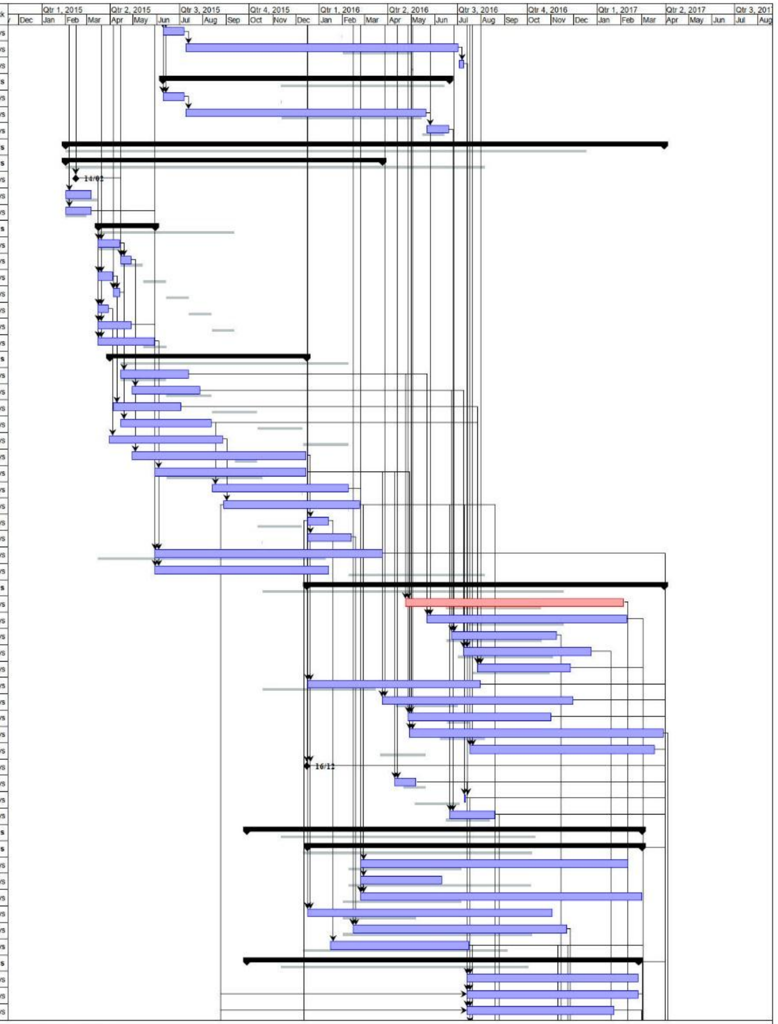


	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Project B Schedule (Actual)**	**974 days**	**20/11/14...**	**20/07/17...**		**0 days**
2		**Key milestone**	**73 days**	**20/11/14...**	**01/02/15...**		**0 days**
3		EPC Contract signing	0 days	20/11/14 ...	20/11/14 ...		0 days
4		Conceptual design	45 days	20/11/14 ...	03/01/15 ...	3	28 days
5	01/02/15...	Notice to proceed	0 days	01/02/15 ...	01/02/15 ...	3	0 days
6		**Detailed Engineering work**	**129 days**	**01/02/15...**	**09/06/15...**		**190 days**
7		Civil detailed engineering	43 days	01/02/15 ...	15/03/15 ...	4;5	0 days
8		Mechanical and process detailed engineering	129 days	01/02/15 ...	09/06/15 ...	4;5	0 days
9		Electrical detailed engineering	128 days	01/02/15 ...	08/06/15 ...	4;5	0 days
10		C&I detailed engineering	128 days	01/02/15 ...	08/06/15 ...	4;5	0 days
11		Balance of plant detailed engineering	128 days	01/02/15 ...	08/06/15 ...	4;5	0 days
12		**Procurement**	**547 days**	**01/02/15...**	**31/07/16...**		**354 days**
13		**GTG1**	**447 days**	**01/02/15...**	**22/04/16...**		**0 days**
14		Confirm order to GTG	18 days	01/02/15 ...	18/02/15 ...	4;5	0 days
15		Manufacturing	400 days	19/02/15 ...	24/03/16 ...	14	0 days
16		Transportation	29 days	25/03/16 ...	22/04/16 ...	15	0 days
17		**GTG2**	**476 days**	**01/02/15...**	**21/05/16...**		**27 days**
18		Confirm order to GTG	18 days	01/02/15 ...	18/02/15 ...	4;5	0 days
19		Manufacturing	429 days	19/02/15 ...	22/04/16 ...	18	0 days
20		Transportation	29 days	23/04/16 ...	21/05/16 ...	19	0 days
21		**HRSG1**	**508 days**	**01/02/15...**	**22/06/16...**		**86 days**
22		Confirm order to HRSG	104 days	01/02/15 ...	15/05/15 ...	4;5	0 days
23		Manufacturing	367 days	16/05/15 ...	16/05/16 ...	22	0 days
24		Transportation	37 days	17/05/16 ...	22/06/16 ...	23	0 days
25		**HRSG2**	**524 days**	**01/02/15...**	**08/07/16...**		**54 days**
26		Confirm order to HRSG	104 days	01/02/15 ...	15/05/15 ...	4;5	0 days
27		Manufacturing	378 days	16/05/15 ...	27/05/16 ...	26	0 days
28		Transportation	42 days	28/05/16 ...	08/07/16 ...	27	0 days
29		**Steam turbine**	**542 days**	**01/02/15...**	**26/07/16...**		**113 days**
30		Confirm order to STG	104 days	01/02/15 ...	15/05/15 ...	4;5	0 days
31		Manufacturing	346 days	16/05/15 ...	25/04/16 ...	30	0 days
32		Transportation	92 days	26/04/16 ...	26/07/16 ...	31	0 days
33		**Gas compressor**	**453 days**	**01/02/15...**	**28/04/16...**		**29 days**
34		Confirm order to gas compressor	130 days	01/02/15 ...	10/06/15 ...	4;5	0 days
35		Manufacturing	286 days	11/06/15 ...	22/03/16 ...	34	0 days
36		Transportation	37 days	23/03/16 ...	28/04/16 ...	35	0 days
37		**Cooling tower**	**287 days**	**10/06/15...**	**22/03/16...**		**149 days**
38		Confirm order to cooling tower	29 days	10/06/15 ...	08/07/15 ...	4;5;8	0 days
39		Manufacturing	251 days	09/07/15 ...	15/03/16 ...	38	0 days
40		Transportation	7 days	16/03/16 ...	22/03/16 ...	39	0 days
41		**Turbine bypass valve**	**418 days**	**10/06/15...**	**31/07/16...**		**354 days**
42		Confirm order to turbine bypass valve	112 days	10/06/15 ...	29/09/15 ...	4;5;8	0 days
43		Manufacturing	260 days	30/09/15 ...	15/06/16 ...	42	0 days
44		Transportation	46 days	16/06/16 ...	31/07/16 ...	43	354 days
45		**Chiller**	**322 days**	**10/06/15...**	**26/04/16...**		**178 days**
46		Confirm order to chiller	62 days	10/06/15 ...	10/08/15 ...	4;5;8;11	0 days
47		Manufacturing	253 days	11/08/15 ...	19/04/16 ...	46	0 days
48		Transportation	7 days	20/04/16 ...	26/04/16 ...	47	0 days
49		**Pump**	**403 days**	**10/06/15...**	**16/07/16...**		**42 days**
50		Confirm order to pumps	65 days	10/06/15 ...	13/08/15 ...	4;5;8;11	0 days
51		Manufacturing	308 days	14/08/15 ...	16/06/16 ...	50	0 days
52		Transportation	30 days	17/06/16 ...	16/07/16 ...	51	0 days
53		**Emergency diesel generator**	**0 days**	**09/06/15...**	**09/06/15...**		**689 days**
54		Confirm order to energency diesel generator	0 days	09/06/15 ...	09/06/15 ...	4;5;8;9;11	0 days
55		Manufacturing	0 days	09/06/15 ...	09/06/15 ...	54	0 days
56		Transportation	0 days	09/06/15 ...	09/06/15 ...	55	189 days
57		**Transformer**	**305 days**	**09/06/15...**	**08/04/16...**		**72 days**
58		Confirm order to transformers	28 days	09/06/15 ...	06/07/15 ...	4;5;9;11	0 days
59		Manufacturing	261 days	07/07/15 ...	23/03/16 ...	58	0 days
60		Transportation	16 days	24/03/16 ...	08/04/16 ...	59	0 days
61		**Switchgear**	**397 days**	**09/06/15...**	**09/07/16...**		**7 days**



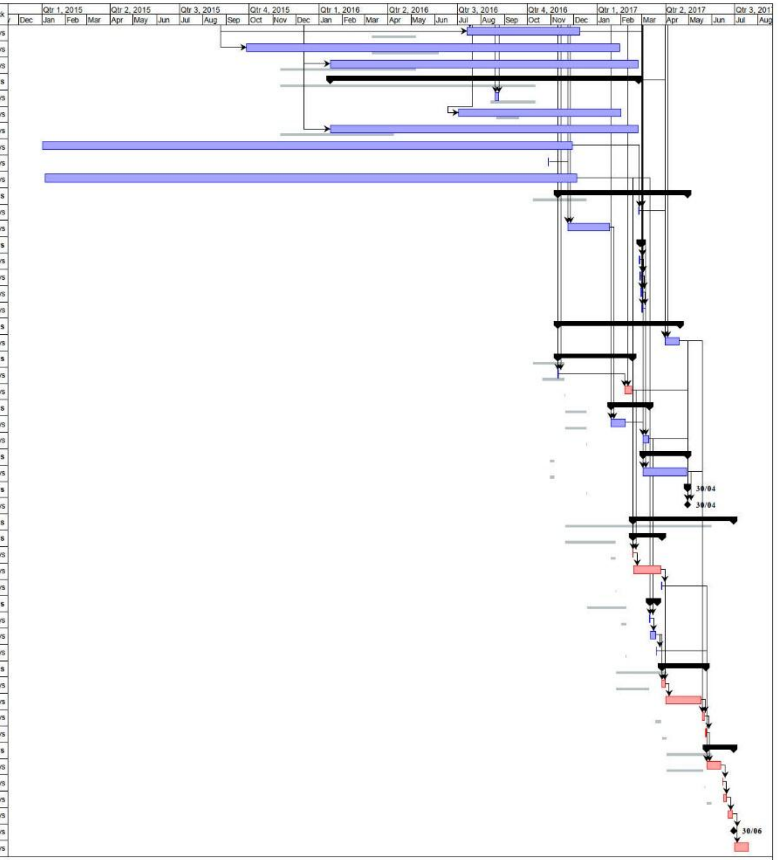
Project B Schedule (Actual) - page1

	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
62		Confirm order to switchgear	30 days	09/06/15 ...	08/07/15 ...	4;5;9;11	0 days
63		Manufacturing	360 days	09/07/15 ...	02/07/16 ...	62	0 days
64		Transportation	7 days	03/07/16 ...	09/07/16 ...	63	0 days
65		**DCS panel**	**378 days**	**09/06/15...**	**20/06/16...**		**191 days**
66		Confirm order to DCS	30 days	09/06/15 ...	08/07/15 ...	4;5;9;10	0 days
67		Manufacturing	318 days	09/07/15 ...	21/05/16 ...	66	0 days
68		Transportation	30 days	22/05/16 ...	20/06/16 ...	67	0 days
69		**Construction work**	**789 days**	**01/02/15...**	**30/03/17...**		**112 days**
70		**Civil work**	**418 days**	**01/02/15...**	**24/03/16...**		**483 days**
71	14/02/15...	Permit to start civil work	0 days	14/02/15 ...	14/02/15 ...	4;5	30 days
72		Site mobilization and site temporary office	35 days	01/02/15 ...	07/03/15 ...	5	866 days
73		Site preparation, clearing and levelling work	35 days	01/02/15 ...	07/03/15 ...	5	8 days
74		**Piling works**	**75 days**	**16/03/15...**	**29/05/15...**		**370 days**
75		GTG piling	30 days	16/03/15 ...	14/04/15 ...	7;71;73	0 days
76		HRSG piling	15 days	15/04/15 ...	29/04/15 ...	7;71;73;75	0 days
77		STG piling	20 days	16/03/15 ...	04/04/15 ...	7;71;73	0 days
78		Steam turbine hall piling	10 days	05/04/15 ...	14/04/15 ...	7;71;73;77	0 days
79		Control building piling	15 days	16/03/15 ...	30/03/15 ...	7;71;73	0 days
80		Pipe rack and pipe bridge piling	45 days	16/03/15 ...	29/04/15 ...	7;71;73	0 days
81		Tank piling and miscellaneous balance of plant	75 days	16/03/15 ...	29/05/15 ...	7;71;73	0 days
82		**Foundations**	**260 days**	**31/03/15...**	**15/12/15...**		**337 days**
83		GTG foundation	90 days	15/04/15 ...	13/07/15 ...	75	284 days
84		HRSG foundation	90 days	30/04/15 ...	28/07/15 ...	76	330 days
85		STG founndation	90 days	05/04/15 ...	03/07/15 ...	77	389 days
86		Steam turbine hall	120 days	15/04/15 ...	12/08/15 ...	78	0 days
87		Control building	150 days	31/03/15 ...	27/08/15 ...	79	0 days
88		Pipe rack and pipe bridge foundation	230 days	30/04/15 ...	15/12/15 ...	80	0 days
89		Tank foundation and miscellaneous balance of plan	200 days	30/05/15 ...	15/12/15 ...	81	0 days
90		Steam turbine hall	180 days	13/08/15 ...	08/02/16 ...	86	15 days
91		Control building	180 days	28/08/15 ...	23/02/16 ...	87	0 days
92		Pipe rack and pipe bridge steel structure erection	30 days	16/12/15 ...	14/01/16 ...	88	0 days
93		Miscellaneous buildings	60 days	16/12/15 ...	13/02/16 ...	89	0 days
94		Water/wastewater pond	300 days	30/05/15 ...	24/03/16 ...	7;73;81	371 days
95		Road and paving	230 days	30/05/15 ...	14/01/16 ...	80;81	553 days
96		**Main equipment erection work**	**471 days**	**15/12/15...**	**30/03/17...**		**29 days**
97		GTG1	289 days	23/04/16 ...	05/02/17 ...	16;83	0 days
98		GTG2	264 days	22/05/16 ...	09/02/17 ...	20;83	20 days
99		HRSG1	140 days	23/06/16 ...	09/11/16 ...	24;84	0 days
100		HRSG2	169 days	09/07/16 ...	24/12/16 ...	28;84	25 days
101		STG	124 days	27/07/16 ...	27/11/16 ...	32;85;86	94 days
102		Service water tank	229 days	16/12/15 ...	31/07/16 ...	8;89	242 days
103		Cooling tower	253 days	23/03/16 ...	30/11/16 ...	40;89	120 days
104		Chiller	189 days	27/04/16 ...	01/11/16 ...	48;89	149 days
105		Gas compressor	336 days	29/04/16 ...	30/03/17 ...	36;89	0 days
106		Pump	244 days	17/07/16 ...	17/03/17 ...	6;52	13 days
107		Emergency diesel generator	0 days	15/12/15 ...	15/12/15 ...	56;89	471 days
108		Transformer	30 days	09/04/16 ...	08/05/16 ...	60;89	65 days
109		Switchgear	3 days	10/07/16 ...	12/07/16 ...	64;91	0 days
110		DCS panel	60 days	21/06/16 ...	19/08/16 ...	68;91	0 days
111		**Balance of plant erection work**	**522 days**	**27/09/15...**	**01/03/17...**		**58 days**
112		**Mechanical work**	**442 days**	**16/12/15...**	**01/03/17...**		**29 days**
113		Air conditioning and ventilation system	354 days	24/02/16 ...	11/02/17 ...	91	76 days
114		Plumbing and drainage	108 days	24/02/16 ...	10/06/16 ...	91	322 days
115		Firefighting	372 days	24/02/16 ...	01/03/17 ...	8;11;90;91	58 days
116		Compressed air system	324 days	16/12/15 ...	03/11/16 ...	8;9;10;11;89	176 days
117		Demineralization water system	283 days	14/02/16 ...	22/11/16 ...	8;11;93	0 days
118		Piping system	184 days	15/01/16 ...	16/07/16 ...	92	0 days
119		**Electrical work**	**517 days**	**27/09/15...**	**24/02/17...**		**0 days**
120		High voltage system installation	227 days	13/07/16 ...	24/02/17 ...	108;109	7 days
121		Medium voltage system installation	227 days	13/07/16 ...	24/02/17 ...	91SS+30 days;108;109	2 days
122		Low voltage system installation	195 days	13/07/16 ...	23/01/17 ...	91SS+30 days;108;109	35 days



