# REFERENCES


1. R.K. Gupta , Z.A. Alaywan , R.B. Stuart , T.A. Reece. " STEADY STATE VOLTAGE INSTABILITY OPERATIONS PERSPECTIVE. " IEEE Trans. Vol.5 No 4; NOV 1990 : 1345-1354.
2. P. Kundur , M. Klein , G.J. Rogers , M.S. Zywno. " APPLICATION OF POWER SYSTEM STABILIZERS FOR ENHANCEMENT OF OVERALL SYSTEM STABILITY. " IEEE Trans. Vol.4 No 2; MAY 1989 : 614-626.
3. E. Lerch, L. Xu. " ADVANCED SVC CONTROL FOR DAMPING POWER SYSTEM OSCILLATIONS." IEEE Trans. Vol.6 No 2; MAY 1991 : 524-535.
4. R.I. Piwko , E.V. Larsen. " SUBSYNCHRONOUS TORSIONAL INTERACTIONS WITH STATIC VAR COMPENSATOR. " IEEE Trans. Vol.5 No 4; NOV 1990: 1324-1332.
5. Yuan-Yih Hsu, Chuan-Sheng Liu , C.J. Lin,C.T. Huang. " APPLICATION OF POWER SYSTEM STABILIZERS AND STATIC VAR COMPENSATORS ON A LONGITUDINAL POWER SYSTEM. " IEEE Trans. Vol.3 No 4; NOV 1988 : 1464-1470.
6. S.S. Choi , J.R. Stewart , B. Singh , P.F. Carington ,E.H. Goddard , C.E. Carter. " PERFORMANCE TESTING OF A LONG DISTANCE RADIAL STATIC VAR COMPENSATED TRANSMISSION SYSTEM AND VALIDATION OF SIMULATION RESULTS. " IEEE Trans. Vol.3 No 4; NOV 1988:1509-1517.
7. J.R. Smith , D.A. Pierre , I. Sadighi , M.H. Nehrir. " A SUPPLEMENTARY ADAPTIVE VAR UNIT CONTROLLER FOR POWER SYSTEM DAMPING. " IEEE Trans. Vol.4 No 3; AUG 1989:1017-1023.
8. A.E. Hammad. " ANALYSIS OF POWER SYSTEM STABILITY ENHANCEMENT BY STATIC VAR COMPENSATORS. " IEEE Trans. Vol. PWRS-1 No 4; NOV 1986 : 222-227.
9. O.O. Obadina,G.J. Berg. " VAR PLANNING FOR POWER SYSTEM SECURITY." IEEE Trans. Vol. 4 No 2; MAY 1989 : 677-684.

10. Nelson Martins , T.G. Lima. " DETERMINATION OF SUITABLE LOCATIONS FOR POWER SYSTEM STABILIZERS AND STATIC VAR COMPENSATORS FOR DAMPING ELECTROMECHANICAL OSCILLATIONS IN LARGE SCALE POWER SYSTEMS. " IEEE Trans. Vol. 5 No 4; NOV 1990 : 1455-1469.

11. A.E. Hammad , M.Z. El-Sadek. " PREVENTION OF TRANSIENT VOLTAGE INSTABILITIES DUE TO INDUCTION MOTOR LOADS BY STATIC VAR COMPENSATORS. " IEEE Trans. Vol. 4 No 3; AUG 1989 : 1182-1190.

12. Abdel-Aty Edris. " CONTROLLABLE VAR COMPENSATOR : A POTENTIAL SOLUTION TO LOADABILITY PROBLEM OF LOW CAPACITY POWER SYSTEMS. " IEEE Trans. Vol. PWRS-2 No 3; AUG 1987 : 561-567.

13. Abdel-Aty Edris. " ENHANCEMENT OF FIRST-SWING STABILITY USING A HIGH SPEED PHASE SHIFTER. " IEEE Trans. Vol. 6 No 3; AUG 1991 : 1113-1118.

14. Howard A. Smalleck. " MODELLING AND ANALYSIS OF THE INDUCTION MACHINE : A COMPUTATIONAL/EXPERIMENTAL APPROACH. " IEEE Trans. Vol. 5 No 2; MAY 1990 : 482-485.

15. R. Billinton, K. Chu. " TRANSIENT STABILITY EVALUATION IN AN UNDERGRADUATE CURRICULUM - A PROBABILISTIC APPROACH. " IEEE Trans Vol. PWRS-1 No 4 ; NOV 1986 : 171-178.

16. Marc Langevin , Phillippe Auriol. " LOAD RESPONSE TO VOLTAGE VARIATIONS AND DYNAMIC STABILITY. " IEEE Trans. Vol. PWRS-1 No 4 NOV 1986 : 112-118.

17. R.B.I. Johnson , M.J. Short , B.J. Cory. " IMPROVED SIMULATION TECHNIQUES FOR POWER SYSTEM DYNAMICS. " IEEE Trans. Vol. 3 No 4 ; NOV 1988 : 1691-1698.

18. A.H.M.A. Rahim , A.R. Laldin. " AGGREGATION OF INDUCTION MOTOR LOADS FOR TRANSIENT STABILITY STUDIES. " IEEE Trans. Vol. EC-2 No 1 ; MARCH 1987 : 55-61.

19. F. Iliceto , A. Ceyhan , G. Ruckstuhl. " BEHAVIOR OF LOADS DURING VOLTAGE DIPS ENCOUNTERED IN STABILITY STUDIES. " IEEE Trans. Vol. PAS-91 ; 1972 : 2470-2479.

20. F. Nozari , M.D. Kankam , W.W. Price. " AGGREGATION OF INDUCTION MOTORS FOR TRANSIENT STABILITY LOAD MODELLING. " IEEE Trans. Vol. PWRS-2 ; 1987 : 1096-1103.

21. Selden B. Crary. " POWER SYSTEM STABILITY. " John WILEY & SONS, INC. , NEW YORK. 1955.

22. Irving L. Kosow. " CONTROL OF ELECTRIC MACHINES. " PRENTICE-HALL, INC., NEW JERSEY,1978.

23. Robert W. Smeaton. " MOTOR APPLICATION AND MAINTENANCE HANDBOOK. " McGRAW-HILL , NEW YORK , 1969.

24. K.B. Raina , K.C. Singal , Y.K. Anand. " TRANSMISSION AND DISTRIBUTION OF ELECTRICAL POWER. " McGRAW-HILL, NEW DELHI, 1985.

25. Jonh C. Andreas. " ENERGY-EFFICIENT ELECTRIC MOTORS. " MARCEL DEKKER, INC., NEW YORK, 1982.

26. Walter N. Alerich. " ELECTRIC MOTOR CONTROL. " VAN NOSTRAND REINHOLD COMPANY, NEW YORK, 1979.

27. B.M. Weedy. " ELECTRIC POWER SYSTEM. " John WILEY & SONS, INC., NEW YORK, 1972

28. Lars Lindkvist. " SIMPOW USER'S MANUAL VOLUME I. " ABB POWER SYSTEM, I989.

29. Lars Lindkvist. " SIMPOW USER'S MANUAL VOLUME II. " ABB POWER SYSTEM, I989.

30. Paul C. Krause. " ANALYSIS OF ELECTRIC MACHINERY. " McGRAW-HILL , NEW YORK , 1989.

# APPENDIX A

# COMPUTOR SIMULATION TOOLS

## 1 Introduction

This chapter describes the fundamentals of SIMPOW SOFTWARE PACKAGE and the VAX 2000 computer system

## 2 The VAX 2000 Computer System

The VAX 2000 computer system contains the following main parts

- VAX-station 2000 system unit with CPU including 6 Mb of main memory and 160 Mb of diskmemory.
- Extension box cabinet including TK 50 tape cartridge unit.
- Console Keyboard, Graphic Monitor and Mouse.
- Laser printer.

## 3 SIMPOW SOFTWARE PACKAGE

SIMPOW is an acronym for "simulation of power system". The development of the package was initiated in 1977.

The computer program package SIMPOW is a tool for power system analysis. It is designed for calculations of loadflow distributions, transient stabilities condition, eigenvalues and short circuit analysis.

The SIMPOW program package consists of:

- OPTPOW for load flow calculations
- STAPOW for short cricuit calculations
- DYNPOW for dynamic calculations
- DYNPOST for post-processing the output from the DYNPOW program
- DSL dynamic simulation language for modelling of special functions

3.1 Program System Structure

The basic program functions are the optimal power flow and the transient stability calculations i.e. program subsystem OPTPOW and DYNPOW, respectively.

The transmission system configuration and the data of the transmission system elements, given by their positive sequence parameters, the static PQ models of the production sources and load are given as input data to OPTPOW. As the result of the calculation, the steady-state situation defined by the complex node voltages.

OPTPOW is structured into three basic modules:the preprocessor that reads the input data, writes it in an edited form, converts it to per unit quantities, performs checks, arranges the nodes in an optimal order etc., the calculation module that solves the system of the equations, and the postprocessor that lists the results.

For a transient stability calculation OPTPOW is employed to calculate the initial steady-state conditions, which together with the transmission system configuration and data are transferred to the DYNPOW subsystem. Supplementary input data to DYNPOW such as the data of the dynamic models of generators, regulators, and SVC systems etc., faults and protective systems are given by the user. The state variables as functions of time are obtained as results of the calculation. DYNPOW is also structured into three basic program modules: the preprocessor, the calculation module and the postprocessor During the calculation, most state variables are stored on a file at each integration time step. The output variables are specified as input data for the postprocessor, which performs the listing and plotting. The postprocessor can be executed as a separate activity and retrieve data from the same batch of state variables determined at one calculation, thus allowing the analysis to be performed in steps, without rerunning the calculation module, which is the most costly part. A transient stability calculation can be restarted and continued i.e. it can be performed in steps. On a restart, new events, e.g. faults can be defined, This feature allows econcmic use of the processor time.

No limits on the number of the different types of system elements, transmission lines, transformers, generators etc., are built into the program. The maximum size of the power system that can be simulated is merely determined by the capacity of the computer system employed for the calculations and a reasonable calculation times.

## 3.2 Properties Of The Numerical Technique

The system of algebraic and differential equations defined by the static and dynamic models of the power system components and their interconnections in the transient stability problem, are solved by a version of Gear's integration method.

All the equations are solved simultaneously, instead of sequential solving of the set of algebraic power flow equations and the set of differential equations as was usually done in the past, thereby avoiding interface problems and approximations. It is achieved by proper structuring of the system of equations.

Gear's method is an implicit, predictor-corrector type of integration method. It is numerically stable also for time steps greater than the smallest time constant defined by the system parameters. Basically, the state variables are expressed in the form of polynomial functions of the independent variable, time. The order of these polynomials and the time step are chosen such that the maximum local truncation error of the polynomials is kept within a tolerance chosen by the user in the input data and so that the time step is maximized. Thus, the time step is varied automatically so that smaller time steps are used during periods with rapidly varying transients and larger time steps are used when the state changes become slower, but with retained accuracy determined by the user. This feature allows the time step to be increased to very large values with retained numerical stabillity. The same numerical technique is employed for solving the power flow problem. In addition, for solving the optimal power flow problem, it has been possible to include it in a gradient method.