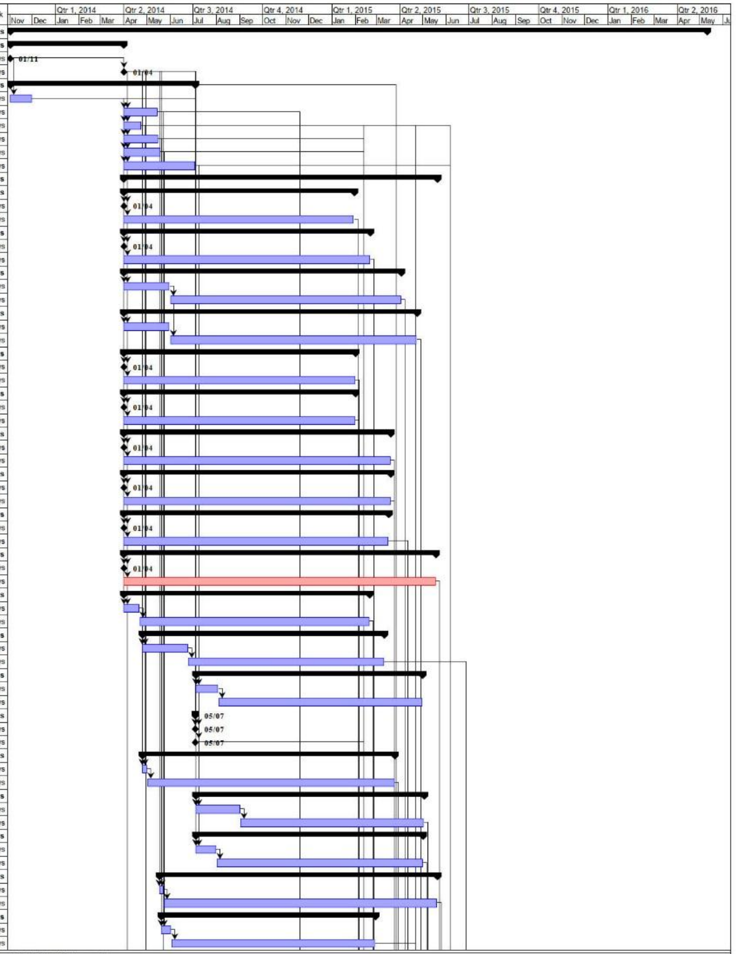
Project B Schedule (Actual) - page2

	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
123		DC and UPS system installation	150 days	13/07/16 ...	09/12/16 ...	91SS+30 days;109	81 days
124		Lighting for building	493 days	27/09/15 ...	31/01/17 ...	91SS+30 days	31 days
125		Cable tray and cabling	407 days	15/01/16 ...	24/02/17 ...	92SS+30 days	7 days
126		**Control and Instrument work**	**407 days**	**15/01/16...**	**24/02/17...**		**0 days**
127		DCS system installation	5 days	20/08/16 ...	24/08/16 ...	91;110	191 days
128		Field instrument installation	216 days	02/07/16 ...	02/02/17 ...	118FS-15 days	29 days
129		Cable tray and cabling work	407 days	15/01/16 ...	24/02/17 ...	92SS+30 days	7 days
130	01/01/15...	Transmission line	699 days	01/01/15 ...	29/11/16 ...		87 days
131	29/10/16...	Raw water available	1 day	29/10/16 ...	29/10/16 ...		24 days
132	05/01/15...	Gas available	702 days	05/01/15 ...	06/12/16 ...		72 days
133		**Cold commissioning**	**171 days**	**10/11/16...**	**29/04/17...**		**82 days**
134		Back energization	1 day	25/02/17 ...	25/02/17 ...	119;126;130	0 days
135		Pre commissioning of demineralization water plant	57 days	23/11/16 ...	18/01/17 ...	117;118;131	0 days
136		**Cold commissioning of electrical system**	**4 days**	**26/02/17...**	**01/03/17...**		**0 days**
137		HV system	1 day	26/02/17 ...	26/02/17 ...	119;126;134	0 days
138		MV system	1 day	27/02/17 ...	27/02/17 ...	121;137	0 days
139		LV system	1 day	28/02/17 ...	28/02/17 ...	122;138	0 days
140		DC and UPS system	1 day	01/03/17 ...	01/03/17 ...	123;139	0 days
141		**Cold commissioning of balnace of plant system**	**161 days**	**10/11/16...**	**19/04/17...**		**29 days**
142		Cold commissioning of balance of plant equipment	20 days	31/03/17 ...	19/04/17 ...	94;102;103;104;105;106;107;108;109;110;112;119;126;134	10 days
143		**Cold commissioning of GTG and HRSG1**	**99 days**	**10/11/16...**	**16/02/17...**		**0 days**
144		Hydrostatic test, flush and cleaning	2 days	10/11/16 ...	11/11/16 ...	99;118	86 days
145		Function test	11 days	06/02/17 ...	16/02/17 ...	97;144	0 days
146		**Cold commissioning of GTG and HRSG2**	**51 days**	**19/01/17...**	**10/03/17...**		**7 days**
147		Hydrostatic test, flush and cleaning	20 days	19/01/17 ...	07/02/17 ...	100;118;135	22 days
148		Function test	9 days	02/03/17 ...	10/03/17 ...	98;140;147	0 days
149		**Cold commissioning of STG**	**59 days**	**02/03/17...**	**29/04/17...**		**19 days**
150		Function test	59 days	02/03/17 ...	29/04/17 ...	101;118;136	0 days
151		**Overall mechanical completion**	**0 days**	**29/04/17...**	**29/04/17...**		**82 days**
152		Overall mechanical completion	0 days	29/04/17 ...	29/04/17 ...	142;145;148;150	82 days
153		**Hot commissionoing work**	**133 days**	**17/02/17...**	**29/06/17...**		**0 days**
154		**Commissioning of GTG unit 1**	**39 days**	**17/02/17...**	**27/03/17...**		**58 days**
155		GTG1 first firing	1 day	17/02/17 ...	17/02/17 ...	145;132	0 days
156		Function test with DCS	37 days	18/02/17 ...	26/03/17 ...	155	0 days
157		GTG1 first synchronization	1 day	27/03/17 ...	27/03/17 ...	156	58 days
158		**Commissioning of GTG unit 2**	**10 days**	**11/03/17...**	**20/03/17...**		**65 days**
159		GTG2 first firing	1 day	11/03/17 ...	11/03/17 ...	148;132	0 days
160		Function test with DCS	8 days	12/03/17 ...	19/03/17 ...	159	0 days
161		GTG2 first synchronization	1 day	20/03/17 ...	20/03/17 ...	160	65 days
162		**Commissioning of STG**	**59 days**	**27/03/17...**	**24/05/17...**		**0 days**
163		Main steam header blowout	5 days	27/03/17 ...	31/03/17 ...	156;160	0 days
164		Function test	48 days	01/04/17 ...	18/05/17 ...	163	0 days
165		STG first steam	5 days	19/05/17 ...	23/05/17 ...	142;150;164	0 days
166		STG first synchronization	1 day	24/05/17 ...	24/05/17 ...	165	0 days
167		**Overall commissioning work**	**36 days**	**25/05/17...**	**29/06/17...**		**0 days**
168		Combined cycle function test	20 days	25/05/17 ...	13/06/17 ...	166;161;157	0 days
169		Plant performance test	2 days	14/06/17 ...	15/06/17 ...	168	0 days
170		Plant trial run	6 days	16/06/17 ...	21/06/17 ...	169	0 days
171		Remaining plant's function test	8 days	22/06/17 ...	29/06/17 ...	170	0 days
172		COD	0 days	29/06/17 ...	29/06/17 ...	171	21 days
173		Remaining plant's function test	21 days	30/06/17 ...	20/07/17 ...	171	0 days



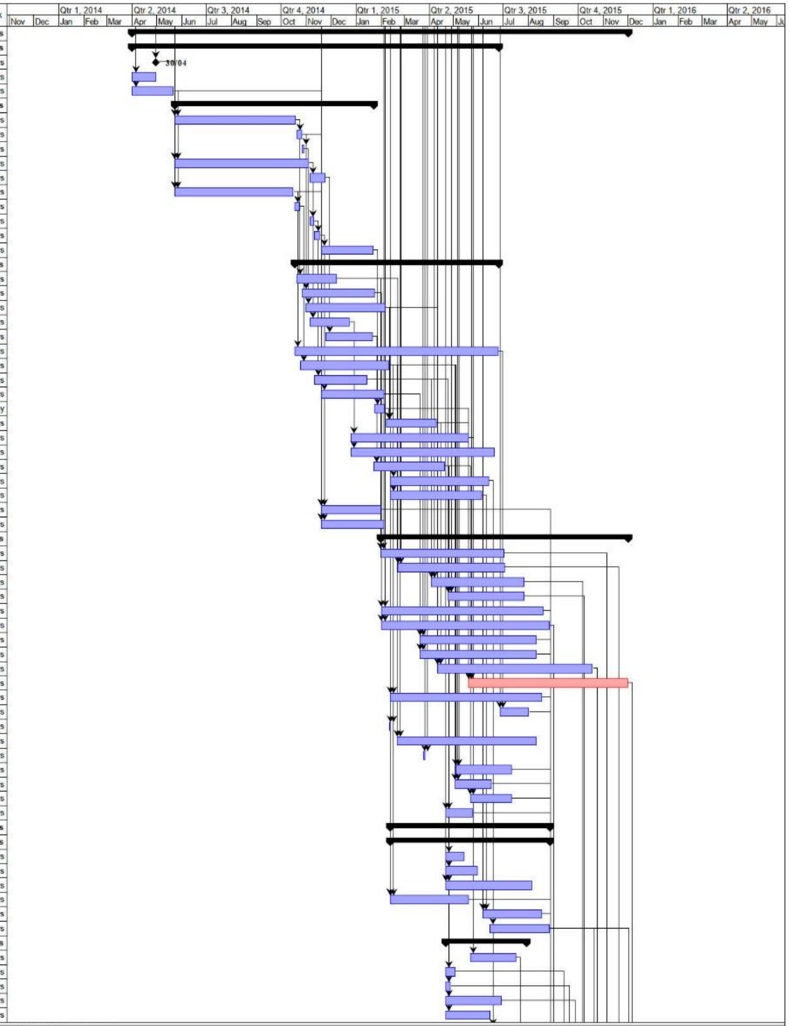
Appendix C Detailed results of construction schedules analysis of Project C

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project C**	**922 days?**	**01/11/13...**	**10/05/16...**		**0 days**
2		**Key milestone**	**151 days**	**01/11/13...**	**01/04/14...**		**0 days**
3		EPC Contract signing	0 days	01/11/13 ...	01/11/13 ...		0 days
4	01/04/14 ...	Notice to proceed	0 days	01/04/14 ...	01/04/14 ...	3	0 days
5		**Detailed Engineering work**	**246 days**	**01/11/13...**	**04/07/14...**		**176 days**
6		Conceptual design	30 days	01/11/13 ...	30/11/13 ...	3	121 days
7		Civil detialed engineering	45 days	01/04/14 ...	15/05/14 ...	4;6	7 days
8		Mechanical and process detailed engineering	24 days	01/04/14 ...	24/04/14 ...	4;6	0 days
9		Electrical detailed engineering	46 days	01/04/14 ...	16/05/14 ...	4;6	0 days
10		C&I detailed engineering	49 days	01/04/14 ...	19/05/14 ...	4;6	0 days
11		Balance of plant detailed engineering	95 days	01/04/14 ...	04/07/14 ...	4;6	0 days
12		**Procurement**	**415 days**	**01/04/14...**	**20/05/15...**		**356 days**
13		**GTG1**	**305 days**	**01/04/14...**	**30/01/15...**		**180 days**
14		Confirm order to GTG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
15		Manufacturing and transportation	305 days	01/04/14 ...	30/01/15 ...	14	0 days
16		**GTG2**	**326 days**	**01/04/14...**	**20/02/15...**		**445 days**
17		Confirm order to GTG	0 days	01/04/14 ...	01/04/14 ...	4;6	771 days
18		Manufacturing and transportation	326 days	01/04/14 ...	20/02/15 ...	14	0 days
19		**GTG3**	**367 days**	**01/04/14...**	**02/04/15...**		**105 days**
20		Confirm order to GTG	61 days	01/04/14 ...	31/05/14 ...	4;6	0 days
21		Manufacturing and transportation	306 days	01/06/14 ...	02/04/15 ...	20	0 days
22		**GTG4**	**388 days**	**01/04/14...**	**23/04/15...**		**383 days**
23		Confirm order to GTG	61 days	01/04/14 ...	31/05/14 ...	4;6	710 days
24		Manufacturing and transportation	327 days	01/06/14 ...	23/04/15 ...	20	0 days
25		**HRSG1**	**306 days**	**01/04/14...**	**31/01/15...**		**63 days**
26		Confirm order to HRSG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
27		Manufacturing and transportation	306 days	01/04/14 ...	31/01/15 ...	26	0 days
28		**HRSG2**	**306 days**	**01/04/14...**	**31/01/15...**		**55 days**
29		Confirm order to HRSG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
30		Manufacturing and transportation	306 days	01/04/14 ...	31/01/15 ...	29	0 days
31		**HRSG3**	**353 days**	**01/04/14...**	**19/03/15...**		**59 days**
32		Confirm order to HRSG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
33		Manufacturing and transportation	353 days	01/04/14 ...	19/03/15 ...	32	0 days
34		**HRSG4**	**353 days**	**01/04/14...**	**19/03/15...**		**38 days**
35		Confirm order to HRSG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
36		Manufacturing and transportation	353 days	01/04/14 ...	19/03/15 ...	35	0 days
37		**Steam turbine 1**	**350 days**	**01/04/14...**	**16/03/15...**		**36 days**
38		Confirm order to STG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
39		Manufacturing and transportation	350 days	01/04/14 ...	16/03/15 ...	38	25 days
40		**Steam turbine 2**	**413 days**	**01/04/14...**	**18/05/15...**		**0 days**
41		Confirm order to STG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
42		Manufacturing and transportation	413 days	01/04/14 ...	18/05/15 ...	41	0 days
43		**Gas compressor**	**325 days**	**01/04/14...**	**19/02/15...**		**273 days**
44		Confirm order to gas compressor	21 days	01/04/14 ...	21/04/14 ...	4;6	0 days
45		Manufacturing and transportation	304 days	22/04/14 ...	19/02/15 ...	44	0 days
46		**Cooling tower**	**321 days**	**25/04/14...**	**11/03/15...**		**207 days**
47		Confirm order to cooling tower	61 days	25/04/14 ...	24/06/14 ...	4;8;6	0 days
48		Manufacturing and transportation	260 days	25/06/14 ...	11/03/15 ...	47	106 days
49		**Turbine bypass valve**	**300 days**	**05/07/14...**	**30/04/15...**		**376 days**
50		Confirm order to turbine bypass valve	30 days	05/07/14 ...	03/08/14 ...	4;6;8;11	0 days
51		Manufacturing and transportation	270 days	04/08/14 ...	30/04/15 ...	50	376 days
52		**Chiller**	**0 days**	**04/07/14...**	**04/07/14...**		**675 days**
53		Confirm order to chiller	0 days	04/07/14 ...	04/07/14 ...	4;8;11;6	0 days
54		Manufacturing and transportation	0 days	04/07/14 ...	04/07/14 ...	53	222 days
55		**Pump**	**335 days**	**25/04/14...**	**25/03/15...**		**411 days**
56		Confirm order to pumps	7 days	25/04/14 ...	01/05/14 ...	4;6;8	0 days
57		Manufacturing and transportation	328 days	02/05/14 ...	25/03/15 ...	56	0 days
58		**Emergency diesel generator**	**302 days**	**05/07/14...**	**02/05/15...**		**122 days**
59		Confirm order to energency diesel generator	59 days	05/07/14 ...	01/09/14 ...	4;8;9;11;6	0 days
60		Manufacturing and transportation	243 days	02/09/14 ...	02/05/15 ...	59	0 days
61		**Transformer**	**301 days**	**05/07/14...**	**01/05/15...**		**146 days**
62		Confirm order to transformers	28 days	05/07/14 ...	01/08/14 ...	4;9;11;6	0 days
63		Manufacturing and transportation	273 days	02/08/14 ...	01/05/15 ...	62	0 days
64		**Switchgear**	**369 days**	**17/05/14...**	**20/05/15...**		**122 days**
65		Confirm order to switchgear	7 days	17/05/14 ...	23/05/14 ...	4;6;9	0 days
66		Manufacturing and transportation	362 days	24/05/14 ...	20/05/15 ...	65	0 days
67		**DCS panel**	**284 days**	**20/05/14...**	**27/02/15...**		**222 days**
68		Confirm order to DCS	14 days	20/05/14 ...	02/06/14 ...	4;6;10	0 days
69		Manufacturing and transportation	270 days	03/06/14 ...	27/02/15 ...	68	52 days