As part of the solution procedure, the corrector is calculated from the power system equations employing Newton-Raphson's iterative method. The system of equations has a sparsity structure, which is exploited by treating only non-zero elements of its Jacobian matrix, employing LR factorization and by keeping the number of non-zero fill-in elements small by an optimal ordering of the equations.

when the system configuration is changed, e.g. due to a fault, disconnection, etc. the integration step is truncated at the instant of time for such a state change. This allows limiters in controllers to be treated accurately, through determination of the instant of time when kneepoint is reached and continuing the calculation from this time on.

3.3 OPTPOW

The OPTPOW program is a member of the SIMPOW family. It calculates an initial power flow in networks of unlimited number of nodes and the components (practically limited only by the computer as no limits are build into the program).

The electrical state in the ac system is assumed to be symmetrical and sinusoidal at power frequency. Hence, the ac system is represented by a single phase power frequency model. The electrical state is described by the positive sequence phasors of the node voltages, the injected currents from loads and the productions sources, and the turns ratios of the transformers and the phase shifters.

The purpose of a power flow calculation may be manifold: Basically, it involves the studying of the active and reactive power balance and distribution, node voltage magnitudes and phase angles, for a power system under normal operating conditions. Different control measures may be studied, e.g. the need for shunt capacitors, reactors, static compensators for handling surplus or deficiency of reactive power which are reflected in high and low voltage magnitudes respectively, LTC of transformers for control of the reactive power flow, or phase shifters for control of the active power flow to eliminate potential overload and stability problems. A wide application of a power flow calculation is to establish initial conditions for a dynamic simulation, e.g. a transient stability or overvoltage calculation. Basically, the complex positive sequence node voltages are calculated for symmetrical, steady-state conditions and within the constraints of the power system with or without minimization of the transmission losses or production cost.

(i) Modelling

Most system elements can be represented such as passive and motor loads,active and reactive productions sources,transformers, transmission lines, shunt reactors and capacitors, and series capacitors.

Most control functions and constraints can be represented e.g. voltage control by means of reactive power sources and transformer tap changes, control of the power flow by means of power injections and phase shifters.

(ii) Numerical Methods

The numerical technique employed, (Gear's method) assures convergence of the solution defined by the system model.

The solution procedure for a new case starts with the system de-energized, with zero currents i.e. with a known solution. Then the reactive power sources are energized and the voltages are established, after which the active power is taken up, and finally the control variables are adjusted so that all constraints on power flow and voltages are fulfilled.

(iii) Program execution

The preparation of input file to the program can be made

- in a separate activity using the computer editor
- in a separate activity using the forms input system

All data are given in data groups. The power flow output can be printed out in lists or displayed on the single-line diagram of the network.

3.4 DYNPOW

The DYNPOW program is a computer program in the SIMPOW family for dynamic calculations.

The initial conditions for the varibles are given by a preceeding load flow with the OPTPOW program and additional data are given by user. Input data to the DYNPOW program consists of data for machines as well as data for controlling the calculation and the output.

The purpose of a transient stability calculation is to study electromechanical pheonomena in a power system after a disturbance has occured.

## 3.5 DYNPOST

The DYNPOST program is a computer program in the SIMPOW family for post-processor to the transient stability program. The program reads the result from the transient calculation, prints the results an generates data to a general plot program, which performs the plotting of the result.

The input is the result from the transient calculation and user's input data, which specifies the variables to be printed/plotted and the laout of the diagrams. Input data is stored on file.

Three type of output diagram can be created:

- a variable as a function of time
- a variable versus another variable
- frequency scanning

# APPENDIX B

This appendix show the computer simulation result of SIMPOW software package. The power, reactive power, current and voltage are all in the phase value. The list below are results.

Figure A15.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

Figure A15.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

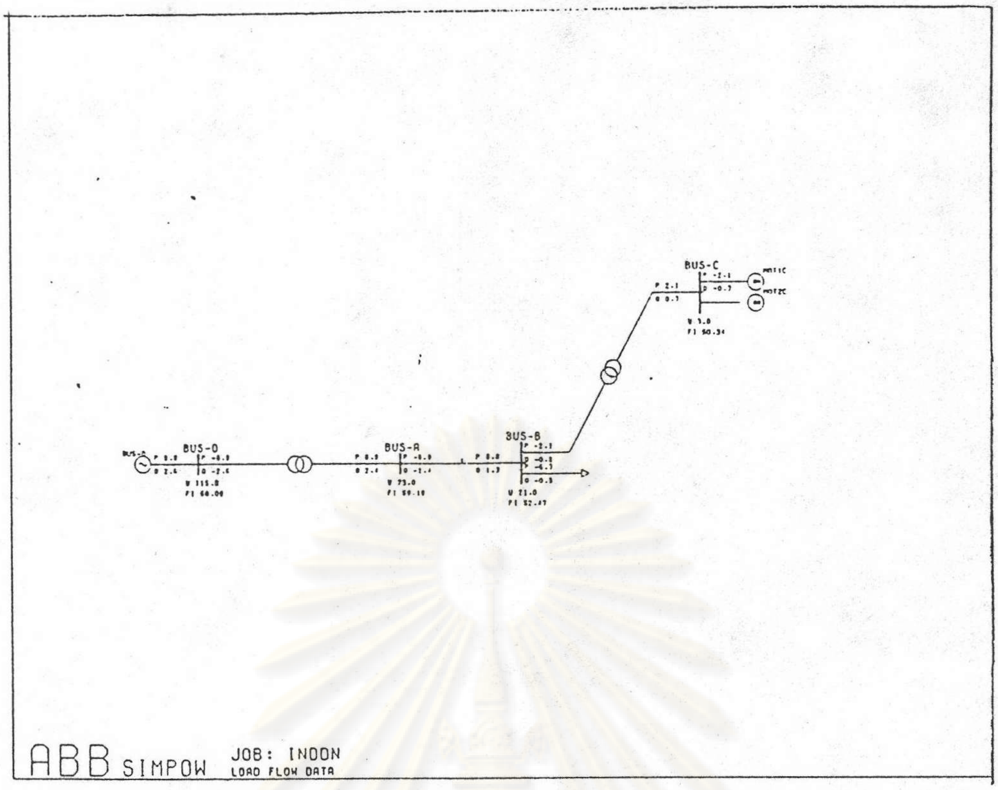


Figure A1.1 NETWORK SINGLE LINE DIAGRAM (SINGLE DISTRIBUTION LINE)



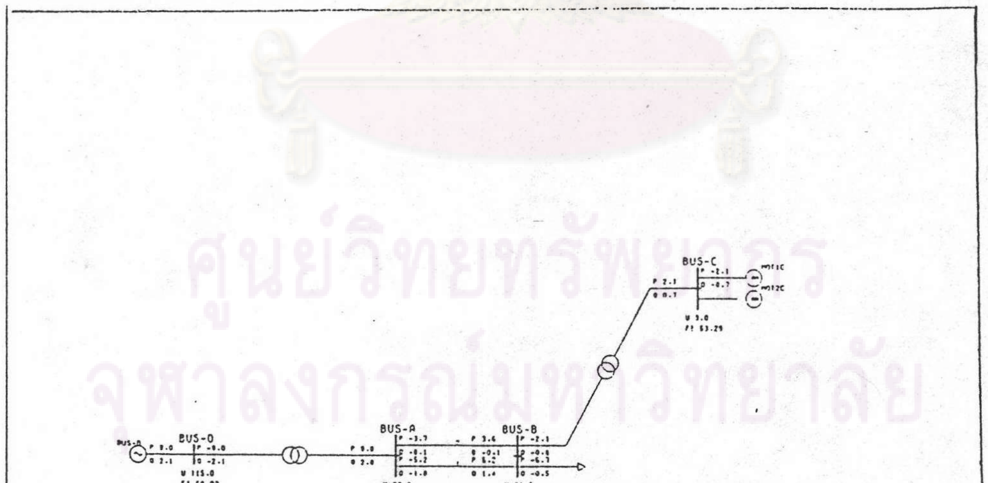


Figure A1.2 NETWORK SINGLE LINE DIAGRAM (DOUBLE DISTRIBUTION LINE)

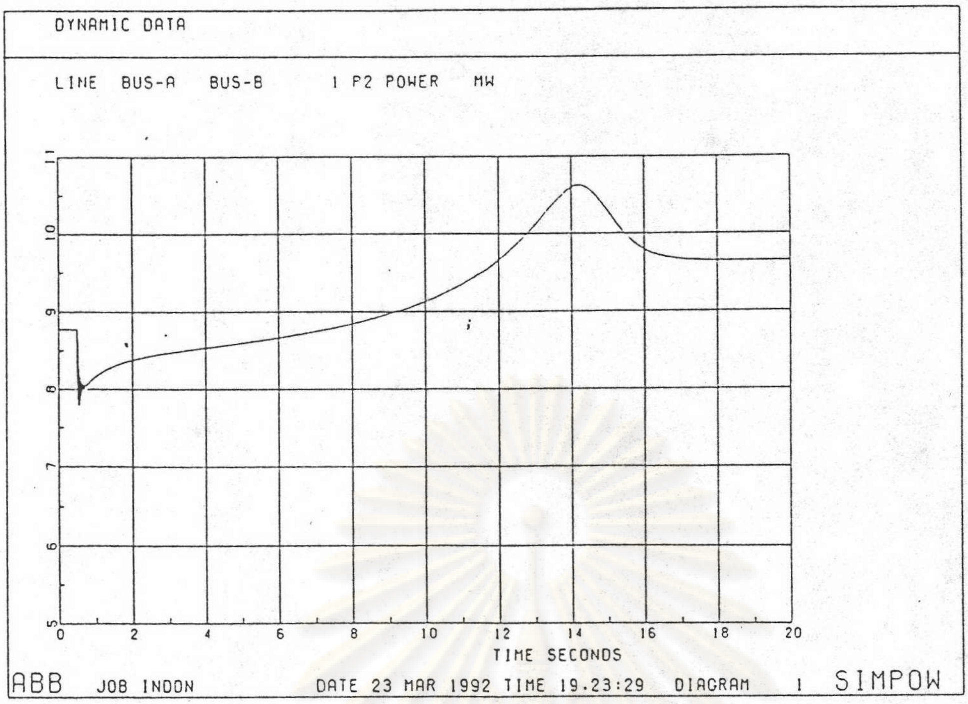


Figure A2.1 POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE USING DOL STARTING)

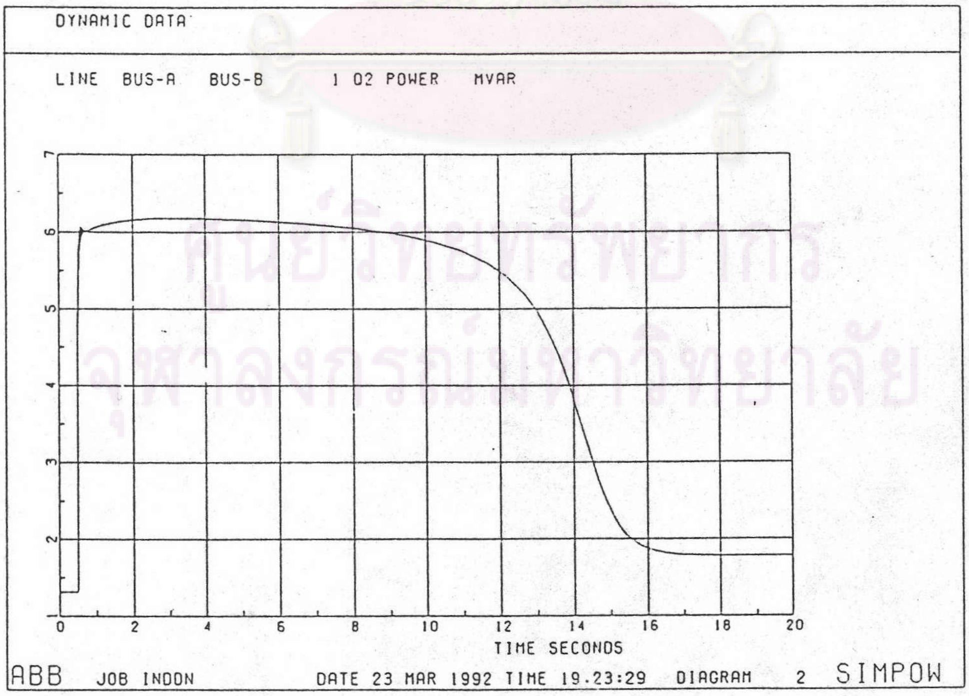


Figure A2.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE USING DOL STARTING)

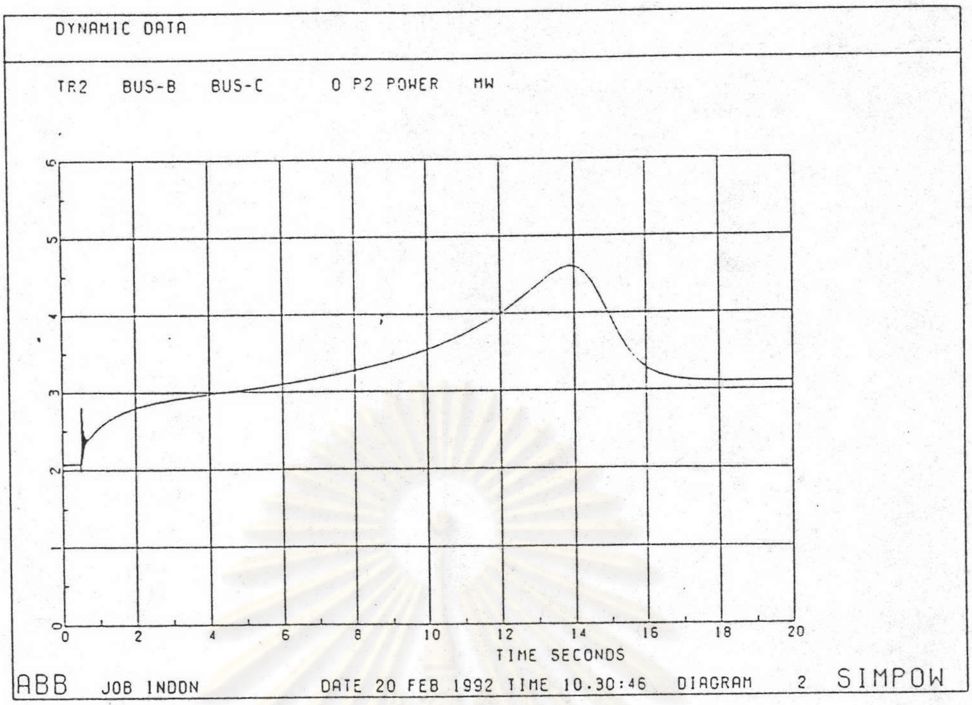


Figure A2.3 POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE USING DOL STARTING)

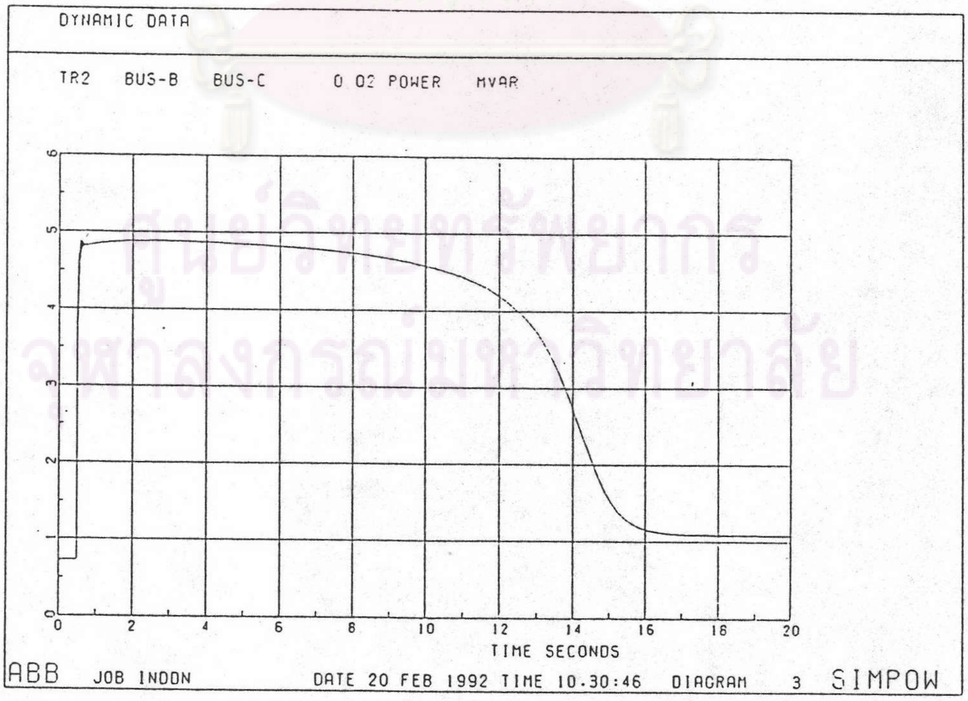


Figure A2.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE USING DOL STARTING)

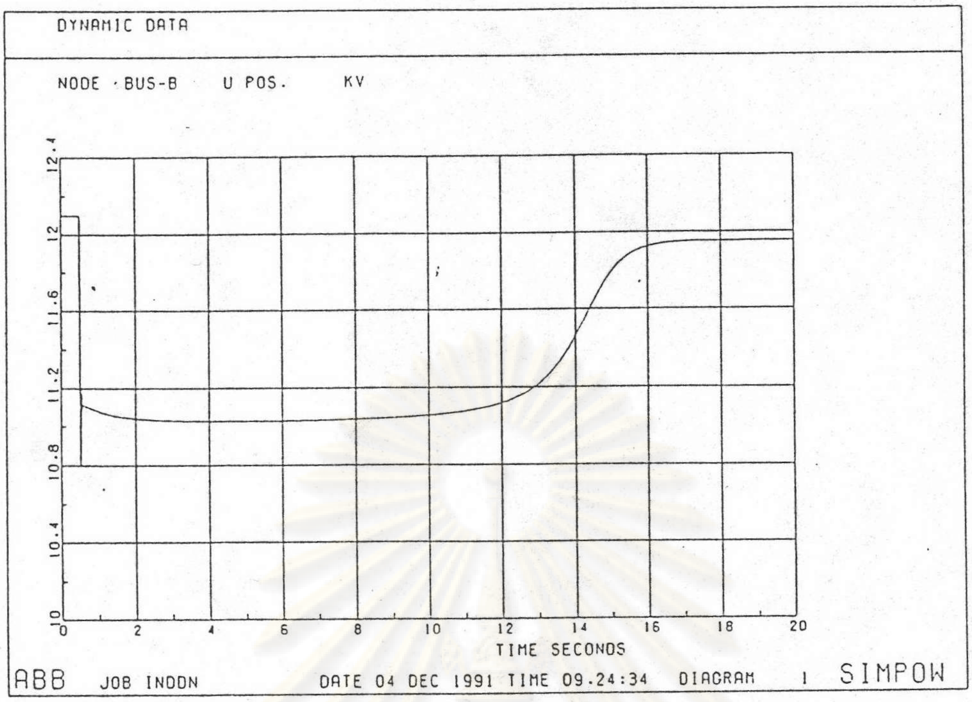


Figure A2.5 VOLTAGE AT BUS-B
(SINGLE DISTRIBUTION LINE USING DOL STARTING)

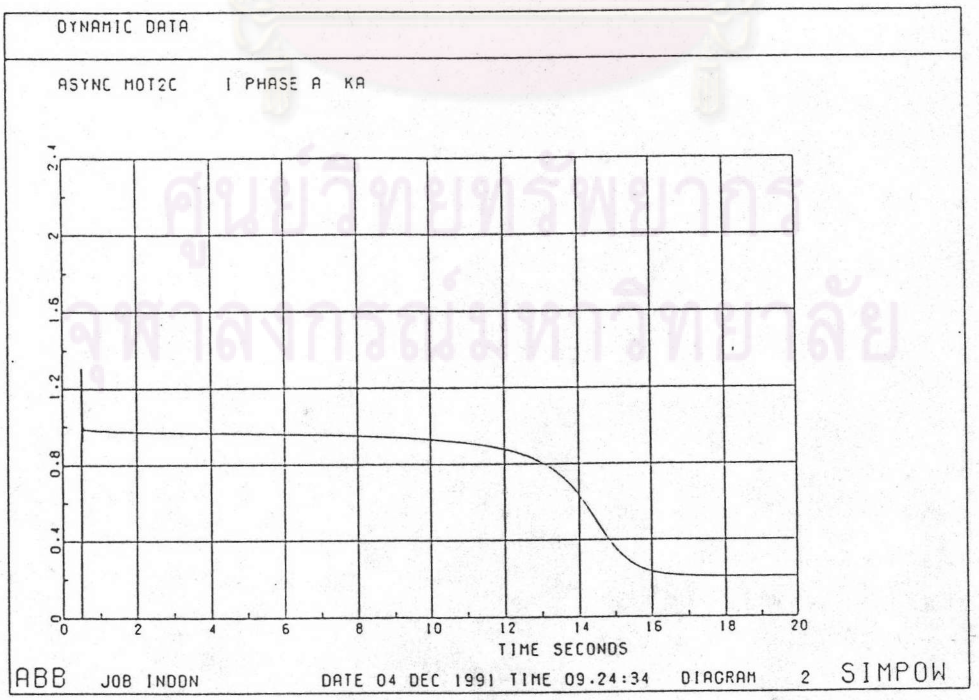


Figure A2.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(SINGLE DISTRIBUTION LINE USING DOL STARTING)