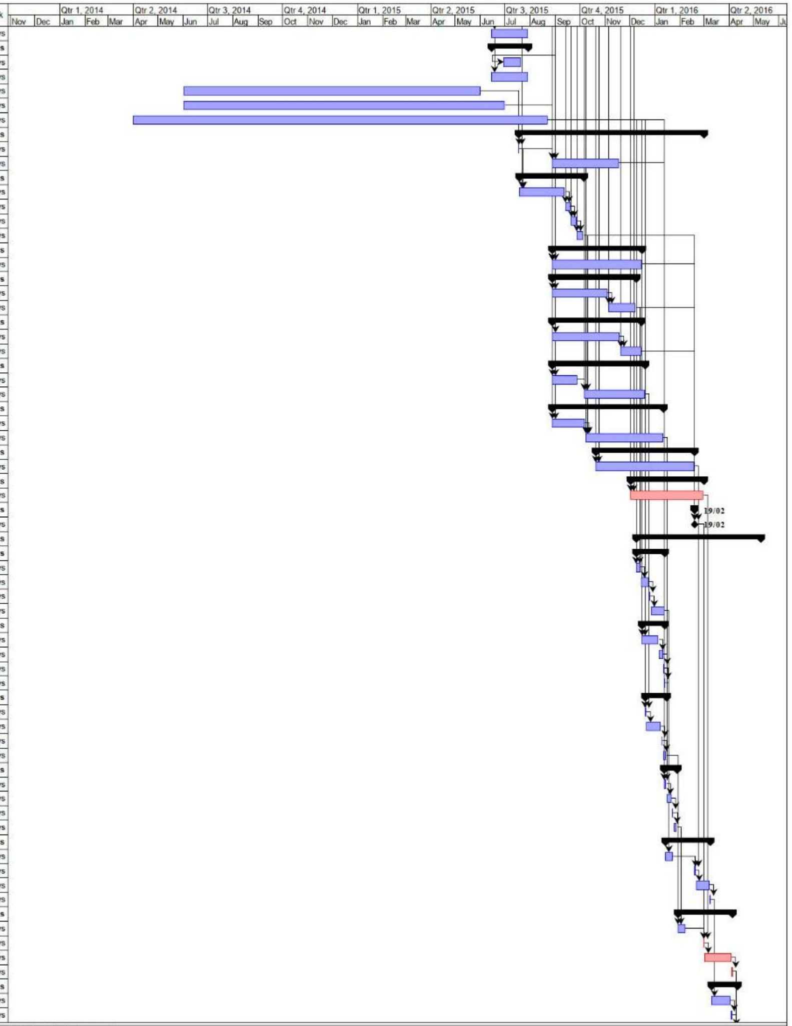


Project C Schedule (Plan) - page1

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
70		**Construction work**	**610 days**	**01/04/14...**	**01/12/15...**		**161 days**
71		**Civil work**	**451 days**	**01/04/14...**	**25/06/15...**		**320 days**
72	30/04/14 ...	Permit to start civil work	0 days	30/04/14 ...	30/04/14 ...	4;6	23 days
73		Site mobilization and site temporary office	30 days	01/04/14 ...	30/04/14 ...	4	741 days
74		Site preparation, clearing and levelling work	52 days	01/04/14 ...	22/05/14 ...	4	0 days
75		**Piling works**	**245 days**	**23/05/14...**	**22/01/15...**		**54 days**
76		GTG1 2 piling	150 days	23/05/14 ...	19/10/14 ...	7;72;74	0 days
77		HRSG1 2 piling	7 days	20/10/14 ...	26/10/14 ...	76	0 days
78		STG1 piling	3 days	27/10/14 ...	29/10/14 ...	77	0 days
79		Substation piling	166 days	23/05/14 ...	04/11/14 ...	7;72;74	0 days
80		Control building piling	20 days	05/11/14 ...	24/11/14 ...	79	0 days
81		Cooling tower piling	147 days	23/05/14 ...	16/10/14 ...	7;72;74	0 days
82		Balance of plant area piling	8 days	17/10/14 ...	24/10/14 ...	81	0 days
83		GTG3 4 piling	6 days	05/11/14 ...	10/11/14 ...	79	0 days
84		HRSG3 4 piling	8 days	11/11/14 ...	18/11/14 ...	83	0 days
85		STG2 piling	65 days	19/11/14 ...	22/01/15 ...	84	0 days
86		**Foundations**	**252 days**	**17/10/14...**	**25/06/15...**		**101 days**
87		GTG1 2 foundation	50 days	20/10/14 ...	08/12/14 ...	76	53 days
88		HRSG1 2 foundation	90 days	27/10/14 ...	24/01/15 ...	77	7 days
89		STG1 foundation	100 days	30/10/14 ...	06/02/15 ...	78	0 days
90		Substation foundation	50 days	05/11/14 ...	24/12/14 ...	79	0 days
91		Control building foundation	58 days	25/11/14 ...	21/01/15 ...	80	0 days
92		Cooling tower foundation	252 days	17/10/14 ...	25/06/15 ...	81	0 days
93		Tank foundation and miscellaneous balance of plant	110 days	25/10/14 ...	11/02/15 ...	82	0 days
94		GTG3 4 foundation	66 days	11/11/14 ...	15/01/15 ...	83	77 days
95		HRSG3 4 foundation	78 days	19/11/14 ...	04/02/15 ...	84	43 days
96		STG2 foundation	14 days	23/01/15 ...	05/02/15 ...	85	1 day
97		Steam turbine hall erection	63 days	07/02/15 ...	10/04/15 ...	89;96	0 days
98		Substation of block 1 erection	147 days	25/12/14 ...	20/05/15 ...	90	0 days
99		Substation of block 2 erection	178 days	25/12/14 ...	20/06/15 ...	90	325 days
100		Control building construction	89 days	22/01/15 ...	20/04/15 ...	91	0 days
101		Pipe rack and pipe bridge erection	122 days	12/02/15 ...	13/06/15 ...	93	0 days
102		Water treatment plant construction	114 days	12/02/15 ...	05/06/15 ...	93	0 days
103		Water/wastewater pond	74 days	19/11/14 ...	31/01/15 ...	7;74;77;84	208 days
104		Road and paving	78 days	19/11/14 ...	04/02/15 ...	81;77;84	461 days
105		**Main equipment erection work**	**305 days**	**31/01/15...**	**01/12/15...**		**161 days**
106		GTG1	153 days	31/01/15 ...	02/07/15 ...	15;87	125 days
107		GTG2	133 days	21/02/15 ...	03/07/15 ...	18;87	139 days
108		GTG3	116 days	03/04/15 ...	27/07/15 ...	21;94	70 days
109		GTG4	95 days	24/04/15 ...	27/07/15 ...	24;94	72 days
110		HRSG1	200 days	01/02/15 ...	19/08/15 ...	27;88	8 days
111		HRSG2	208 days	01/02/15 ...	27/08/15 ...	30;88	0 days
112		HRSG3	145 days	20/03/15 ...	11/08/15 ...	33;95	16 days
113		HRSG4	145 days	20/03/15 ...	11/08/15 ...	36;95	16 days
114		STG1	192 days	11/04/15 ...	19/10/15 ...	39;89;97	0 days
115		STG2	197 days	19/05/15 ...	01/12/15 ...	42;96;97	0 days
116		Service water tank	187 days	12/02/15 ...	17/08/15 ...	8;93	10 days
117		Cooling tower	37 days	26/06/15 ...	01/08/15 ...	48;92	26 days
118		Chiller	1 day	12/02/15 ...	12/02/15 ...	54;93	453 days
119		Gas compressor	173 days	20/02/15 ...	11/08/15 ...	45;93	273 days
120		Pump	1 day	26/03/15 ...	26/03/15 ...	5;57	411 days
121		Emergency diesel generator	70 days	03/05/15 ...	11/07/15 ...	60;93	47 days
122		Transformer	47 days	02/05/15 ...	17/06/15 ...	63;93	71 days
123		Switchgear	52 days	21/05/15 ...	11/07/15 ...	66;100	47 days
124		DCS panel	34 days	21/04/15 ...	24/05/15 ...	69;100	95 days
125		**Balance of plant erection work**	**197 days**	**12/02/15...**	**27/08/15...**		**257 days**
126		**Mechanical work**	**197 days**	**12/02/15...**	**27/08/15...**		**257 days**
127		Air conditioning and ventilation system	24 days	21/04/15 ...	14/05/15 ...	100	362 days
128		Plumbing and drainage	40 days	21/04/15 ...	30/05/15 ...	100	346 days
129		Firefighting	107 days	21/04/15 ...	05/08/15 ...	8;11;100	279 days
130		Compressed air system	98 days	12/02/15 ...	20/05/15 ...	8;9;10;11;93	99 days
131		Demineralization water system	73 days	06/06/15 ...	17/08/15 ...	8;11;102	10 days
132		Piping system	75 days	14/06/15 ...	27/08/15 ...	101	0 days
133		**Electrical work**	**100 days**	**21/04/15...**	**29/07/15...**		**286 days**
134		High voltage system installation	58 days	21/05/15 ...	17/07/15 ...	98	0 days
135		Medium voltage system installation	13 days	21/04/15 ...	03/05/15 ...	100	132 days
136		Low voltage system installation	7 days	21/04/15 ...	27/04/15 ...	100	145 days
137		DC and UPS system installation	70 days	21/04/15 ...	29/06/15 ...	100	89 days
138		Lighting for building	56 days	21/04/15 ...	15/06/15 ...	100	330 days

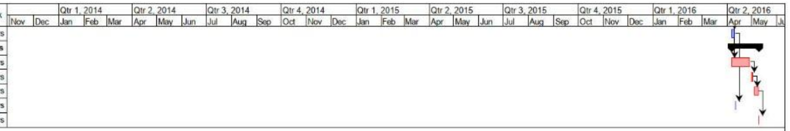


	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
139		Cable tray and cabling	46 days	14/06/15 ...	29/07/15 ...	101	286 days
140		**Control and Instrument work**	**46 days**	**14/06/15...**	**29/07/15...**		**286 days**
141		Field instrument installation	22 days	29/06/15 ...	20/07/15 ...	132FS-60 days	295 days
142		Cable tray and cabling work	46 days	14/06/15 ...	29/07/15 ...	101	286 days
143	01/06/14 ...	Transmission line	366 days	01/06/14 ...	01/06/15 ...		46 days
144	01/06/14 ...	Raw water available	396 days	01/06/14 ...	01/07/15 ...		57 days
145	01/04/14 ...	Gas available	509 days	01/04/14 ...	22/08/15 ...		108 days
146		**Cold commissioning**	**227 days**	**18/07/15...**	**29/02/16...**		**0 days**
147		Back energization	1 day	18/07/15 ...	18/07/15 ...	134;143	0 days
148		Pre commissioning of demineralization water plant	83 days	28/08/15 ...	18/11/15 ...	131;132;147;144	20 days
149		**Cold commissioning of electrical system**	**79 days**	**19/07/15...**	**05/10/15...**		**24 days**
150		HV system	56 days	19/07/15 ...	12/09/15 ...	134;147	0 days
151		MV system	7 days	13/09/15 ...	19/09/15 ...	135;150	0 days
152		LV system	7 days	20/09/15 ...	26/09/15 ...	136;151	0 days
153		DC and UPS system	9 days	27/09/15 ...	05/10/15 ...	137;152	0 days
154		**Cold commissioning of mechanical system**	**111 days**	**28/08/15...**	**16/12/15...**		**75 days**
155		Cold commissioning of balance of plant equipment	111 days	28/08/15 ...	16/12/15 ...	103;116;117;121;122;123;124;130;132	64 days
156		**Cold commissioning of GTG and HRSG1**	**103 days**	**28/08/15...**	**08/12/15...**		**55 days**
157		Hydrostatic test, flush and cleaning	69 days	28/08/15 ...	04/11/15 ...	110;132	0 days
158		Function test	34 days	05/11/15 ...	08/12/15 ...	106;153;157	0 days
159		**Cold commissioning of GTG and HRSG2**	**110 days**	**28/08/15...**	**15/12/15...**		**55 days**
160		Hydrostatic test, flush and cleaning	84 days	28/08/15 ...	19/11/15 ...	111;132	0 days
161		Function test	26 days	20/11/15 ...	15/12/15 ...	107;153;160	0 days
162		**Cold commissioning of GTG and HRSG3**	**114 days**	**28/08/15...**	**19/12/15...**		**35 days**
163		Hydrostatic test, flush and cleaning	31 days	28/08/15 ...	27/09/15 ...	112;132	8 days
164		Function test	75 days	06/10/15 ...	19/12/15 ...	108;153;163	0 days
165		**Cold commissioning of GTG and HRSG4**	**137 days**	**28/08/15...**	**11/01/16...**		**22 days**
166		Hydrostatic test, flush and cleaning	41 days	28/08/15 ...	07/10/15 ...	113;132	0 days
167		Function test	96 days	08/10/15 ...	11/01/16 ...	109;153;166	0 days
168		**Cold commissioning of STG1**	**122 days**	**20/10/15...**	**18/02/16...**		**11 days**
169		Function test	122 days	20/10/15 ...	18/02/16 ...	114;132;153	0 days
170		**Cold commissioning of STG2**	**90 days**	**02/12/15...**	**29/02/16...**		**0 days**
171		Function test	90 days	02/12/15 ...	29/02/16 ...	115;132;153	0 days
172		**Overall mechanical completion of balance of plant**	**0 days**	**18/02/16...**	**18/02/16...**		**11 days**
173		Overall mechanical completion of balance of plant	0 days	18/02/16 ...	18/02/16 ...	153;155;158;161;169	0 days
174		**Hot commissionoing work**	**153 days?**	**09/12/15...**	**09/05/16...**		**0 days**
175		**Commissioning of GTG unit 1**	**36 days**	**09/12/15...**	**13/01/16...**		**55 days**
176		GTG1 first firing	6 days	09/12/15 ...	14/12/15 ...	148;158;145	0 days
177		Function test with DCS (No-load test)	10 days	15/12/15 ...	24/12/15 ...	176	0 days
178		GTG1 first synchronization	2 days	25/12/15 ...	26/12/15 ...	177	0 days
179		GTG1 on load test	18 days	27/12/15 ...	13/01/16 ...	178	0 days
180		**Commissioning of GTG unit 2**	**29 days?**	**16/12/15...**	**13/01/16...**		**55 days**
181		GTG2 first firing	21 days	16/12/15 ...	05/01/16 ...	148;161;145	0 days
182		Function test with DCS (No-load test)	6 days	06/01/16 ...	11/01/16 ...	181	0 days
183		GTG2 first synchronization	1 day	12/01/16 ...	12/01/16 ...	182	0 days
184		GTG2 on load test	1 day?	13/01/16 ...	13/01/16 ...	183	0 days
185		**Commissioning of GTG unit 3**	**27 days**	**20/12/15...**	**15/01/16...**		**35 days**
186		GTG1 first firing	2 days	20/12/15 ...	21/12/15 ...	148;164;145	0 days
187		Function test with DCS (No-load test)	18 days	22/12/15 ...	08/01/16 ...	186	0 days
188		GTG1 first synchronization	2 days	09/01/16 ...	10/01/16 ...	187	0 days
189		GTG1 on load test	5 days	11/01/16 ...	15/01/16 ...	188	13 days
190		**Commissioning of GTG unit 4**	**17 days**	**12/01/16...**	**28/01/16...**		**22 days**
191		GTG2 first firing	4 days	12/01/16 ...	15/01/16 ...	148;167;145	0 days
192		Function test with DCS (No-load test)	6 days	16/01/16 ...	21/01/16 ...	191	0 days
193		GTG2 first synchronization	2 days	22/01/16 ...	23/01/16 ...	192	0 days
194		GTG2 on load test	5 days	24/01/16 ...	28/01/16 ...	193	0 days
195		**Commissioning of STG1**	**56 days**	**14/01/16...**	**09/03/16...**		**29 days**
196		Main steam header blowout	10 days	14/01/16 ...	23/01/16 ...	179;184	26 days
197		STG first steam	1 day	19/02/16 ...	19/02/16 ...	169;173;196	0 days
198		Function test	18 days	20/02/16 ...	08/03/16 ...	197	0 days
199		STG first synchronization	1 day	09/03/16 ...	09/03/16 ...	198	0 days
200		**Commissioning of STG2**	**68 days**	**29/01/16...**	**05/04/16...**		**0 days**
201		Main steam header blowout	10 days	29/01/16 ...	07/02/16 ...	189;194	22 days
202		STG first steam	1 day	01/03/16 ...	01/03/16 ...	171;173;201	0 days
203		Function test	34 days	02/03/16 ...	04/04/16 ...	202	0 days
204		STG first synchronization	1 day	05/04/16 ...	05/04/16 ...	203	0 days
205		**Overall commissioning work of block1**	**32 days**	**10/03/16...**	**10/04/16...**		**29 days**
206		Combined cycle function test of block 1	24 days	10/03/16 ...	02/04/16 ...	199	0 days
207		Plant performance test of block 1	3 days	03/04/16 ...	05/04/16 ...	206	0 days

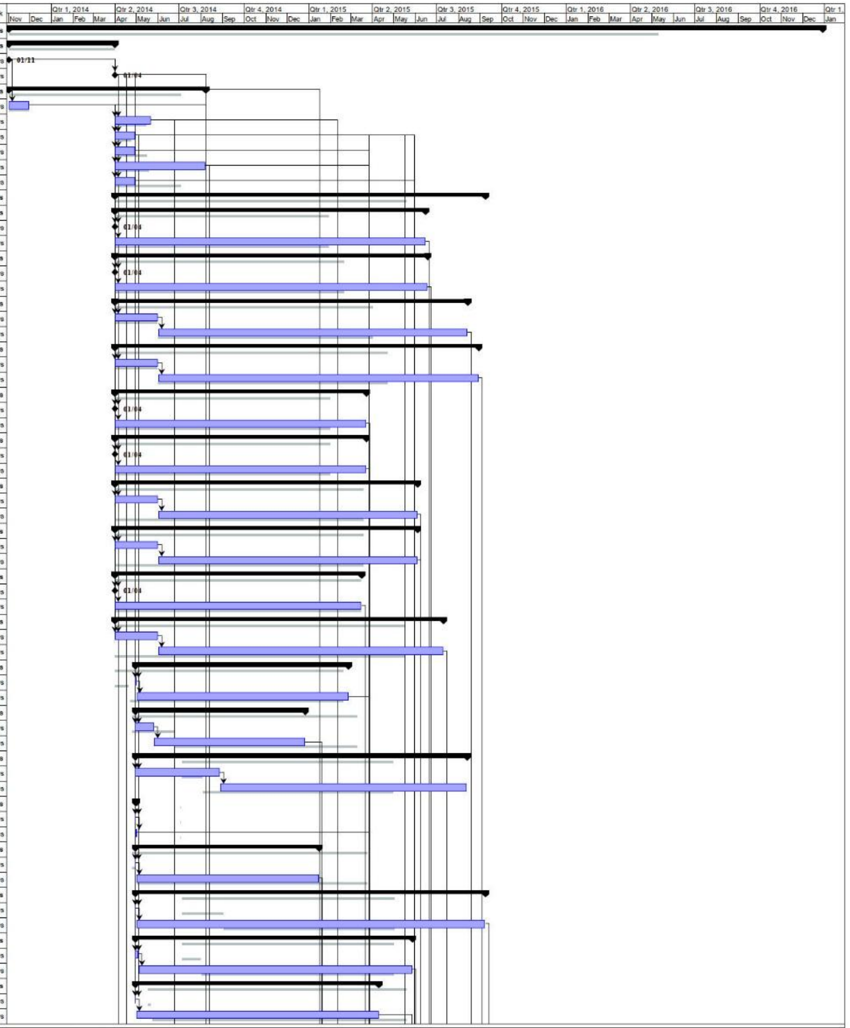


Project C Schedule (Plan) - page3

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
208		Plant trial run of block 1	5 days	06/04/16 ...	10/04/16 ...	207	0 days
209		**Overall commissioning work of block2**	**34 days**	**06/04/16...**	**09/05/16...**		**0 days**
210		Combined cycle function test of block 2	24 days	06/04/16 ...	29/04/16 ...	204	0 days
211		Plant performance test of block 2	4 days	30/04/16 ...	03/05/16 ...	210	0 days
212		Plant trial run of block 2	6 days	04/05/16 ...	09/05/16 ...	211	0 days
213		SCOD of block 1	1 day	11/04/16 ...	11/04/16 ...	208	29 days
214		SCOD of block 2	1 day	10/05/16 ...	10/05/16 ...	212	0 days

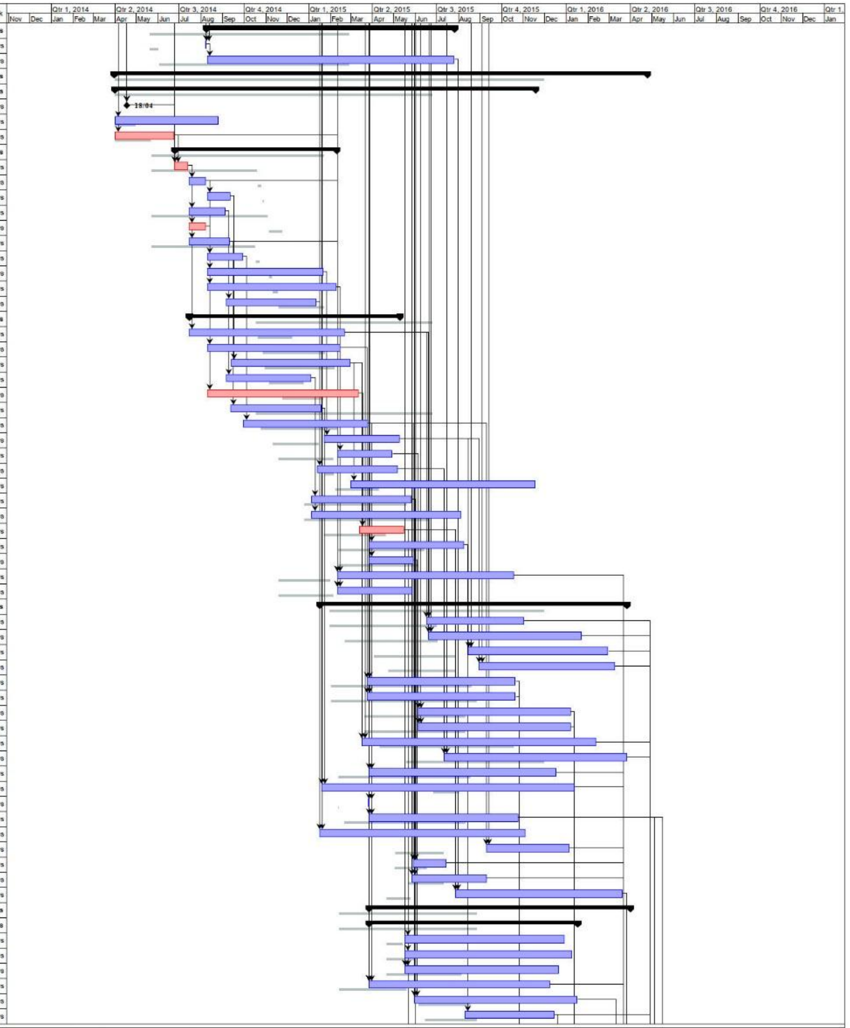


	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project C**	**1,155 days**	**01/11/13...**	**29/12/16...**		**0 days**
2		**Key milestone**	**151 days**	**01/11/13...**	**01/04/14...**		**0 days**
3		EPC Contract signing	0 days	01/11/13 ...	01/11/13 ...		0 days
4	01/04/14...	Notice to proceed	0 days	01/04/14 ...	01/04/14 ...	3	0 days
5		**Detailed Engineering work**	**280 days**	**01/11/13...**	**07/08/14...**		**80 days**
6		Conceptual design	30 days	01/11/13 ...	30/11/13 ...	3	121 days
7		Civil detialed engineering	52 days	01/04/14 ...	22/05/14 ...	4;6	33 days
8		Mechanical and process detailed engineering	29 days	01/04/14 ...	29/04/14 ...	4;6	0 days
9		Electrical detailed engineering	29 days	01/04/14 ...	29/04/14 ...	4;6	0 days
10		C&I detailed engineering	129 days	01/04/14 ...	07/08/14 ...	4;6	0 days
11		Balance of plant detailed engineering	29 days	01/04/14 ...	29/04/14 ...	4;6	0 days
12		**Procurement**	**526 days**	**01/04/14...**	**08/09/15...**		**478 days**
13		**GTG1**	**441 days**	**01/04/14...**	**15/06/15...**		**177 days**
14		Confirm order to GTG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
15		Manufacturing and transportation	441 days	01/04/14 ...	15/06/15 ...	14	0 days
16		**GTG2**	**444 days**	**01/04/14...**	**18/06/15...**		**96 days**
17		Confirm order to GTG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
18		Manufacturing and transportation	444 days	01/04/14 ...	18/06/15 ...	17	0 days
19		**GTG3**	**501 days**	**01/04/14...**	**14/08/15...**		**84 days**
20		Confirm order to GTG	62 days	01/04/14 ...	01/06/14 ...	4;6	0 days
21		Manufacturing and transportation	439 days	02/06/14 ...	14/08/15 ...	20	0 days
22		**GTG4**	**516 days**	**01/04/14...**	**29/08/15...**		**75 days**
23		Confirm order to GTG	62 days	01/04/14 ...	01/06/14 ...	4;6	0 days
24		Manufacturing and transportation	454 days	02/06/14 ...	29/08/15 ...	23	0 days
25		**HRSG1**	**357 days**	**01/04/14...**	**23/03/15...**		**183 days**
26		Confirm order to HRSG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
27		Manufacturing and transportation	357 days	01/04/14 ...	23/03/15 ...	26	0 days
28		**HRSG2**	**357 days**	**01/04/14...**	**23/03/15...**		**148 days**
29		Confirm order to HRSG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
30		Manufacturing and transportation	357 days	01/04/14 ...	23/03/15 ...	29	0 days
31		**HRSG3**	**430 days**	**01/04/14...**	**04/06/15...**		**129 days**
32		Confirm order to HRSG	62 days	01/04/14 ...	01/06/14 ...	4;6	0 days
33		Manufacturing and transportation	368 days	02/06/14 ...	04/06/15 ...	32	0 days
34		**HRSG4**	**430 days**	**01/04/14...**	**04/06/15...**		**130 days**
35		Confirm order to HRSG	62 days	01/04/14 ...	01/06/14 ...	4;6	0 days
36		Manufacturing and transportation	368 days	02/06/14 ...	04/06/15 ...	35	0 days
37		**Steam turbine 1**	**350 days**	**01/04/14...**	**16/03/15...**		**153 days**
38		Confirm order to STG	0 days	01/04/14 ...	01/04/14 ...	4;6	0 days
39		Manufacturing and transportation	350 days	01/04/14 ...	16/03/15 ...	38	0 days
40		**Steam turbine 2**	**466 days**	**01/04/14...**	**10/07/15...**		**116 days**
41		Confirm order to STG	62 days	01/04/14 ...	01/06/14 ...	4;6	0 days
42		Manufacturing and transportation	404 days	02/06/14 ...	10/07/15 ...	41	0 days
43		**Gas compressor**	**303 days**	**30/04/14...**	**26/02/15...**		**221 days**
44		Confirm order to gas compressor	2 days	30/04/14 ...	01/05/14 ...	4;6;8	0 days
45		Manufacturing and transportation	301 days	02/05/14 ...	26/02/15 ...	44	28 days
46		**Cooling tower**	**241 days**	**30/04/14...**	**26/12/14...**		**171 days**
47		Confirm order to cooling tower	27 days	30/04/14 ...	26/05/14 ...	4;8;6	0 days
48		Manufacturing and transportation	214 days	27/05/14 ...	26/12/14 ...	47	23 days
49		**Turbine bypass valve**	**471 days**	**30/04/14...**	**13/08/15...**		**504 days**
50		Confirm order to turbine bypass valve	121 days	30/04/14 ...	28/08/14 ...	4;6;8;11	0 days
51		Manufacturing and transportation	350 days	29/08/14 ...	13/08/15 ...	50	504 days
52		**Chiller**	**2 days**	**30/04/14...**	**01/05/14...**		**972 days**
53		Confirm order to chiller	1 day	30/04/14 ...	30/04/14 ...	4;8;11;6	0 days
54		Manufacturing and transportation	1 day	01/05/14 ...	01/05/14 ...	53	329 days
55		**Pump**	**261 days**	**30/04/14...**	**15/01/15...**		**421 days**
56		Confirm order to pumps	1 day	30/04/14 ...	30/04/14 ...	4;6;8	0 days
57		Manufacturing and transportation	260 days	01/05/14 ...	15/01/15 ...	56	0 days
58		**Emergency diesel generator**	**497 days**	**30/04/14...**	**08/09/15...**		**156 days**
59		Confirm order to energency diesel generator	1 day	30/04/14 ...	30/04/14 ...	4;8;9;11;6	0 days
60		Manufacturing and transportation	496 days	01/05/14 ...	08/09/15 ...	59	0 days
61		**Transformer**	**393 days**	**30/04/14...**	**27/05/15...**		**330 days**
62		Confirm order to transformers	5 days	30/04/14 ...	04/05/14 ...	4;9;11;6	0 days
63		Manufacturing and transportation	388 days	05/05/14 ...	27/05/15 ...	62	0 days
64		**Switchgear**	**346 days**	**30/04/14...**	**10/04/15...**		**319 days**
65		Confirm order to switchgear	1 day	30/04/14 ...	30/04/14 ...	4;6;9	0 days
66		Manufacturing and transportation	345 days	01/05/14 ...	10/04/15 ...	65	46 days