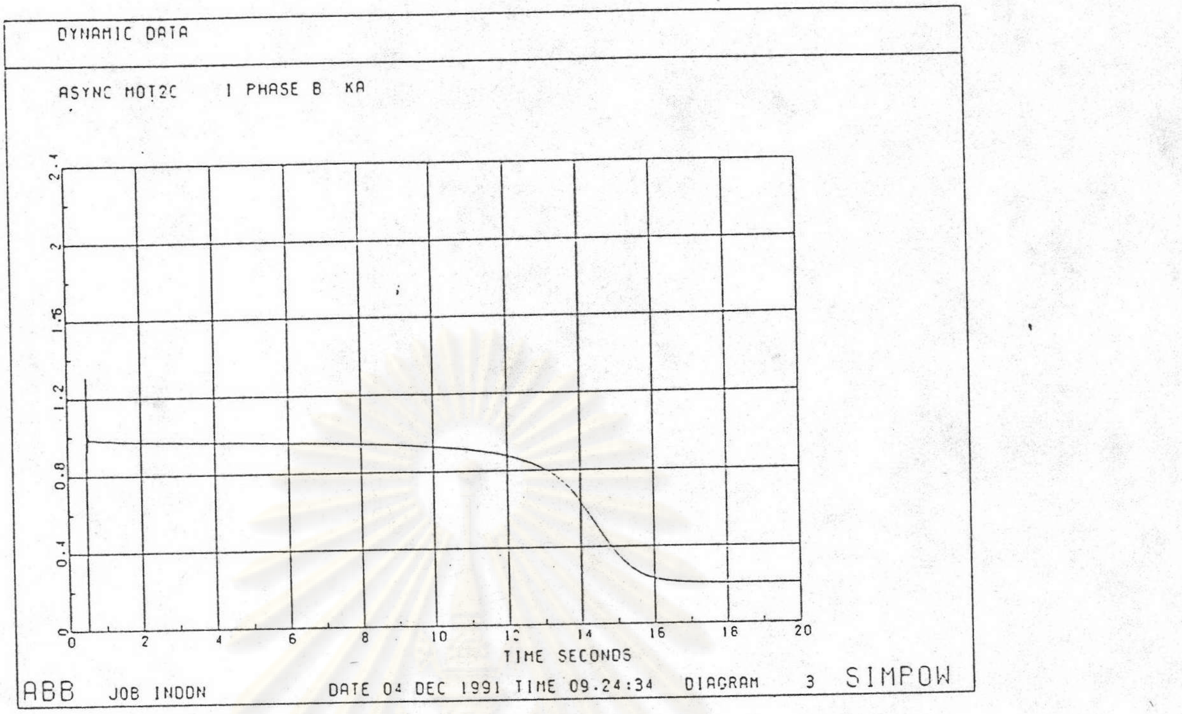


Figure A2.7 ASYNCHRONOUS MOTOR PHASE B CURRENT (SINGLE DISTRIBUTION LINE USING DOL STARTING)

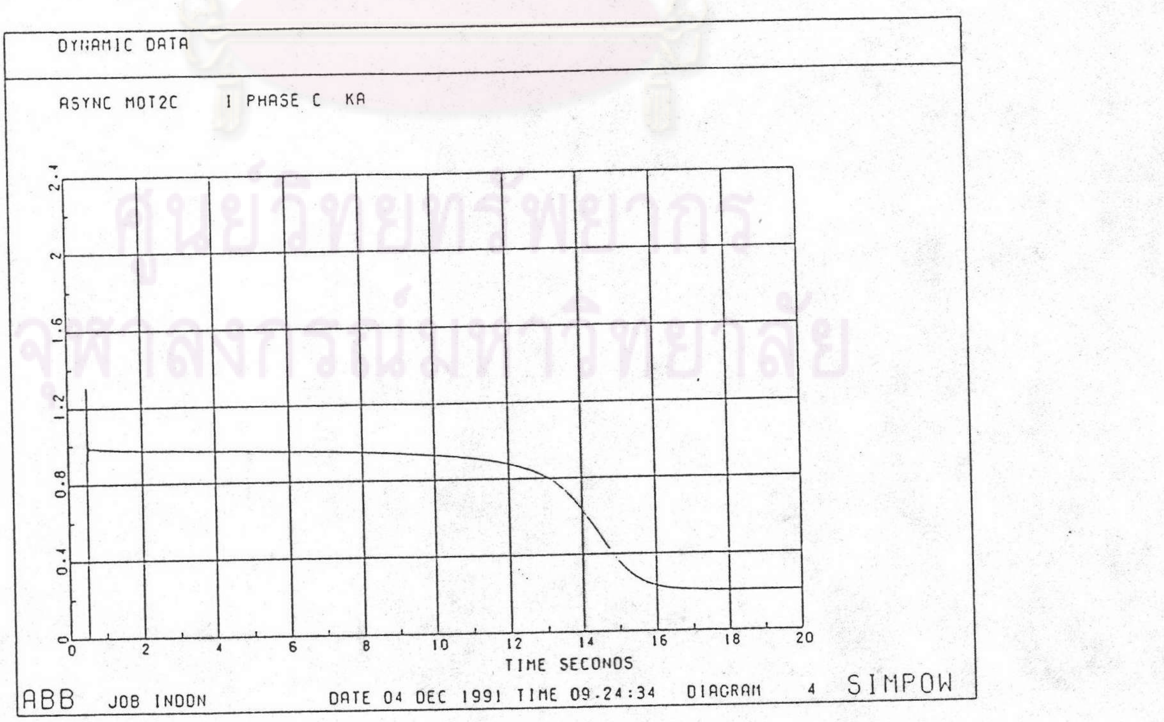


Figure A2.8 ASYNCHRONOUS MOTOR PHASE C CURRENT (SINGLE DISTRIBUTION LINE USING DOL STARTING)

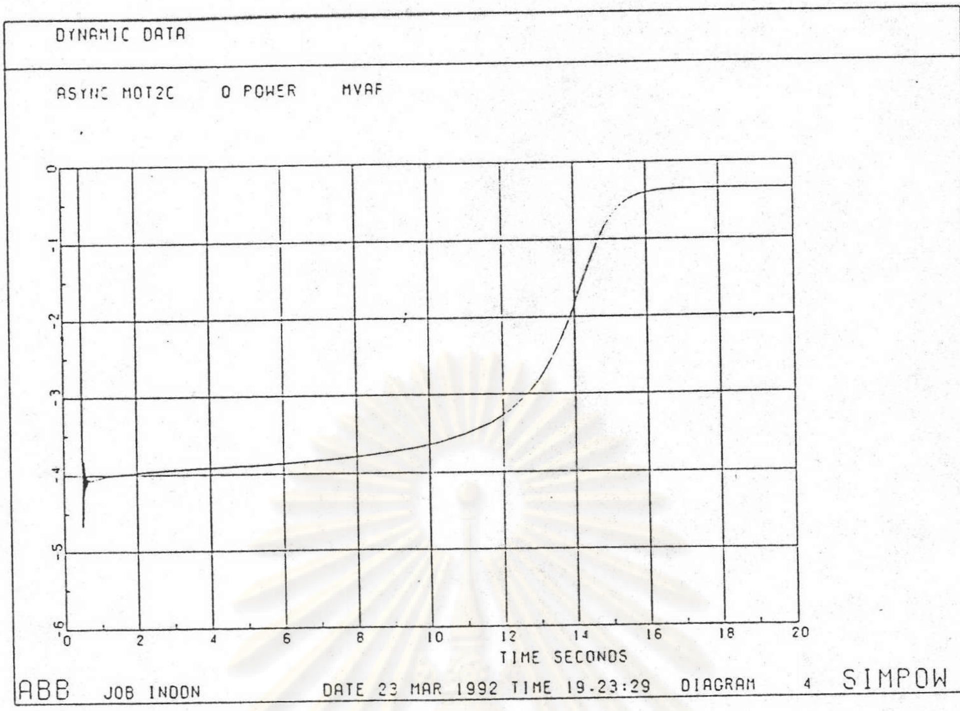


Figure A2.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT (SINGLE DISTRIBUTION LINE USING DOL STARTING)

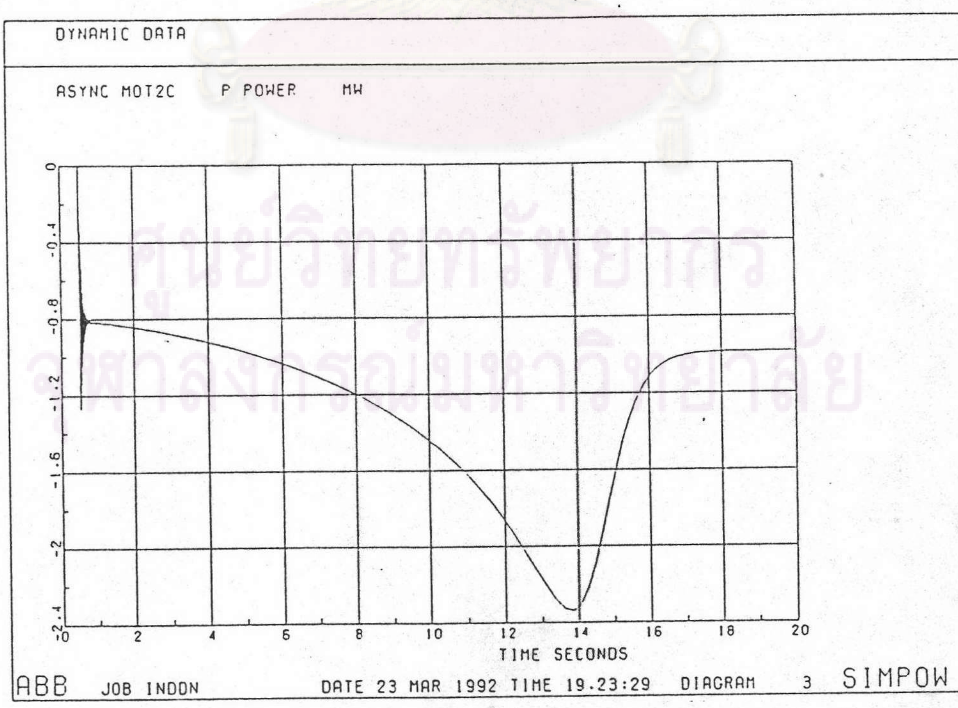


Figure A2.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT (SINGLE DISTRIBUTION LINE USING DOL STARTING)