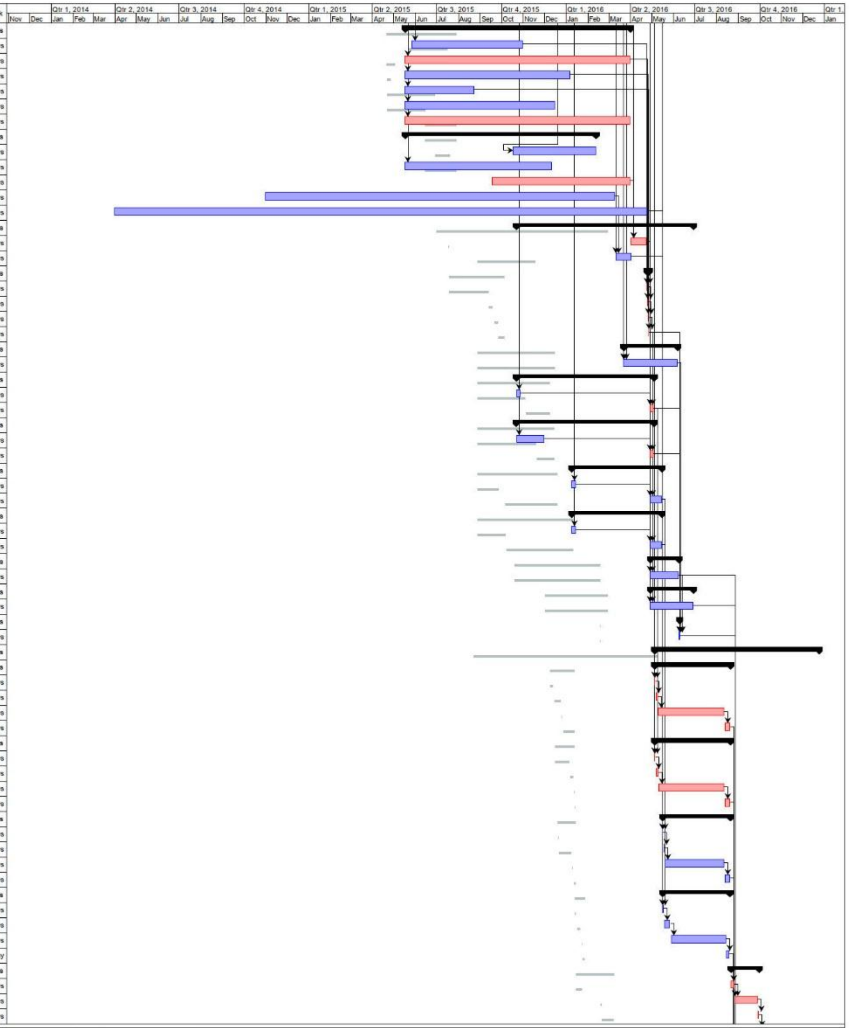


Project C Schedule (Actual) - page1

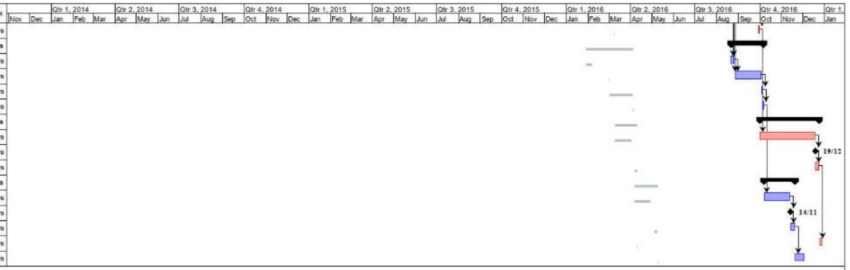
	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
67		**DCS panel**	**353 days**	**08/08/14...**	**26/07/15...**		**80 days**
68		Confirm order to DCS	1 day	08/08/14 ...	08/08/14 ...	4;6;10	0 days
69		Manufacturing and transportation	352 days	09/08/14 ...	26/07/15 ...	68	0 days
70		**Construction work**	**756 days**	**31/03/14...**	**24/04/16...**		**249 days**
71		**Civil work**	**597 days**	**01/04/14...**	**18/11/15...**		**407 days**
72	17/04/14...	Permit to start civil work	1 day	17/04/14 ...	17/04/14 ...	4;6	68 days
73		Site mobilization and site temporary office	148 days	01/04/14 ...	26/08/14 ...	4	856 days
74		Site preparation, clearing and levelling work	85 days	01/04/14 ...	24/06/14 ...	4	0 days
75		**Piling works**	**230 days**	**25/06/14...**	**09/02/15...**		**165 days**
76		GTG1 2 piling	20 days	25/06/14 ...	14/07/14 ...	7;72;74	0 days
77		HRSG1 2 piling	25 days	15/07/14 ...	08/08/14 ...	76	0 days
78		STG1 piling	35 days	09/08/14 ...	12/09/14 ...	77	0 days
79		Substation piling	52 days	15/07/14 ...	04/09/14 ...	76	0 days
80		Control building	25 days	15/07/14 ...	08/08/14 ...	76	0 days
81		Cooling tower	59 days	15/07/14 ...	11/09/14 ...	76	0 days
82		Balance of plant area	52 days	09/08/14 ...	29/09/14 ...	77	0 days
83		GTG3 4 piling	166 days	09/08/14 ...	21/01/15 ...	80	0 days
84		HRSG3 4 piling	185 days	09/08/14 ...	09/02/15 ...	77	0 days
85		STG2 piling	129 days	05/09/14 ...	11/01/15 ...	79	0 days
86		**Foundations**	**299 days**	**15/07/14...**	**09/05/15...**		**181 days**
87		GTG1 2 foundation	222 days	15/07/14 ...	21/02/15 ...	76	114 days
88		HRSG1 2 foundation	190 days	09/08/14 ...	14/02/15 ...	77	37 days
89		STG1 founndation	169 days	13/09/14 ...	28/02/15 ...	78	0 days
90		Substation foundation	122 days	05/09/14 ...	04/01/15 ...	79	0 days
91		Control building foundation	217 days	09/08/14 ...	13/03/15 ...	80	0 days
92		Cooling tower foundation	129 days	12/09/14 ...	18/01/15 ...	81	0 days
93		Tank foundation and miscellaneous balance of plant	178 days	30/09/14 ...	26/03/15 ...	82	0 days
94		GTG3 4 foundation	108 days	22/01/15 ...	09/05/15 ...	83	97 days
95		HRSG3 4 foundation	79 days	10/02/15 ...	29/04/15 ...	84	36 days
96		STG2 foundation	116 days	12/01/15 ...	07/05/15 ...	85	64 days
97		Steam turbine hall	263 days	01/03/15 ...	18/11/15 ...	89	407 days
98		Substation of block 1	142 days	05/01/15 ...	26/05/15 ...	90	0 days
99		Substation of block 2	212 days	05/01/15 ...	04/08/15 ...	90	513 days
100		Control building	64 days	14/03/15 ...	16/05/15 ...	91	0 days
101		Pipe rack and pipe bridge	136 days	27/03/15 ...	09/08/15 ...	93	0 days
102		Water treatment plant	64 days	27/03/15 ...	29/05/15 ...	93	0 days
103		Water/wastewater pond	252 days	10/02/15 ...	19/10/15 ...	7;74;77;84	154 days
104		Road and paving	107 days	10/02/15 ...	27/05/15 ...	81;77;84	582 days
105		**Main equipment erection work**	**436 days**	**16/01/15...**	**26/03/16...**		**278 days**
106		GTG1	140 days	16/06/15 ...	02/11/15 ...	15;87	177 days
107		GTG2	218 days	19/06/15 ...	22/01/16 ...	18;87	96 days
108		GTG3	199 days	15/08/15 ...	29/02/16 ...	21;94	58 days
109		GTG4	194 days	30/08/15 ...	10/03/16 ...	24;94	48 days
110		HRSG1	212 days	24/03/15 ...	21/10/15 ...	27;88	0 days
111		HRSG2	212 days	24/03/15 ...	21/10/15 ...	30;88	0 days
112		HRSG3	217 days	05/06/15 ...	07/01/16 ...	33;95	0 days
113		HRSG4	217 days	05/06/15 ...	07/01/16 ...	36;95	0 days
114		STG1	333 days	17/03/15 ...	12/02/16 ...	39;89	75 days
115		STG2	260 days	11/07/15 ...	26/03/16 ...	42;96	32 days
116		Water storage tanks	267 days	27/03/15 ...	18/12/15 ...	8;93	94 days
117		Cooling tower	360 days	19/01/15 ...	13/01/16 ...	48;92	68 days
118		Chiller	1 day	27/03/15 ...	27/03/15 ...	54;93	643 days
119		Gas compressor	212 days	27/03/15 ...	24/10/15 ...	45;93	193 days
120		Pump	293 days	16/01/15 ...	04/11/15 ...	5;57	421 days
121		Emergency diesel generator	119 days	09/09/15 ...	05/01/16 ...	60;93	76 days
122		Transformer	49 days	28/05/15 ...	15/07/15 ...	63;93	250 days
123		Switchgear	107 days	27/05/15 ...	10/09/15 ...	66;98	193 days
124		DCS panel	239 days	27/07/15 ...	21/03/16 ...	69;100	0 days
125		**Balance of plant erection work**	**371 days**	**27/03/15...**	**31/03/16...**		**273 days**
126		**Mechanical work**	**296 days**	**27/03/15...**	**16/01/16...**		**348 days**
127		Air conditioning and ventilation system	227 days	17/05/15 ...	29/12/15 ...	100	366 days
128		Plumbing and drainage	238 days	17/05/15 ...	09/01/16 ...	100	355 days
129		Firefighting	219 days	17/05/15 ...	21/12/15 ...	8;11;100	374 days
130		Compressed air system	257 days	27/03/15 ...	08/12/15 ...	8;9;10;11;93	104 days
131		Demineralization water system	232 days	30/05/15 ...	16/01/16 ...	8;11;102	54 days
132		Piping system	128 days	10/08/15 ...	15/12/15 ...	101	0 days



	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
133		**Electrical work**	**320 days**	**17/05/15...**	**31/03/16...**		**0 days**
134		High voltage system installation	158 days	27/05/15 ...	31/10/15 ...	98	152 days
135		Medium voltage system installation	320 days	17/05/15 ...	31/03/16 ...	100	0 days
136		Low voltage system installation	235 days	17/05/15 ...	06/01/16 ...	100	85 days
137		DC and UPS system installation	99 days	17/05/15 ...	23/08/15 ...	100	221 days
138		Lighting for building	214 days	17/05/15 ...	16/12/15 ...	100	106 days
139		Cable tray and cabling	320 days	17/05/15 ...	31/03/16 ...	100	0 days
140		**Control and Instrument work**	**272 days**	**17/05/15...**	**12/02/16...**		**321 days**
141		Field instrument installation	119 days	17/10/15 ...	12/02/16 ...	132FS-60 days	321 days
142		Cable tray and cabling work	209 days	17/05/15 ...	11/12/15 ...	100	384 days
143	17/09/15...	Transmission line	197 days	17/09/15 ...	31/03/16 ...		0 days
144	31/10/14...	Raw water available	497 days	31/10/14 ...	10/03/16 ...		0 days
145	31/03/14...	Gas available	756 days	31/03/14 ...	24/04/16 ...		10 days
146		**Cold commissioning**	**252 days**	**22/10/15...**	**29/06/16...**		**84 days**
147		Back energization	23 days	01/04/16 ...	23/04/16 ...	133;143	0 days
148		Pre commissioning of demineralization water plant	23 days	11/03/16 ...	02/04/16 ...	131;132;144	32 days
149		**Cold commissioning of electrical system**	**4 days**	**24/04/16...**	**27/04/16...**		**0 days**
150		HV system	1 day	24/04/16 ...	24/04/16 ...	134;147	0 days
151		MV system	1 day	25/04/16 ...	25/04/16 ...	135;150	0 days
152		LV system	1 day	26/04/16 ...	26/04/16 ...	136;151	0 days
153		DC and UPS system	1 day	27/04/16 ...	27/04/16 ...	137;152	0 days
154		**Cold commissioning of mechanical system**	**77 days**	**22/03/16...**	**06/06/16...**		**80 days**
155		Cold commissioning of balance of plant equipment	77 days	22/03/16 ...	06/06/16 ...	103;116;117;121;122;123;124;130;132	2 days
156		**Cold commissioning of GTG and HRSG1**	**196 days**	**22/10/15...**	**04/05/16...**		**0 days**
157		Hydrostatic test, flush and cleaning	6 days	22/10/15 ...	27/10/15 ...	110	183 days
158		Function test	7 days	28/04/16 ...	04/05/16 ...	106;153;157	0 days
159		**Cold commissioning of GTG and HRSG2**	**196 days**	**22/10/15...**	**04/05/16...**		**0 days**
160		Hydrostatic test, flush and cleaning	41 days	22/10/15 ...	01/12/15 ...	111	148 days
161		Function test	7 days	28/04/16 ...	04/05/16 ...	107;153;160	0 days
162		**Cold commissioning of GTG and HRSG3**	**129 days**	**08/01/16...**	**15/05/16...**		**26 days**
163		Hydrostatic test, flush and cleaning	8 days	08/01/16 ...	15/01/16 ...	112	103 days
164		Function test	18 days	28/04/16 ...	15/05/16 ...	108;153;163	0 days
165		**Cold commissioning of GTG and HRSG4**	**129 days**	**08/01/16...**	**15/05/16...**		**27 days**
166		Hydrostatic test, flush and cleaning	8 days	08/01/16 ...	15/01/16 ...	113	103 days
167		Function test	18 days	28/04/16 ...	15/05/16 ...	109;153;166	0 days
168		**Cold commissioning of STG1**	**42 days**	**28/04/16...**	**08/06/16...**		**78 days**
169		Function test	42 days	28/04/16 ...	08/06/16 ...	114;132;153	0 days
170		**Cold commissioning of STG2**	**63 days**	**28/04/16...**	**29/06/16...**		**84 days**
171		Function test	63 days	28/04/16 ...	29/06/16 ...	115;132;153	58 days
172		**Overall mechanical completion of balance of pl...**	**1 day**	**09/06/16...**	**09/06/16...**		**78 days**
173		Overall mechanical completion of balance of plant	1 day	09/06/16 ...	09/06/16 ...	153;155;158;161;169	78 days
174		**Hot commissionoing work**	**234 days**	**05/05/16...**	**24/12/16...**		**0 days**
175		**Commissioning of GTG unit 1**	**108 days**	**05/05/16...**	**20/08/16...**		**0 days**
176		GTG1 first firing	2 days	05/05/16 ...	06/05/16 ...	119;148;158;145	0 days
177		Function test with DCS (No-load test)	3 days	07/05/16 ...	09/05/16 ...	176	0 days
178		GTG1 first synchronization	95 days	10/05/16 ...	12/08/16 ...	177	0 days
179		GTG1 on load test	8 days	13/08/16 ...	20/08/16 ...	178	0 days
180		**Commissioning of GTG unit 2**	**108 days**	**05/05/16...**	**20/08/16...**		**0 days**
181		GTG2 first firing	2 days	05/05/16 ...	06/05/16 ...	119;148;161;145	0 days
182		Function test with DCS (No-load test)	4 days	07/05/16 ...	10/05/16 ...	181	0 days
183		GTG2 first synchronization	94 days	11/05/16 ...	12/08/16 ...	182	0 days
184		GTG2 on load test	8 days	13/08/16 ...	20/08/16 ...	183	0 days
185		**Commissioning of GTG unit 3**	**97 days**	**16/05/16...**	**20/08/16...**		**26 days**
186		GTG3 first firing	2 days	16/05/16 ...	17/05/16 ...	119;148;164;145	0 days
187		Function test with DCS (No-load test)	2 days	18/05/16 ...	19/05/16 ...	186	0 days
188		GTG3 first synchronization	85 days	20/05/16 ...	12/08/16 ...	187	0 days
189		GTG3 on load test	8 days	13/08/16 ...	20/08/16 ...	188	0 days
190		**Commissioning of GTG unit 4**	**96 days**	**16/05/16...**	**19/08/16...**		**27 days**
191		GTG4 first firing	3 days	16/05/16 ...	18/05/16 ...	119;148;167;145	0 days
192		Function test with DCS (No-load test)	9 days	19/05/16 ...	27/05/16 ...	191	0 days
193		GTG4 first synchronization	79 days	28/05/16 ...	14/08/16 ...	192	0 days
194		GTG4 on load test	5 days	15/08/16 ...	19/08/16 ...	193	1 day
195		**Commissioning of STG1**	**41 days**	**21/08/16...**	**30/09/16...**		**0 days**
196		Main steam header blowout	6 days	21/08/16 ...	26/08/16 ...	179;184	0 days
197		STG1 first steam	33 days	27/08/16 ...	28/09/16 ...	169;173;196	0 days
198		Function test	1 day	29/09/16 ...	29/09/16 ...	197	0 days

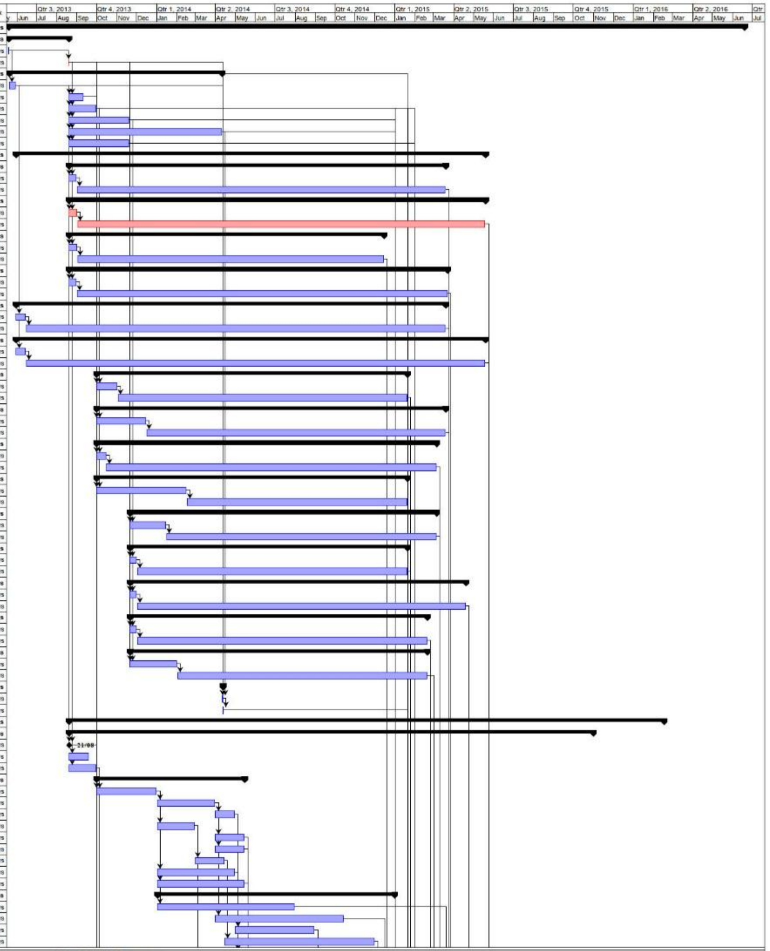


	Constraint...	Name	Duration	Start	Finish	Predecessors	Free Slack
199		STG1 first synchronization	1 day	30/09/16 ...	30/09/16 ...	198	0 days
200		**Commissioning of STG2**	**47 days**	**21/08/16...**	**06/10/16...**		**26 days**
201		Main steam header blowout	6 days	21/08/16 ...	26/08/16 ...	189;194	0 days
202		STG2 first steam	39 days	27/08/16 ...	04/10/16 ...	171;173;201	0 days
203		Function test	1 day	05/10/16 ...	05/10/16 ...	202	0 days
204		STG2 first synchronization	1 day	06/10/16 ...	06/10/16 ...	203	0 days
205		**Overall commissioning work of block1**	**85 days**	**01/10/16...**	**24/12/16...**		**0 days**
206		Combined cycle function test of block 1	79 days	01/10/16 ...	18/12/16 ...	199	0 days
207		Plant performance test of block 1	0 days	18/12/16 ...	18/12/16 ...	206	0 days
208		Plant trial run of block 1	6 days	19/12/16 ...	24/12/16 ...	207	0 days
209		**Overall commissioning work of block2**	**44 days**	**07/10/16...**	**19/11/16...**		**26 days**
210		Combined cycle function test of block 2	38 days	07/10/16 ...	13/11/16 ...	204	0 days
211		Plant performance test of block 2	0 days	13/11/16 ...	13/11/16 ...	210	0 days
212		Plant trial run of block 2	6 days	14/11/16 ...	19/11/16 ...	211	0 days
213		SCOD of block 1	5 days	25/12/16 ...	29/12/16 ...	208	0 days
214		SCOD of block 2	14 days	20/11/16 ...	03/12/16 ...	212	26 days

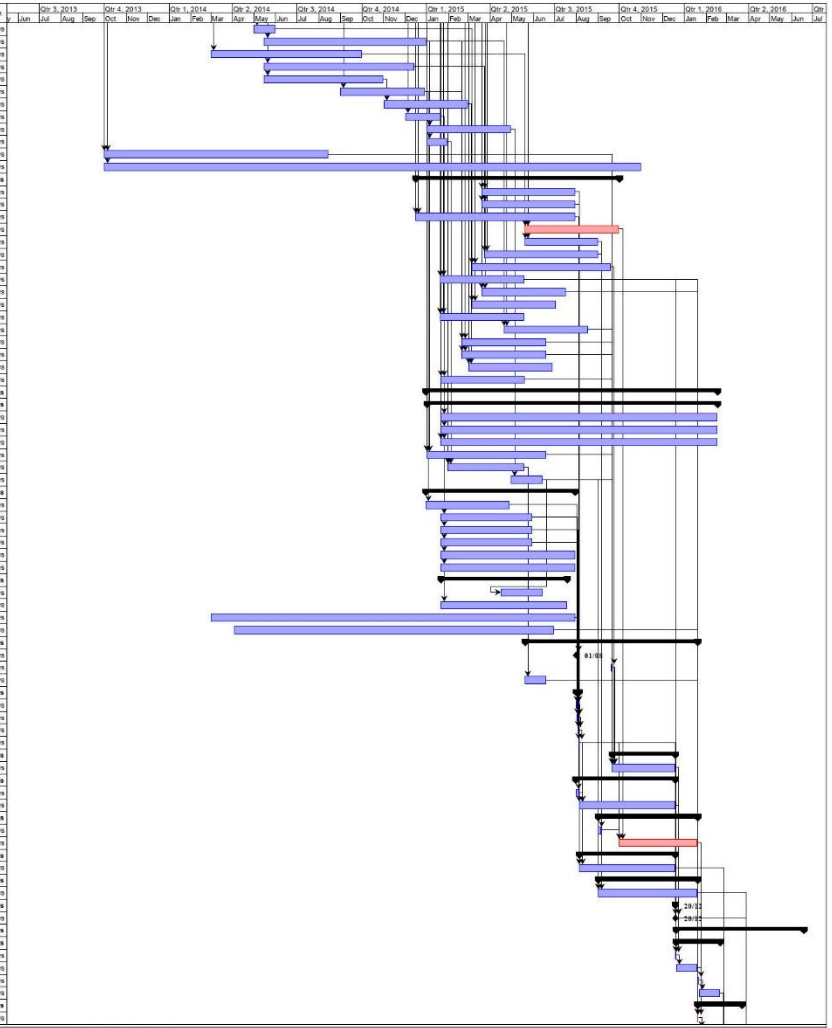


Appendix D Detailed results of construction schedules analysis of Project D

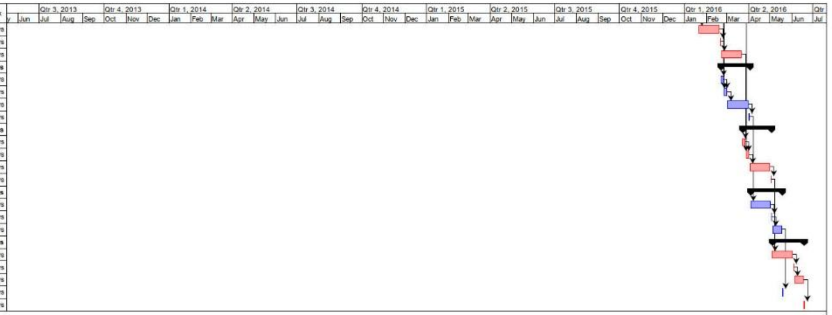
	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project D**	**1,128 days**	**19/05/13...**	**19/06/16...**		**0 days**
2		**Key milestone**	**93 days**	**19/05/13...**	**19/08/13...**		**0 days**
3		EPC Contract signing	1 day	19/05/13 ...	19/05/13 ...		0 days
4	19/08/13 ...	Notice to proceed	1 day	19/08/13 ...	19/08/13 ...	3	0 days
5		**Detailed Engineering work**	**327 days**	**20/05/13...**	**11/04/14...**		**283 days**
6		Conceptual design	11 days	20/05/13 ...	30/05/13 ...	3	0 days
7		Civil detialed engineering	23 days	20/08/13 ...	11/09/13 ...	4;6	19 days
8		Mechanical and process detailed engineering	42 days	20/08/13 ...	30/09/13 ...	4;6	0 days
9		Electrical detailed engineering	93 days	20/08/13 ...	20/11/13 ...	4;6	0 days
10		C&I detailed engineering	235 days	20/08/13 ...	11/04/14 ...	4;6	0 days
11		Balance of plant detailed engineering	93 days	20/08/13 ...	20/11/13 ...	4;6	0 days
12		**Procurement**	**719 days**	**31/05/13...**	**19/05/15...**		**397 days**
13		**GTG1**	**577 days**	**20/08/13...**	**19/03/15...**		**36 days**
14		Confirm order to GTG	12 days	20/08/13 ...	31/08/13 ...	6;4	0 days
15		Manufacturing and transportation	565 days	01/09/13 ...	19/03/15 ...	14	0 days
16		**GTG2**	**638 days**	**20/08/13...**	**19/05/15...**		**0 days**
17		Confirm order to GTG	13 days	20/08/13 ...	01/09/13 ...	6;4	0 days
18		Manufacturing and transportation	625 days	02/09/13 ...	19/05/15 ...	17	0 days
19		**HRSG1**	**483 days**	**20/08/13...**	**15/12/14...**		**31 days**
20		Confirm order to HRSG	13 days	20/08/13 ...	01/09/13 ...	6;4	0 days
21		Manufacturing and transportation	470 days	02/09/13 ...	15/12/14 ...	20	0 days
22		**HRSG2**	**580 days**	**20/08/13...**	**22/03/15...**		**25 days**
23		Confirm order to HRSG	12 days	20/08/13 ...	31/08/13 ...	6;4	0 days
24		Manufacturing and transportation	568 days	01/09/13 ...	22/03/15 ...	23	0 days
25		**Steam turbine 1**	**658 days**	**31/05/13...**	**19/03/15...**		**104 days**
26		Confirm order to STG	15 days	31/05/13 ...	14/06/13 ...	6	0 days
27		Manufacturing and transportation	643 days	15/06/13 ...	19/03/15 ...	26	0 days
28		**Steam turbine 2**	**719 days**	**31/05/13...**	**19/05/15...**		**68 days**
29		Confirm order to STG	15 days	31/05/13 ...	14/06/13 ...	6	0 days
30		Manufacturing and transportation	704 days	15/06/13 ...	19/05/15 ...	29	0 days
31		**Gas compressor**	**476 days**	**01/10/13...**	**19/01/15...**		**245 days**
32		Confirm order to gas compressor	32 days	01/10/13 ...	01/11/13 ...	4;6;8	0 days
33		Manufacturing and transportation	444 days	02/11/13 ...	19/01/15 ...	32	0 days
34		**Gas heater**	**535 days**	**01/10/13...**	**19/03/15...**		**186 days**
35		Confirm order to gas heater	76 days	01/10/13 ...	15/12/13 ...	8;6;4	0 days
36		Manufacturing and transportation	459 days	16/12/13 ...	19/03/15 ...	35	0 days
37		**Condenser**	**521 days**	**01/10/13...**	**05/03/15...**		**99 days**
38		Confirm order to cooling tower	15 days	01/10/13 ...	15/10/13 ...	4;8;6	0 days
39		Manufacturing and transportation	506 days	16/10/13 ...	05/03/15 ...	38	0 days
40		**Turbine control valve**	**476 days**	**01/10/13...**	**19/01/15...**		**517 days**
41		Confirm order to turbine control valve	139 days	01/10/13 ...	16/02/14 ...	4;6;8	0 days
42		Manufacturing and transportation	337 days	17/02/14 ...	19/01/15 ...	41	517 days
43		**Chiller**	**470 days**	**21/11/13...**	**05/03/15...**		**352 days**
44		Confirm order to chiller	56 days	21/11/13 ...	15/01/14 ...	4;8;11;6	0 days
45		Manufacturing and transportation	414 days	16/01/14 ...	05/03/15 ...	44	0 days
46		**Pump**	**425 days**	**21/11/13...**	**19/01/15...**		**397 days**
47		Confirm order to pumps	11 days	21/11/13 ...	01/12/13 ...	4;6;8;11	0 days
48		Manufacturing and transportation	414 days	02/12/13 ...	19/01/15 ...	47	0 days
49		**Emergency diesel generator**	**516 days**	**21/11/13...**	**19/04/15...**		**132 days**
50		Confirm order to energency diesel generator	11 days	21/11/13 ...	01/12/13 ...	4;8;9;11;6	0 days
51		Manufacturing and transportation	504 days	02/12/13 ...	19/04/15 ...	50	0 days
52		**Transformer**	**456 days**	**21/11/13...**	**19/02/15...**		**191 days**
53		Confirm order to transformers	11 days	21/11/13 ...	01/12/13 ...	4;9;11;6	0 days
54		Manufacturing and transportation	445 days	02/12/13 ...	19/02/15 ...	53	0 days
55		**Switchgear**	**456 days**	**21/11/13...**	**19/02/15...**		**191 days**
56		Confirm order to switchgear	73 days	21/11/13 ...	01/02/14 ...	4;6;9	0 days
57		Manufacturing and transportation	383 days	02/02/14 ...	19/02/15 ...	56	0 days
58		**DCS panel**	**2 days**	**12/04/14...**	**13/04/14...**		**503 days**
59		Confirm order to DCS	1 day	12/04/14 ...	12/04/14 ...	4;6;10	0 days
60		Manufacturing and transportation	1 day	13/04/14 ...	13/04/14 ...	59	282 days
61		**Construction work**	**911 days**	**20/08/13...**	**16/02/16...**		**124 days**
62		**Civil work**	**803 days**	**20/08/13...**	**31/10/15...**		**232 days**
63		Permit to start civil work	1 day	20/08/13 ...	20/08/13 ...	4;6	41 days
64		Site mobilization and site temporary office	30 days	20/08/13 ...	18/09/13 ...	4	1,005 days
65		Site preparation, clearing and levelling work	42 days	20/08/13 ...	30/09/13 ...	4	0 days
66		**Piling works**	**227 days**	**01/10/13...**	**15/05/14...**		**362 days**
67		GT1 and ST1 piling	93 days	01/10/13 ...	01/01/14 ...	7;63;65	0 days
68		HRSG1 piling	89 days	02/01/14 ...	31/03/14 ...	67	0 days
69		Substation 1 piling	30 days	01/04/14 ...	30/04/14 ...	68	0 days
70		GT2 and ST2 piling	58 days	02/01/14 ...	28/02/14 ...	67	0 days
71		HRSG2 piling	45 days	01/04/14 ...	15/05/14 ...	68	0 days
72		Substation 2 piling	45 days	01/04/14 ...	15/05/14 ...	68	0 days
73		Control building	45 days	01/03/14 ...	14/04/14 ...	70	0 days
74		Cooling water pipe	119 days	02/01/14 ...	30/04/14 ...	67	0 days
75		Balance of plant area	134 days	02/01/14 ...	15/05/14 ...	67	0 days
76		**Foundations**	**364 days**	**02/01/14...**	**31/12/14...**		**296 days**
77		GT1 and ST1 foundation	211 days	02/01/14 ...	31/07/14 ...	67	231 days
78		HRSG1 foundation	197 days	01/04/14 ...	14/10/14 ...	68	62 days
79		Substation 1 foundation	123 days	01/05/14 ...	31/08/14 ...	69	0 days
80		Control building foundation	230 days	15/04/14 ...	30/11/14 ...	73	0 days