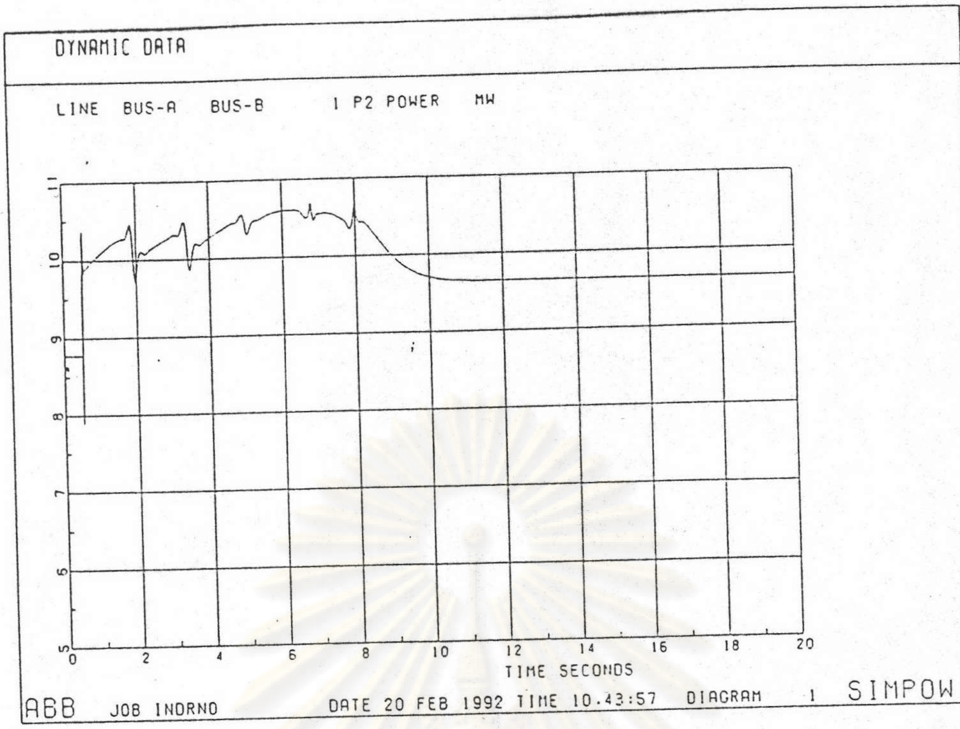


Figure A3.1 POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

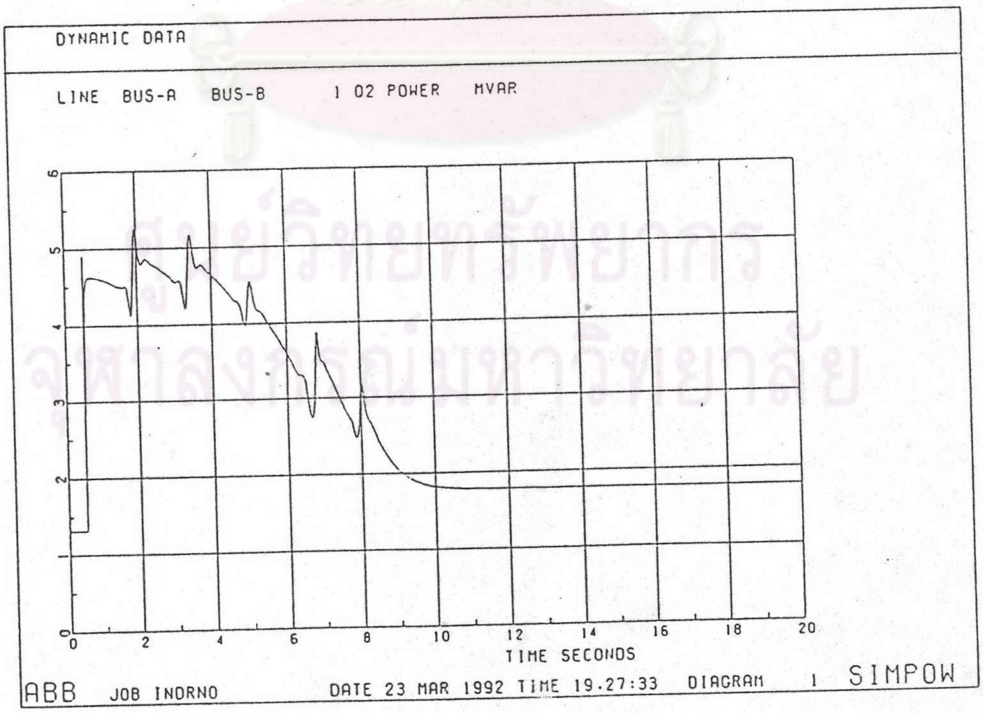


Figure A3.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

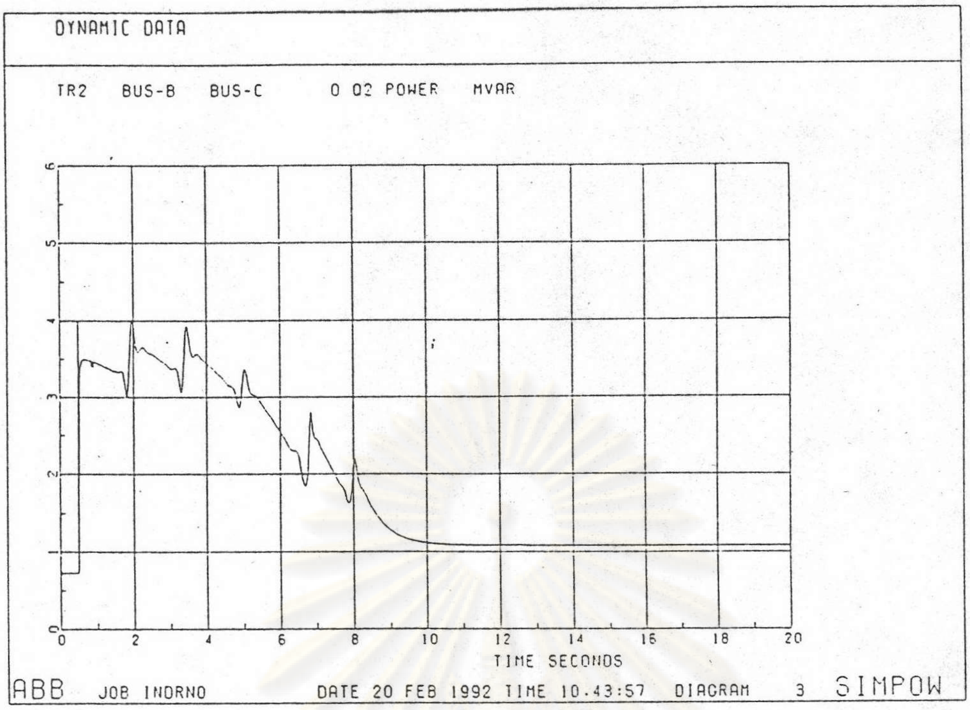


Figure A3.3 POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

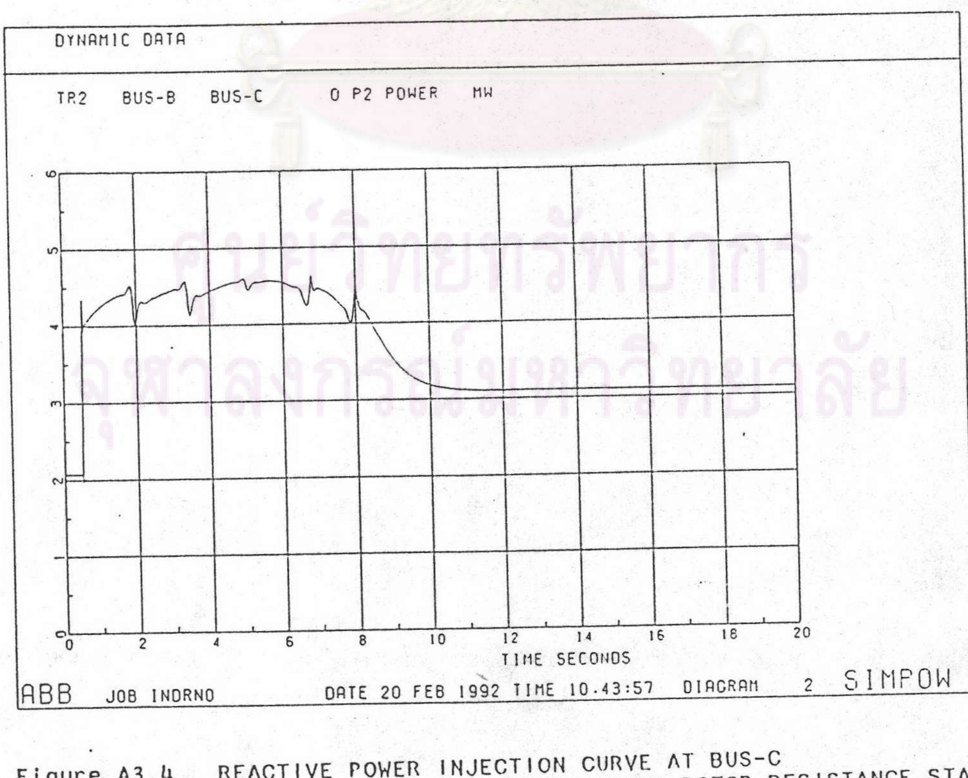




Figure A3.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

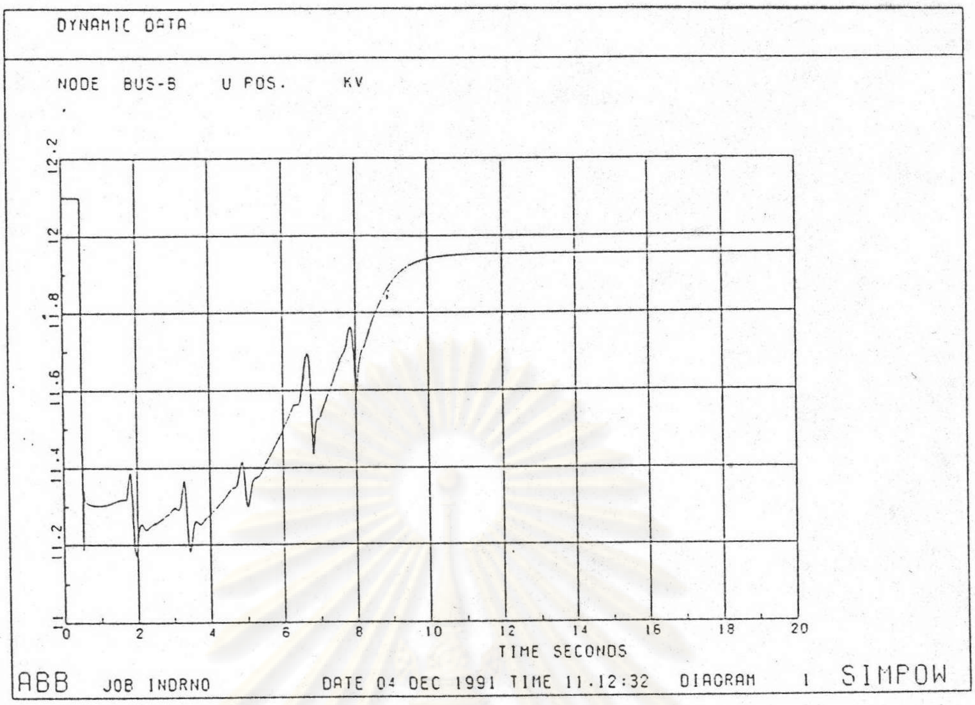


Figure A3.5 VOLTAGE AT BUS-B
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