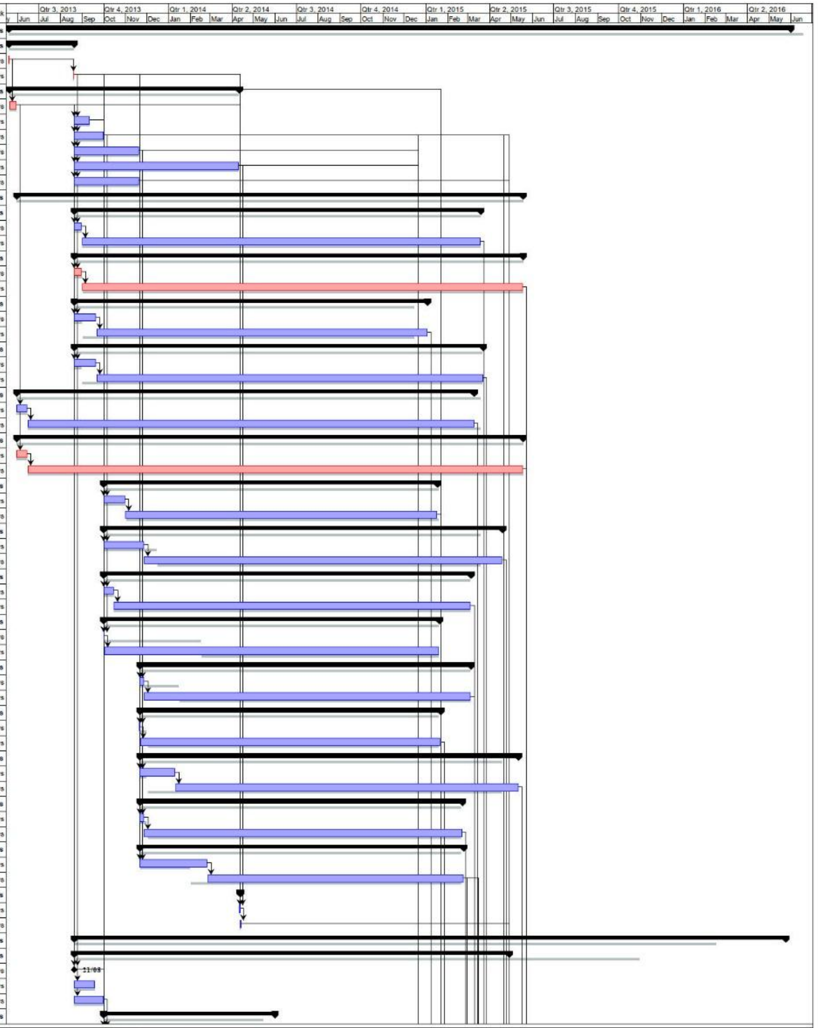
	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
81		Cooling water pipe foundation	31 days	01/05/14 ...	31/05/14 ...	74	278 days
82		Tank foundation and miscellaneous balance of plant	230 days	16/05/14 ...	31/12/14 ...	75	0 days
83		GT2 and ST2 foundation	214 days	01/03/14 ...	30/09/14 ...	70	231 days
84		HRSG2 foundation	213 days	16/05/14 ...	14/12/14 ...	71	98 days
85		Substation 2 foundation	169 days	16/05/14 ...	31/10/14 ...	72	0 days
86		Substation of block 1	120 days	01/09/14 ...	29/12/14 ...	79	0 days
87		Substation of block 2	120 days	01/11/14 ...	28/02/15 ...	85	0 days
88		Control building	51 days	01/12/14 ...	20/01/15 ...	80	0 days
89		Pipe rack and pipe bridge	120 days	01/01/15 ...	30/04/15 ...	82	0 days
90		Water treatment plant	30 days	01/01/15 ...	30/01/15 ...	82	0 days
91		Water/wastewater pond	318 days	01/10/13 ...	14/08/14 ...	7;65	401 days
92		Road and paving	761 days	01/10/13 ...	31/10/15 ...	65	232 days
93		**Main equipment erection work**	**289 days**	**16/12/14...**	**30/09/15...**		**263 days**
94		GTG1	133 days	20/03/15 ...	30/07/15 ...	15;77	5 days
95		ST1	133 days	20/03/15 ...	30/07/15 ...	27;77	5 days
96		HRSG1	227 days	16/12/14 ...	30/07/15 ...	21;78	0 days
97		GTG2	134 days	20/05/15 ...	30/09/15 ...	18;83	0 days
98		ST2	104 days	20/05/15 ...	31/08/15 ...	30;83	0 days
99		HRSG2	162 days	23/03/15 ...	31/08/15 ...	24;84	0 days
100		Cooling water pipe	197 days	06/03/15 ...	18/09/15 ...	39;81	0 days
101		Gas compressor	120 days	20/01/15 ...	19/05/15 ...	33;82	214 days
102		Gas heater	120 days	20/03/15 ...	17/07/15 ...	36;82	155 days
103		Chiller	120 days	06/03/15 ...	03/07/15 ...	45;82	352 days
104		Pumps	120 days	20/01/15 ...	19/05/15 ...	5;48;82	397 days
105		Emergency diesel generator	120 days	20/04/15 ...	17/08/15 ...	51;82	33 days
106		Transformer	120 days	20/02/15 ...	19/06/15 ...	54;82	92 days
107		Switchgear1	120 days	20/02/15 ...	19/06/15 ...	57;86	92 days
108		Switchgear 2	120 days	01/03/15 ...	28/06/15 ...	57;87	357 days
109		DCS panel	120 days	21/01/15 ...	20/05/15 ...	60;88	122 days
110		**Balance of plant erection work**	**414 days**	**30/12/14...**	**16/02/16...**		**124 days**
111		**Mechanical work**	**412 days**	**01/01/15...**	**16/02/16...**		**124 days**
112		Air conditioning and ventilation system	392 days	21/01/15 ...	16/02/16 ...	88	124 days
113		Plumbing and drainage	392 days	21/01/15 ...	16/02/16 ...	88	124 days
114		Firefighting	392 days	21/01/15 ...	16/02/16 ...	8;11;88	124 days
115		Compressed air system	170 days	01/01/15 ...	19/06/15 ...	8;9;10;11;82	92 days
116		Demineralization water system	109 days	31/01/15 ...	19/05/15 ...	8;11;90	0 days
117		Piping system	45 days	01/05/15 ...	14/06/15 ...	89	0 days
118		**Electrical work**	**213 days**	**30/12/14...**	**30/07/15...**		**0 days**
119		High voltage system installation	120 days	30/12/14 ...	28/04/15 ...	86	94 days
120		Medium voltage system installation	130 days	21/01/15 ...	30/05/15 ...	88	63 days
121		Low voltage system installation	130 days	21/01/15 ...	30/05/15 ...	88	64 days
122		DC and UPS system installation	130 days	21/01/15 ...	30/05/15 ...	88	65 days
123		Lighting for building	191 days	21/01/15 ...	30/07/15 ...	88	31 days
124		Cable tray and cabling	191 days	21/01/15 ...	30/07/15 ...	88	31 days
125		**Control and Instrument work**	**180 days**	**21/01/15...**	**19/07/15...**		**336 days**
126		Field instrument installation	60 days	16/04/15 ...	14/06/15 ...	117FS-60 days	371 days
127		Cable tray and cabling work	180 days	21/01/15 ...	19/07/15 ...	88	336 days
128	01/03/14 ...	Transmission line	517 days	01/03/14 ...	30/07/15 ...		0 days
129	03/04/14 ...	Gas available	454 days	03/04/14 ...	30/06/15 ...		172 days
130		**Cold commissioning**	**245 days**	**20/05/15...**	**19/01/16...**		**68 days**
131		Back energization	1 day	31/07/15 ...	31/07/15 ...	118;128	0 days
132		Cooling water available	1 day	19/09/15 ...	19/09/15 ...	100	0 days
133		Pre commissioning of demineralization water plant	31 days	20/05/15 ...	19/06/15 ...	116	183 days
134		**Cold commissioning of electrical system**	**4 days**	**01/08/15...**	**04/08/15...**		**31 days**
135		HV system	1 day	01/08/15 ...	01/08/15 ...	119;131	0 days
136		MV system	1 day	02/08/15 ...	02/08/15 ...	120;135	0 days
137		LV system	1 day	03/08/15 ...	03/08/15 ...	121;136	0 days
138		DC and UPS system	1 day	04/08/15 ...	04/08/15 ...	122;137	0 days
139		**Cold commissioning of mechanical system**	**91 days**	**20/09/15...**	**19/12/15...**		**99 days**
140		Cold commissioning of balance of plant equipment	91 days	20/09/15 ...	19/12/15 ...	91;100;105;106;107;109;115;117;132	0 days
141		**Cold commissioning of GTG and HRSG1**	**142 days**	**31/07/15...**	**19/12/15...**		**31 days**
142		Hydrostatic test, flush and cleaning	5 days	31/07/15 ...	04/08/15 ...	96	0 days
143		Function test	137 days	05/08/15 ...	19/12/15 ...	94;138;142	0 days
144		**Cold commissioning of GTG and HRSG2**	**141 days**	**01/09/15...**	**19/01/16...**		**0 days**
145		Hydrostatic test, flush and cleaning	5 days	01/09/15 ...	05/09/15 ...	99	25 days
146		Function test	111 days	01/10/15 ...	19/01/16 ...	97;138;145	0 days
147		**Cold commissioning of ST1**	**137 days**	**05/08/15...**	**19/12/15...**		**99 days**
148		Function test	137 days	05/08/15 ...	19/12/15 ...	117;138;95	0 days
149		**Cold commissioning of ST2**	**141 days**	**01/09/15...**	**19/01/16...**		**68 days**
150		Function test	141 days	01/09/15 ...	19/01/16 ...	117;138;98	68 days
151		**Overall mechanical completion of balance of plant**	**0 days**	**19/12/15...**	**19/12/15...**		**99 days**
152		Overall mechanical completion of balance of plant	0 days	19/12/15 ...	19/12/15 ...	138;140;143;148	68 days
153		**Hot commissionoing work**	**182 days**	**20/12/15...**	**18/06/16...**		**0 days**
154		**Commissioning of GTG1**	**63 days**	**20/12/15...**	**20/02/16...**		**31 days**
155		GTG1 first firing	1 day	20/12/15 ...	20/12/15 ...	101;102;133;143;129	0 days
156		Function test with DCS (No-load test)	30 days	21/12/15 ...	19/01/16 ...	155	0 days
157		GTG1 first synchronization	2 days	20/01/16 ...	21/01/16 ...	156	0 days
158		GTG1 on load test	30 days	22/01/16 ...	20/02/16 ...	157	0 days
159		**Commissioning of GTG2**	**63 days**	**20/01/16...**	**22/03/16...**		**0 days**
160		GTG2 first firing	1 day	20/01/16 ...	20/01/16 ...	101;102;133;146;129	0 days



	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
161		Function test with DCS (No-load test)	30 days	21/01/16 ...	19/02/16 ...	160	0 days
162		GTG2 first synchronization	2 days	20/02/16 ...	21/02/16 ...	161	0 days
163		GTG2 on load test	30 days	22/02/16 ...	22/03/16 ...	162	0 days
164		**Commissioning of STG1**	**42 days**	**21/02/16...**	**02/04/16...**		**31 days**
165		Main steam header blowout	5 days	21/02/16 ...	25/02/16 ...	158	0 days
166		STG first steam	5 days	26/02/16 ...	01/03/16 ...	148;152;165	0 days
167		Function test	30 days	02/03/16 ...	31/03/16 ...	166	0 days
168		STG first synchronization	2 days	01/04/16 ...	02/04/16 ...	167	0 days
169		**Commissioning of STG2**	**42 days**	**23/03/16...**	**03/05/16...**		**0 days**
170		Main steam header blowout	5 days	23/03/16 ...	27/03/16 ...	163	0 days
171		STG first steam	5 days	28/03/16 ...	01/04/16 ...	150;152;170	0 days
172		Function test	30 days	02/04/16 ...	01/05/16 ...	171	0 days
173		STG first synchronization	2 days	02/05/16 ...	03/05/16 ...	172	0 days
174		**Combined cycle commissioning work of train 1**	**46 days**	**03/04/16...**	**18/05/16...**		**31 days**
175		Combined cycle function test of train 1	30 days	03/04/16 ...	02/05/16 ...	168	0 days
176		Plant performance test of train 1	2 days	03/05/16 ...	04/05/16 ...	175	0 days
177		Plant trial run of train 1	14 days	05/05/16 ...	18/05/16 ...	176	0 days
178		**Combined cycle commissioning work of train 2**	**46 days**	**04/05/16...**	**18/06/16...**		**0 days**
179		Combined cycle function test of train 2	30 days	04/05/16 ...	02/06/16 ...	173	0 days
180		Plant performance test of train 2	2 days	03/06/16 ...	04/06/16 ...	179	0 days
181		Plant trial run of train 2	14 days	05/06/16 ...	18/06/16 ...	180	0 days
182		SCOD of block 1	1 day	19/05/16 ...	19/05/16 ...	177	31 days
183		SCOD of block 2	1 day	19/06/16 ...	19/06/16 ...	181	0 days

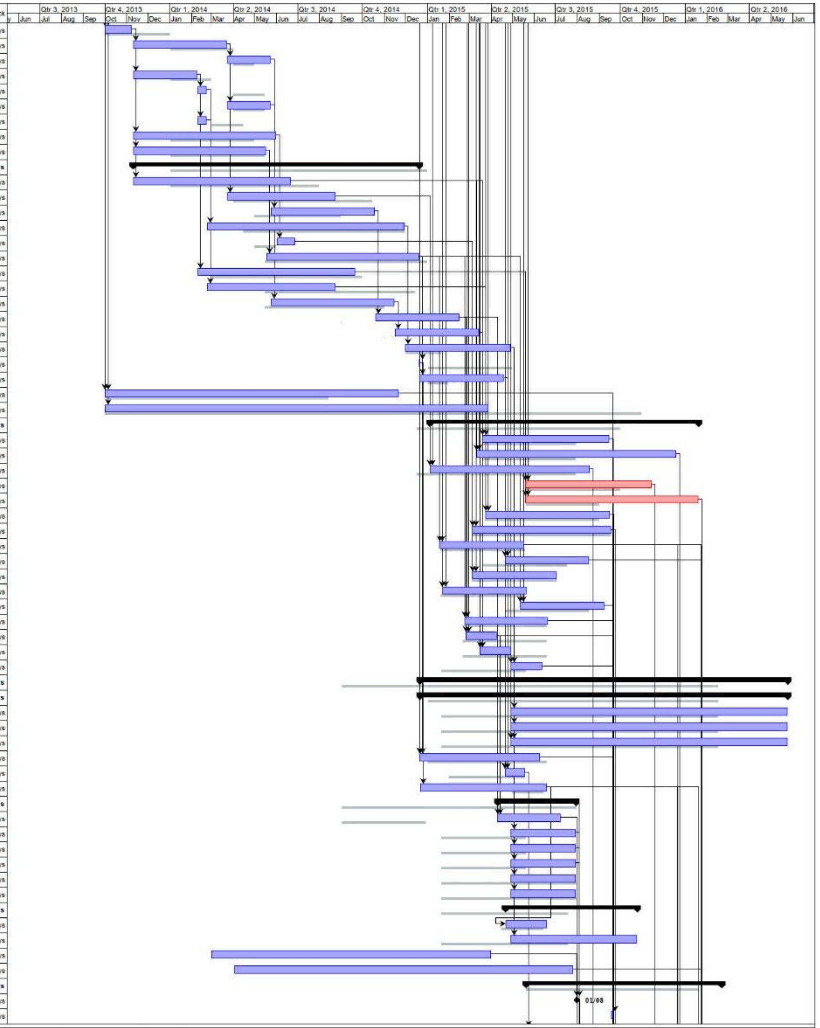


	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
1		**Proejct schedule for Project D**	**1,110 days**	**19/05/13...**	**01/06/16...**		**0 days**
2		**Key milestone**	**93 days**	**19/05/13...**	**19/08/13...**		**0 days**
3		EPC Contract signing	1 day	19/05/13 ...	19/05/13 ...		0 days
4	19/08/13 ...	Notice to proceed	1 day	19/08/13 ...	19/08/13 ...	3	0 days
5		**Detailed Engineering work**	**327 days**	**20/05/13...**	**11/04/14...**		**285 days**
6		Conceptual design	11 days	20/05/13 ...	30/05/13 ...	3	0 days
7		Civil detialed engineering	23 days	20/08/13 ...	11/09/13 ...	4;6	19 days
8		Mechanical and process detailed engineering	42 days	20/08/13 ...	30/09/13 ...	4;6	0 days
9		Electrical detailed engineering	93 days	20/08/13 ...	20/11/13 ...	4;6	0 days
10		C&I detailed engineering	235 days	20/08/13 ...	11/04/14 ...	4;6	0 days
11		Balance of plant detailed engineering	93 days	20/08/13 ...	20/11/13 ...	4;6	0 days
12		**Procurement**	**718 days**	**31/05/13...**	**18/05/15...**		**380 days**
13		**GTG1**	**577 days**	**20/08/13...**	**19/03/15...**		**10 days**
14		Confirm order to GTG	12 days	20/08/13 ...	31/08/13 ...	6;4	0 days
15		Manufacturing and transportation	565 days	01/09/13 ...	19/03/15 ...	14	0 days
16		**GTG2**	**637 days**	**20/08/13...**	**18/05/15...**		**0 days**
17		Confirm order to GTG	12 days	20/08/13 ...	31/08/13 ...	6;4	0 days
18		Manufacturing and transportation	625 days	01/09/13 ...	18/05/15 ...	17	0 days
19		**HRSG1**	**502 days**	**20/08/13...**	**03/01/15...**		**17 days**
20		Confirm order to HRSG	32 days	20/08/13 ...	20/09/13 ...	6;4	0 days
21		Manufacturing and transportation	470 days	21/09/13 ...	03/01/15 ...	20	0 days
22		**HRSG2**	**581 days**	**20/08/13...**	**23/03/15...**		**38 days**
23		Confirm order to HRSG	32 days	20/08/13 ...	20/09/13 ...	6;4	0 days
24		Manufacturing and transportation	549 days	21/09/13 ...	23/03/15 ...	23	0 days
25		**Steam turbine 1**	**649 days**	**31/05/13...**	**10/03/15...**		**10 days**
26		Confirm order to ST1	15 days	31/05/13 ...	14/06/13 ...	6	0 days
27		Manufacturing and transportation	634 days	15/06/13 ...	10/03/15 ...	26	0 days
28		**Steam turbine 2**	**718 days**	**31/05/13...**	**18/05/15...**		**0 days**
29		Confirm order to ST2	15 days	31/05/13 ...	14/06/13 ...	6	0 days
30		Manufacturing and transportation	703 days	15/06/13 ...	18/05/15 ...	29	0 days
31		**Gas compressor**	**474 days**	**01/10/13...**	**17/01/15...**		**227 days**
32		Confirm order to gas compressor	31 days	01/10/13 ...	31/10/13 ...	4;6;8	0 days
33		Manufacturing and transportation	443 days	01/11/13 ...	17/01/15 ...	32	0 days
34		**Gas heater**	**566 days**	**01/10/13...**	**19/04/15...**		**135 days**
35		Confirm order to gas heater	58 days	01/10/13 ...	27/11/13 ...	8;6;4	0 days
36		Manufacturing and transportation	508 days	28/11/13 ...	19/04/15 ...	35	0 days
37		**Condenser**	**521 days**	**01/10/13...**	**05/03/15...**		**42 days**
38		Confirm order to cooling tower	15 days	01/10/13 ...	15/10/13 ...	4;8;6	0 days
39		Manufacturing and transportation	506 days	16/10/13 ...	05/03/15 ...	38	0 days
40		**Turbine control valve**	**476 days**	**01/10/13...**	**19/01/15...**		**499 days**
41		Confirm order to turbine control valve	1 day	01/10/13 ...	01/10/13 ...	4;6;8	0 days
42		Manufacturing and transportation	475 days	02/10/13 ...	19/01/15 ...	41	499 days
43		**Chiller**	**470 days**	**21/11/13...**	**05/03/15...**		**334 days**
44		Confirm order to chiller	7 days	21/11/13 ...	27/11/13 ...	4;8;11;6	0 days
45		Manufacturing and transportation	463 days	28/11/13 ...	05/03/15 ...	44	0 days
46		**Pump**	**427 days**	**21/11/13...**	**21/01/15...**		**377 days**
47		Confirm order to pumps	1 day	21/11/13 ...	21/11/13 ...	4;6;8;11	0 days
48		Manufacturing and transportation	426 days	22/11/13 ...	21/01/15 ...	47	0 days
49		**Emergency diesel generator**	**537 days**	**21/11/13...**	**11/05/15...**		**52 days**
50		Confirm order to energency diesel generator	51 days	21/11/13 ...	10/01/14 ...	4;8;9;11;6	0 days
51		Manufacturing and transportation	486 days	11/01/14 ...	11/05/15 ...	50	0 days
52		**Transformer**	**458 days**	**21/11/13...**	**21/02/15...**		**131 days**
53		Confirm order to transformers	7 days	21/11/13 ...	27/11/13 ...	4;9;11;6	0 days
54		Manufacturing and transportation	451 days	28/11/13 ...	21/02/15 ...	53	0 days
55		**Switchgear**	**460 days**	**21/11/13...**	**23/02/15...**		**74 days**
56		Confirm order to switchgear	97 days	21/11/13 ...	25/02/14 ...	4;6;9	0 days
57		Manufacturing and transportation	363 days	26/02/14 ...	23/02/15 ...	56	0 days
58		**DCS panel**	**2 days**	**12/04/14...**	**13/04/14...**		**520 days**
59		Confirm order to DCS	1 day	12/04/14 ...	12/04/14 ...	4;6;10	0 days
60		Manufacturing and transportation	1 day	13/04/14 ...	13/04/14 ...	59	380 days
61		**Construction work**	**1,009 days**	**20/08/13...**	**24/05/16...**		**8 days**
62		**Civil work**	**617 days**	**20/08/13...**	**28/04/15...**		**400 days**
63		Permit to start civil work	1 day	20/08/13 ...	20/08/13 ...	4;6	41 days
64		Site mobilization and site temporary office	30 days	20/08/13 ...	18/09/13 ...	4	987 days
65		Site preparation, clearing and levelling work	42 days	20/08/13 ...	30/09/13 ...	4	0 days
66		**Piling works**	**243 days**	**01/10/13...**	**31/05/14...**		**392 days**



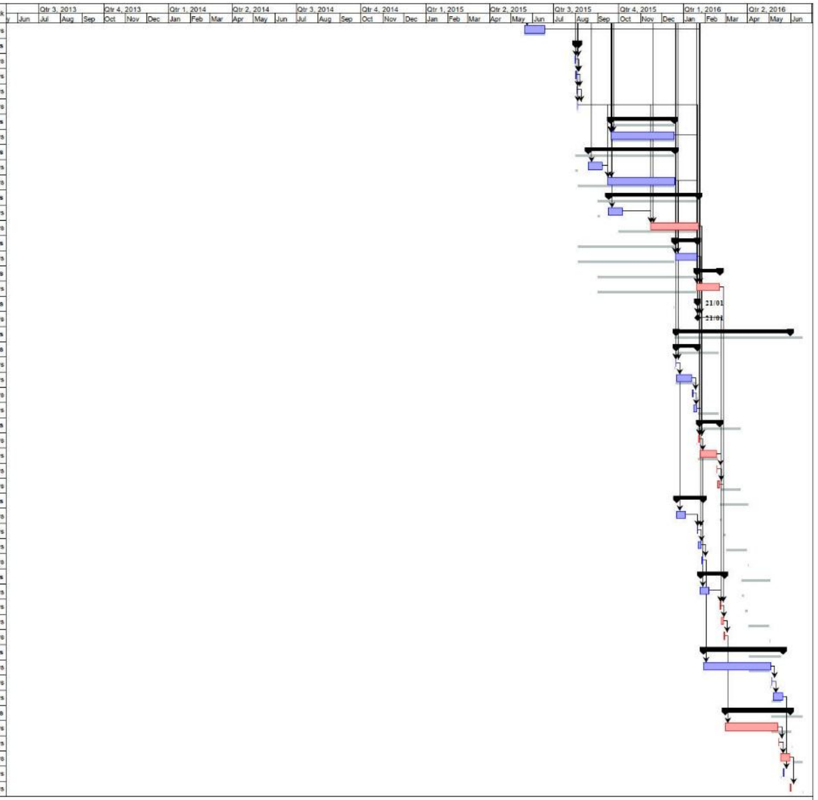
Project D Schedule (Actual) - page1

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
67		GT1 and ST1 piling	40 days	01/10/13 ...	09/11/13 ...	7;63;65	0 days
68		HRSG1 piling	133 days	10/11/13 ...	22/03/14 ...	67	0 days
69		Substation 1 piling	63 days	23/03/14 ...	24/05/14 ...	68	0 days
70		GT2 and ST2 piling	91 days	10/11/13 ...	08/02/14 ...	67	0 days
71		HRSG2 piling	14 days	09/02/14 ...	22/02/14 ...	70	0 days
72		Substation 2 piling	63 days	23/03/14 ...	24/05/14 ...	68	0 days
73		Control building	14 days	09/02/14 ...	22/02/14 ...	70	0 days
74		Cooling water pipe	203 days	10/11/13 ...	31/05/14 ...	67	0 days
75		Balance of plant area	189 days	10/11/13 ...	17/05/14 ...	67	0 days
76		**Foundations**	**406 days**	**10/11/13...**	**20/12/14...**		**364 days**
77		GTG1 and ST1 foundation	224 days	10/11/13 ...	21/06/14 ...	67	262 days
78		HRSG1 foundation	154 days	23/03/14 ...	23/08/14 ...	68	133 days
79		Substation 1 foundation	147 days	25/05/14 ...	18/10/14 ...	69	0 days
80		Control building foundation	280 days	23/02/14 ...	29/11/14 ...	73	0 days
81		Cooling water pipe foundation	27 days	01/06/14 ...	27/06/14 ...	74	251 days
82		Tank foundation and miscellaneous balance of plant	217 days	18/05/14 ...	20/12/14 ...	75	0 days
83		GTG2 and ST2 foundation	224 days	09/02/14 ...	20/09/14 ...	70	240 days
84		HRSG2 foundation	182 days	23/02/14 ...	23/08/14 ...	71	212 days
85		Substation 2 foundation	175 days	25/05/14 ...	15/11/14 ...	72	0 days
86		Substation of block 1	120 days	19/10/14 ...	15/02/15 ...	79	8 days
87		Substation of block 2	120 days	16/11/14 ...	15/03/15 ...	85	0 days
88		Control building	150 days	30/11/14 ...	28/04/15 ...	80	0 days
89		Pipe rack and pipe bridge	1 day	21/12/14 ...	21/12/14 ...	82	0 days
90		Water treatment plant	120 days	21/12/14 ...	19/04/15 ...	82	0 days
91		Water/wastewater pond	417 days	01/10/13 ...	21/11/14 ...	7;65	301 days
92		Road and paving	545 days	01/10/13 ...	29/03/15 ...	65	430 days
93		**Main equipment erection work**	**381 days**	**04/01/15...**	**19/01/16...**		**134 days**
94		GTG1	180 days	20/03/15 ...	15/09/15 ...	15;77	0 days
95		ST1	284 days	11/03/15 ...	19/12/15 ...	27;77	0 days
96		HRSG1	227 days	04/01/15 ...	18/08/15 ...	21;78	0 days
97		GTG2	180 days	19/05/15 ...	14/11/15 ...	18;83	0 days
98		ST2	246 days	19/05/15 ...	19/01/16 ...	30;83	0 days
99		HRSG2	177 days	24/03/15 ...	16/09/15 ...	24;84	0 days
100		Cooling water pipe	197 days	06/03/15 ...	18/09/15 ...	39;81	0 days
101		Gas compressor	120 days	18/01/15 ...	17/05/15 ...	33;82	217 days
102		Gas heater	120 days	20/04/15 ...	17/08/15 ...	36;82	125 days
103		Chiller	120 days	06/03/15 ...	03/07/15 ...	45;82	334 days
104		Pumps	120 days	22/01/15 ...	21/05/15 ...	5;48;82	377 days
105		Emergency diesel generator	120 days	12/05/15 ...	08/09/15 ...	51;82	10 days
106		Transformer	120 days	22/02/15 ...	21/06/15 ...	54;82	89 days
107		Switchgear1	45 days	24/02/15 ...	09/04/15 ...	57;86	0 days
108		Switchgear 2	45 days	16/03/15 ...	29/04/15 ...	57;87	399 days
109		DCS panel	45 days	29/04/15 ...	12/06/15 ...	60;88	98 days
110		**Balance of plant erection work**	**521 days**	**21/12/14...**	**24/05/16...**		**8 days**
111		**Mechanical work**	**521 days**	**21/12/14...**	**24/05/16...**		**8 days**
112		Air conditioning and ventilation system	392 days	29/04/15 ...	24/05/16 ...	88	8 days
113		Plumbing and drainage	392 days	29/04/15 ...	24/05/16 ...	88	8 days
114		Firefighting	392 days	29/04/15 ...	24/05/16 ...	8;11;88	8 days
115		Compressed air system	170 days	21/12/14 ...	08/06/15 ...	8;9;10;11;82	102 days
116		Demineralization water system	30 days	20/04/15 ...	19/05/15 ...	8;11;90	0 days
117		Piping system	180 days	22/12/14 ...	19/06/15 ...	89	0 days
118		**Electrical work**	**112 days**	**10/04/15...**	**30/07/15...**		**0 days**
119		High voltage system installation	90 days	10/04/15 ...	08/07/15 ...	86;107	23 days
120		Medium voltage system installation	93 days	29/04/15 ...	30/07/15 ...	88	2 days
121		Low voltage system installation	93 days	29/04/15 ...	30/07/15 ...	88	3 days
122		DC and UPS system installation	93 days	29/04/15 ...	30/07/15 ...	88	4 days
123		Lighting for building	93 days	29/04/15 ...	30/07/15 ...	88	52 days
124		Cable tray and cabling	93 days	29/04/15 ...	30/07/15 ...	88	52 days
125		**Control and Instrument work**	**188 days**	**21/04/15...**	**25/10/15...**		**220 days**
126		Field instrument installation	60 days	21/04/15 ...	19/06/15 ...	117FS-60 days	348 days
127		Cable tray and cabling work	180 days	29/04/15 ...	25/10/15 ...	88	220 days
128	01/03/14 ...	Transmission line	396 days	01/03/14 ...	31/03/15 ...		121 days
129	03/04/14 ...	Gas available	480 days	03/04/14 ...	26/07/15 ...		147 days
130		**Cold commissioning**	**278 days**	**20/05/15...**	**21/02/16...**		**101 days**
131		Back energization	1 day	31/07/15 ...	31/07/15 ...	118;128	0 days
132		Cooling water available	1 day	19/09/15 ...	19/09/15 ...	100	256 days



Project D Schedule (Actual) - page2

	Constraint ...	Name	Duration	Start	Finish	Predecessors	Free Slack
133		Pre commissioning of demineralization water plant	31 days	20/05/15 ...	19/06/15 ...	116	184 days
134		**Cold commissioning of electrical system**	**4 days**	**01/08/15...**	**04/08/15...**		**52 days**
135		HV system	1 day	01/08/15 ...	01/08/15 ...	119;131	0 days
136		MV system	1 day	02/08/15 ...	02/08/15 ...	120;135	0 days
137		LV system	1 day	03/08/15 ...	03/08/15 ...	121;136	0 days
138		DC and UPS system	1 day	04/08/15 ...	04/08/15 ...	122;137	42 days
139		**Cold commissioning of mechanical system**	**92 days**	**19/09/15...**	**19/12/15...**		**42 days**
140		Cold commissioning of balance of plant equipment	92 days	19/09/15 ...	19/12/15 ...	91;100;105;106;107;109;115;117	32 days
141		**Cold commissioning of GTG and HRSG1**	**124 days**	**19/08/15...**	**20/12/15...**		**10 days**
142		Hydrostatic test, flush and cleaning	21 days	19/08/15 ...	08/09/15 ...	96	7 days
143		Function test	96 days	16/09/15 ...	20/12/15 ...	94;138;142	0 days
144		**Cold commissioning of GTG and HRSG2**	**128 days**	**17/09/15...**	**22/01/16...**		**0 days**
145		Hydrostatic test, flush and cleaning	21 days	17/09/15 ...	07/10/15 ...	99	38 days
146		Function test	69 days	15/11/15 ...	22/01/16 ...	97;138;145	0 days
147		**Cold commissioning of ST1**	**32 days**	**20/12/15...**	**20/01/16...**		**10 days**
148		Function test	32 days	20/12/15 ...	20/01/16 ...	117;138;95	0 days
149		**Cold commissioning of ST2**	**33 days**	**20/01/16...**	**21/02/16...**		**0 days**
150		Function test	33 days	20/01/16 ...	21/02/16 ...	117;138;98	0 days
151		**Overall mechanical completion of balance of plant**	**0 days**	**20/01/16...**	**20/01/16...**		**10 days**
152		Overall mechanical completion of balance of plant	0 days	20/01/16 ...	20/01/16 ...	138;140;143;148	0 days
153		**Hot commissionoing work**	**163 days**	**21/12/15...**	**31/05/16...**		**0 days**
154		**Commissioning of GTG1**	**31 days**	**21/12/15...**	**20/01/16...**		**10 days**
155		GTG1 first firing	1 day	21/12/15 ...	21/12/15 ...	101;102;133;143;129	0 days
156		Function test with DCS (No-load test)	23 days	22/12/15 ...	13/01/16 ...	155	0 days
157		GTG1 first synchronization	1 day	14/01/16 ...	14/01/16 ...	156	0 days
158		GTG1 on load test	6 days	15/01/16 ...	20/01/16 ...	157	0 days
159		**Commissioning of GTG2**	**30 days**	**23/01/16...**	**21/02/16...**		**0 days**
160		GTG2 first firing	1 day	23/01/16 ...	23/01/16 ...	101;102;133;146;129	0 days
161		Function test with DCS (No-load test)	25 days	24/01/16 ...	17/02/16 ...	160	0 days
162		GTG2 first synchronization	1 day	18/02/16 ...	18/02/16 ...	161	0 days
163		GTG2 on load test	3 days	19/02/16 ...	21/02/16 ...	162	0 days
164		**Commissioning of ST1**	**38 days**	**22/12/15...**	**28/01/16...**		**10 days**
165		Main steam header blowout	14 days	22/12/15 ...	04/01/16 ...	155	16 days
166		ST1 first steam	1 day	21/01/16 ...	21/01/16 ...	148;152;158;165	0 days
167		Function test	6 days	22/01/16 ...	27/01/16 ...	166	0 days
168		ST1 first synchronization	1 day	28/01/16 ...	28/01/16 ...	167	0 days
169		**Commissioning of ST2**	**36 days**	**24/01/16...**	**28/02/16...**		**0 days**
170		Main steam header blowout	14 days	24/01/16 ...	06/02/16 ...	160	15 days
171		ST2 first steam	1 day	22/02/16 ...	22/02/16 ...	150;152;163;170	0 days
172		Function test	5 days	23/02/16 ...	27/02/16 ...	171	0 days
173		ST2 first synchronization	1 day	28/02/16 ...	28/02/16 ...	172	0 days
174		**Combined cycle commissioning work of train 1**	**114 days**	**29/01/16...**	**21/05/16...**		**10 days**
175		Combined cycle function test of train 1	97 days	29/01/16 ...	04/05/16 ...	168	0 days
176		Plant performance test of train 1	2 days	05/05/16 ...	06/05/16 ...	175	0 days
177		Plant trial run of train 1	15 days	07/05/16 ...	21/05/16 ...	176	0 days
178		**Combined cycle commissioning work of train 2**	**93 days**	**29/02/16...**	**31/05/16...**		**0 days**
179		Combined cycle function test of train 2	76 days	29/02/16 ...	14/05/16 ...	173	0 days
180		Plant performance test of train 2	2 days	15/05/16 ...	16/05/16 ...	179	0 days
181		Plant trial run of train 2	15 days	17/05/16 ...	31/05/16 ...	180	0 days
182		SCOD of block 1	1 day	22/05/16 ...	22/05/16 ...	177	10 days
183		SCOD of block 2	1 day	01/06/16 ...	01/06/16 ...	181	0 days



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