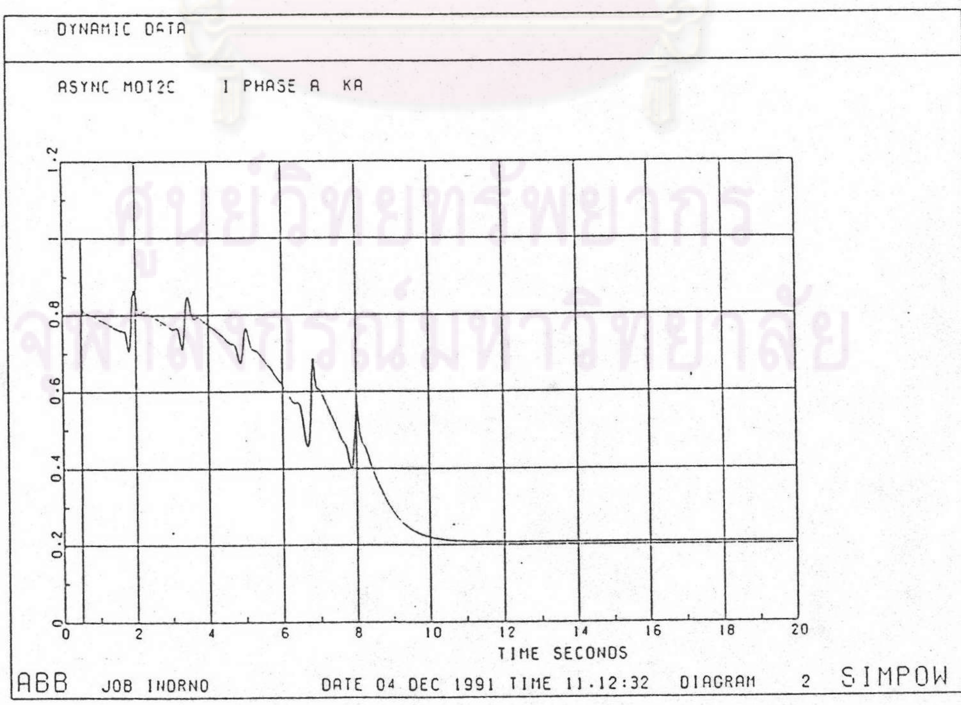


Figure A3.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

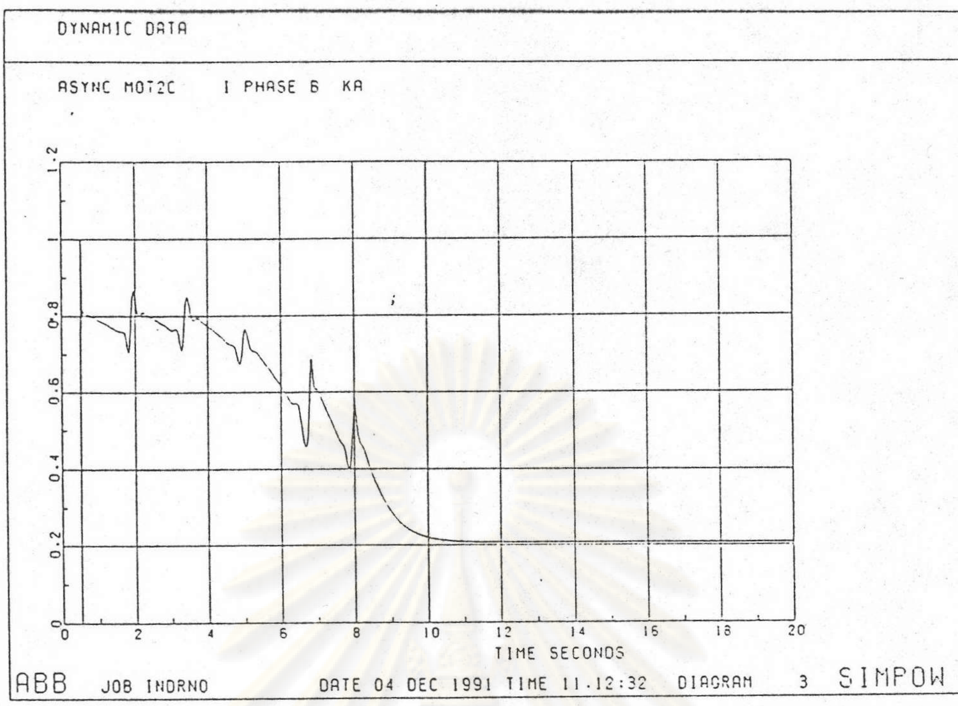


Figure A3.7 ASYNCHRONOUS MOTOR PHASE B CURRENT (SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

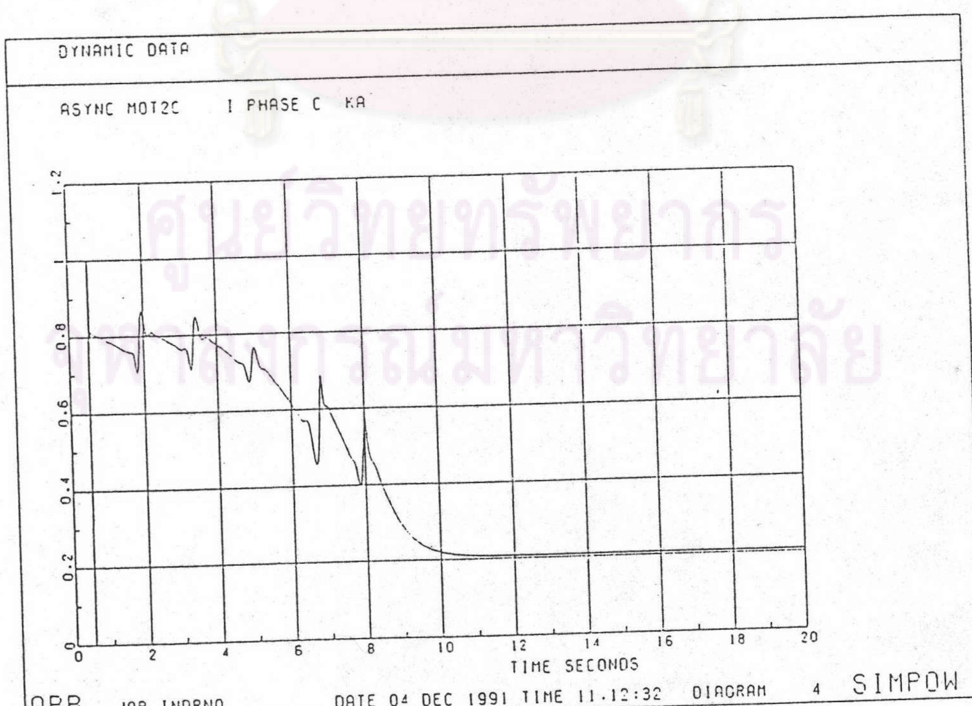


Figure A3.8 ASYNCHRONOUS MOTOR PHASE C CURRENT (SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

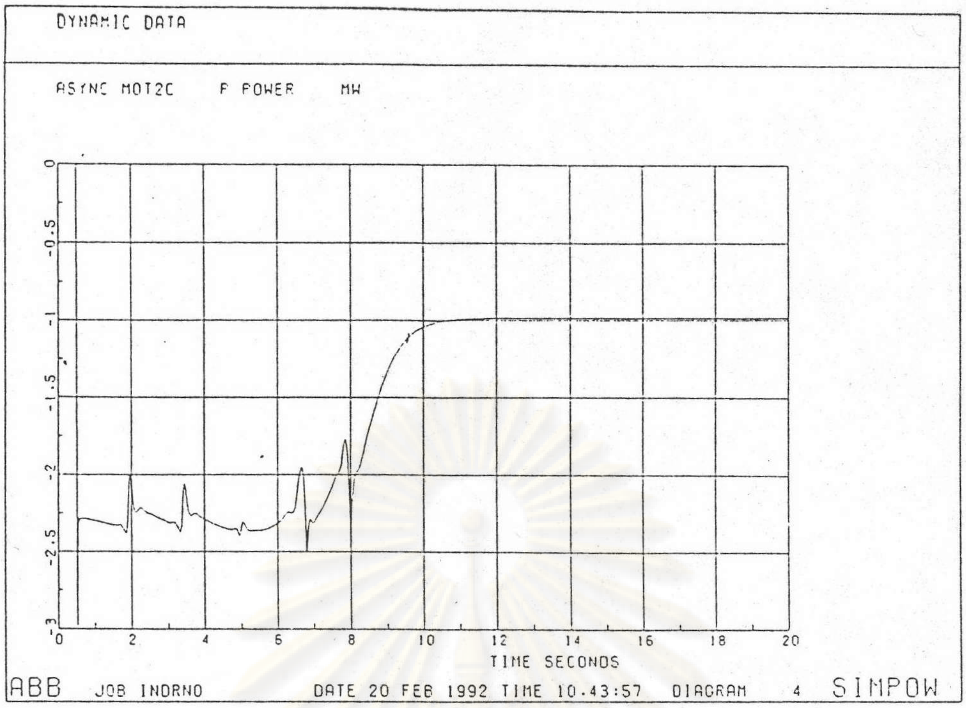


Figure A3.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)



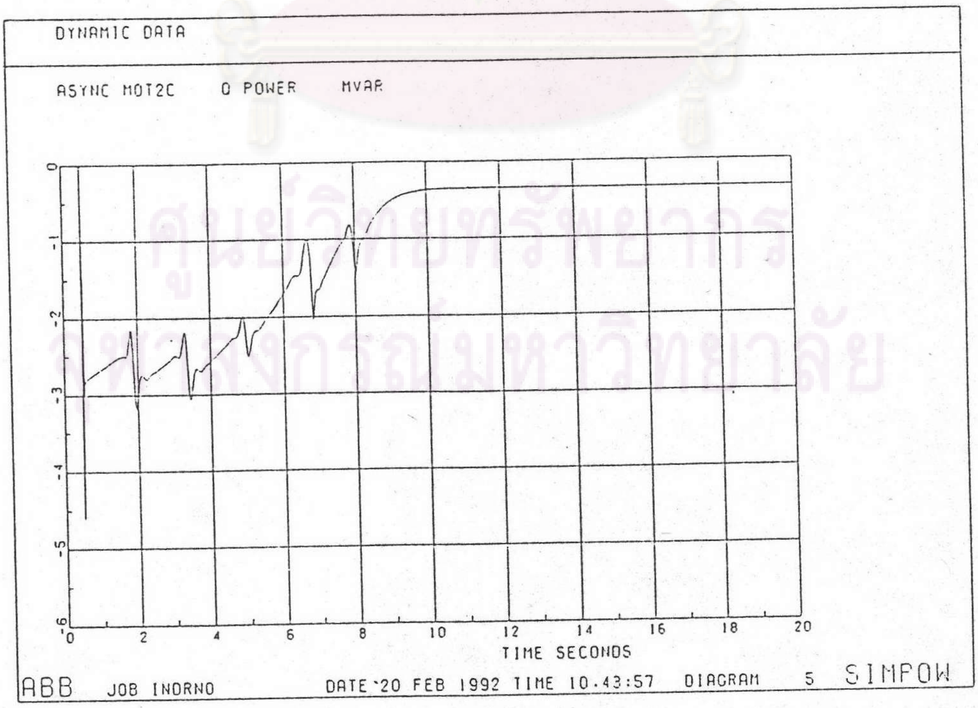


Figure A3.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

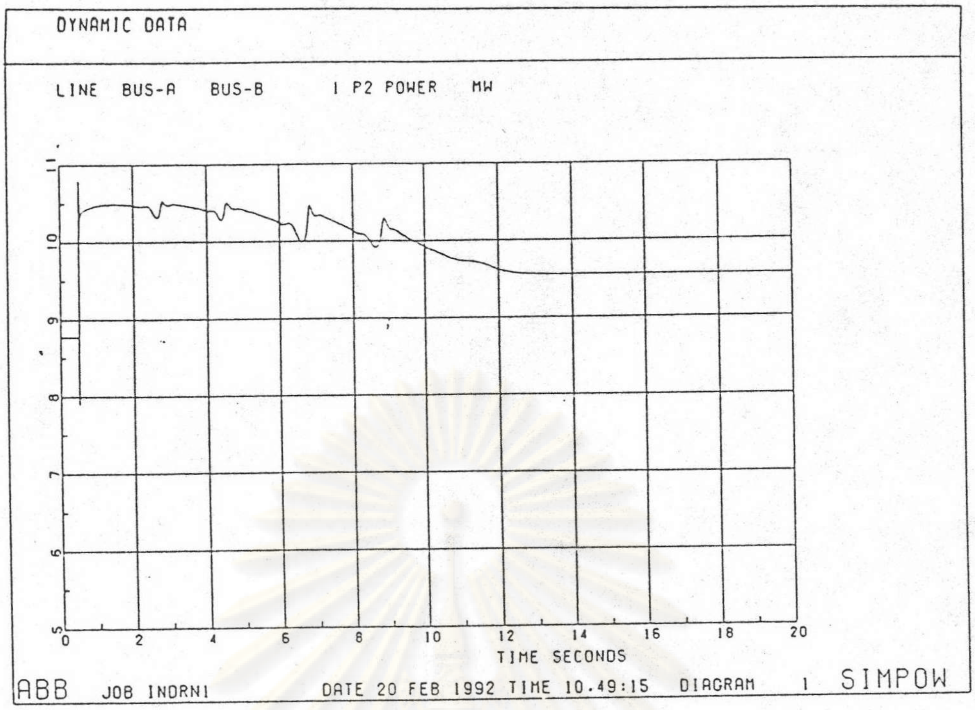


Figure A4.1 POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

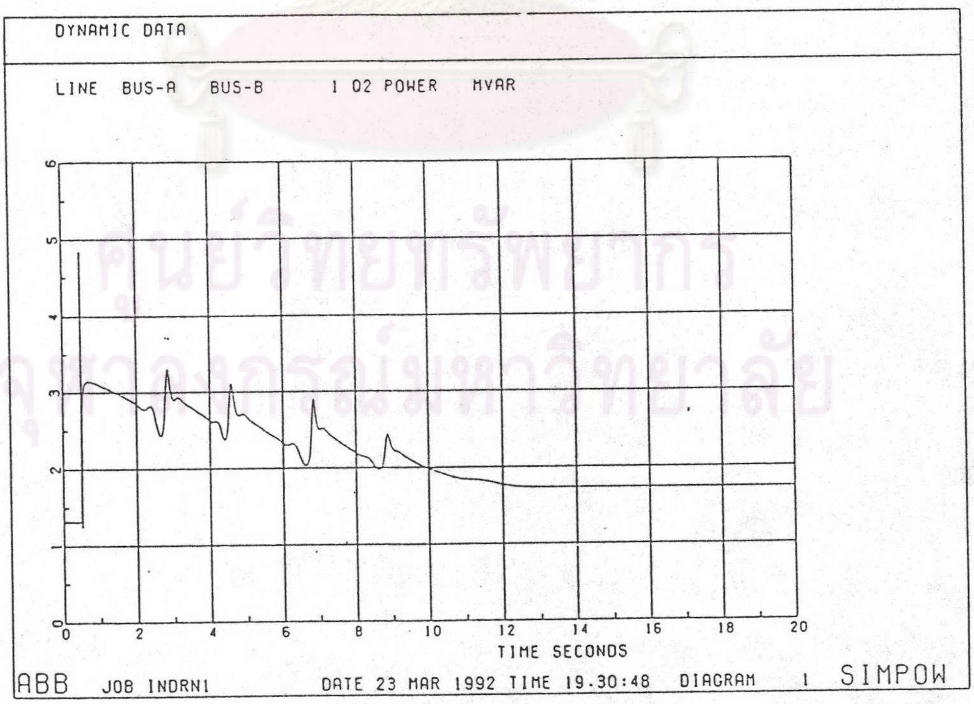


Figure A4.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

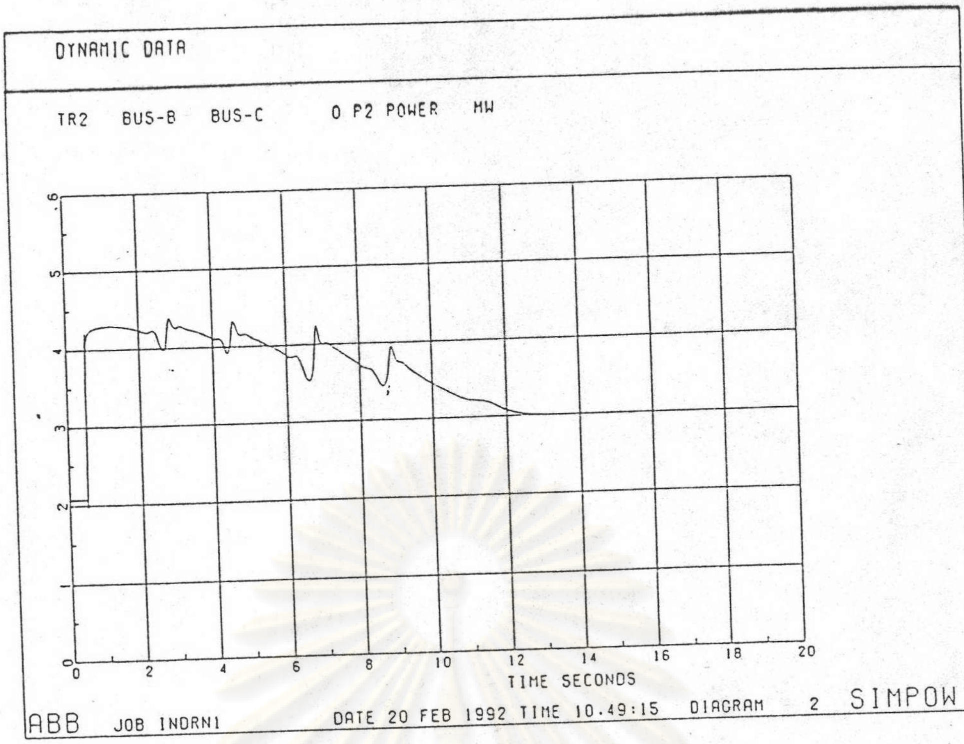


Figure A4.3 POWER INJECTION CURVE AT BUS-C (SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

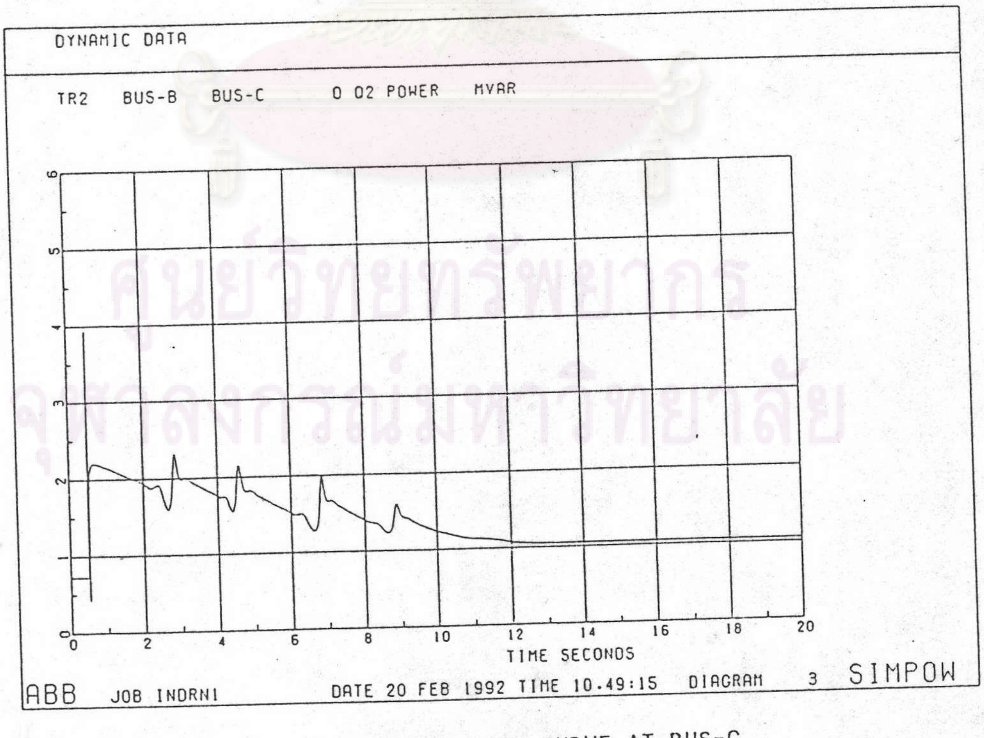


Figure A4.4 REACTIVE POWER INJECTION CURVE AT BUS-C (SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

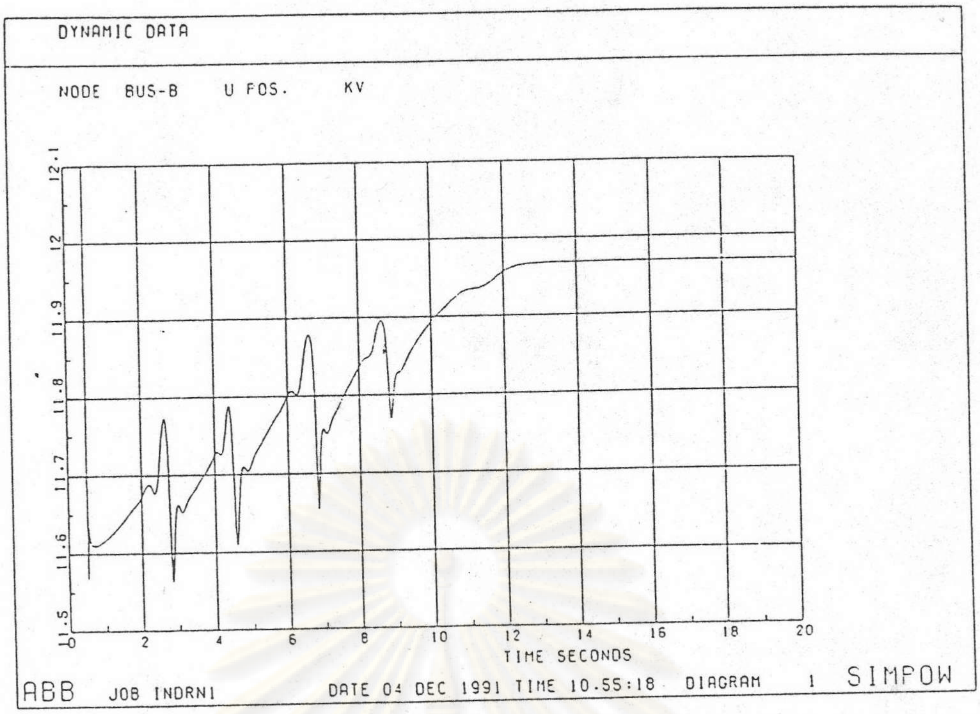


Figure A4.5 VOLTAGE AT BUS-B
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

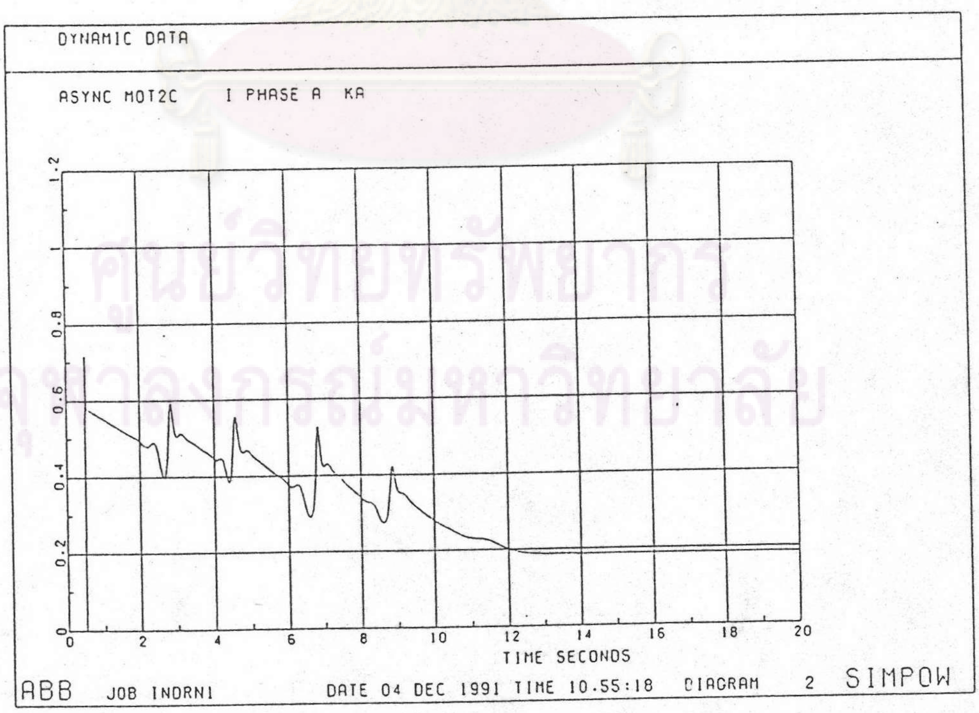


Figure A4.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

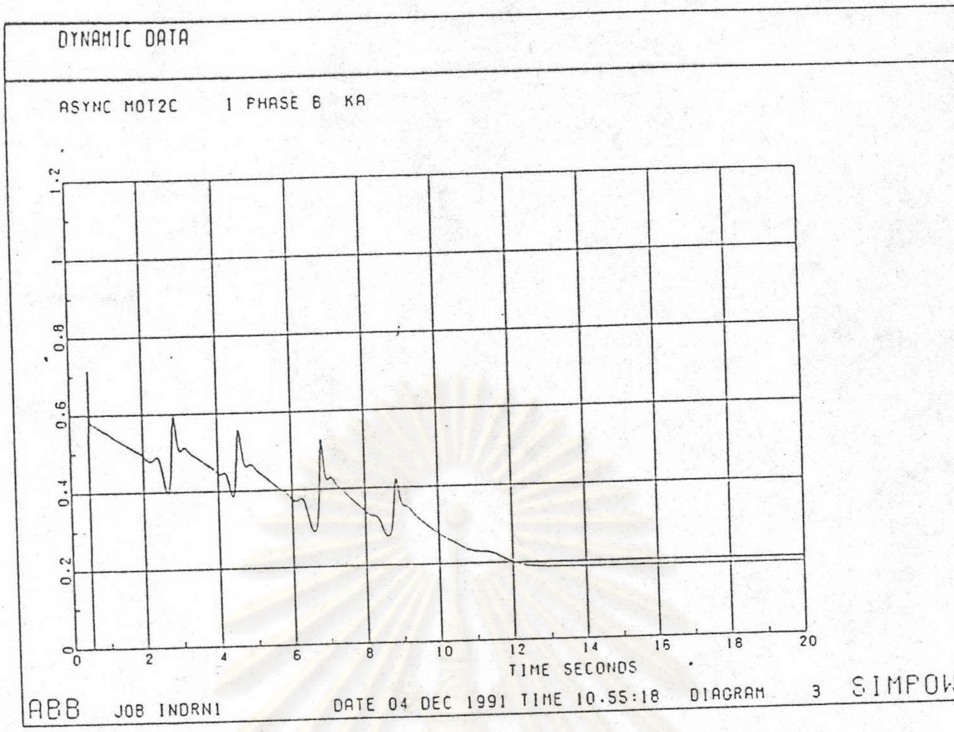


Figure A4.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

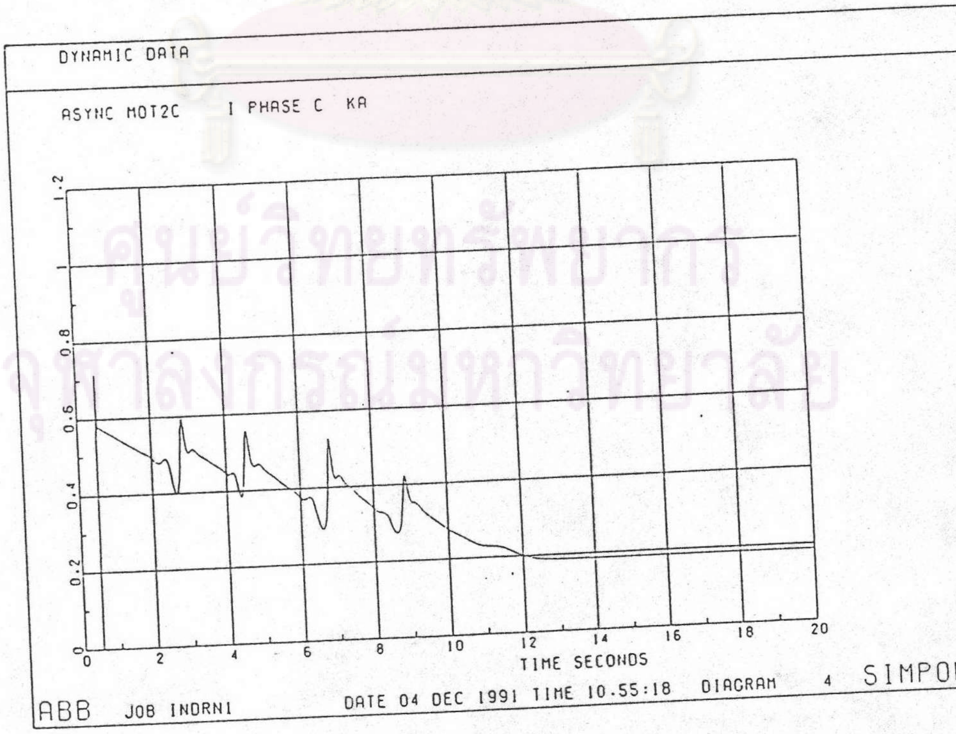


Figure A4.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

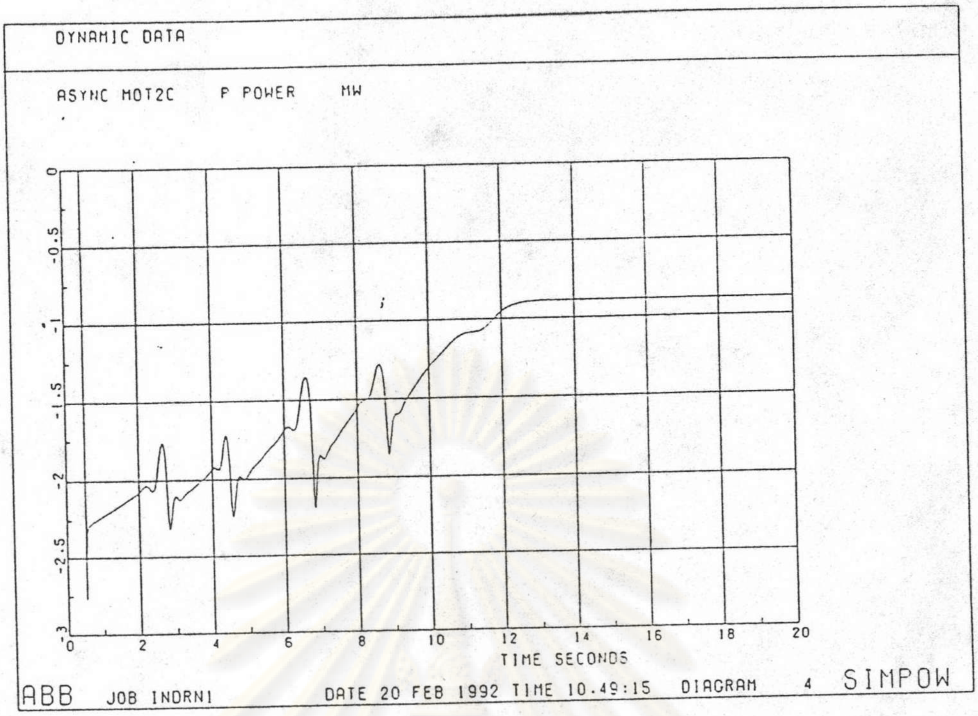


Figure A4.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)



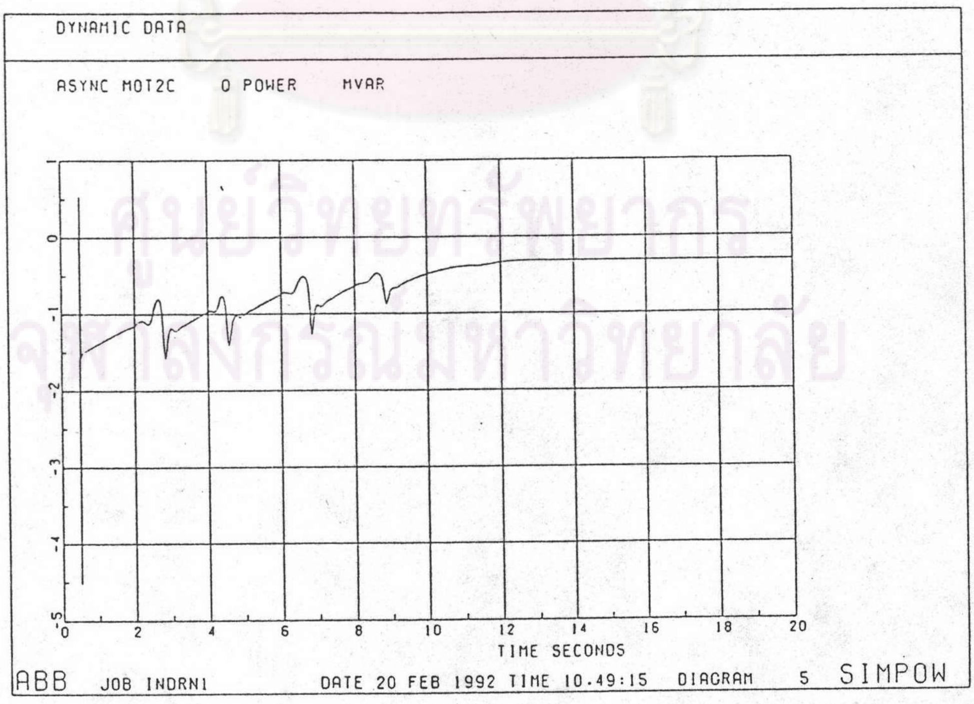


Figure A4.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

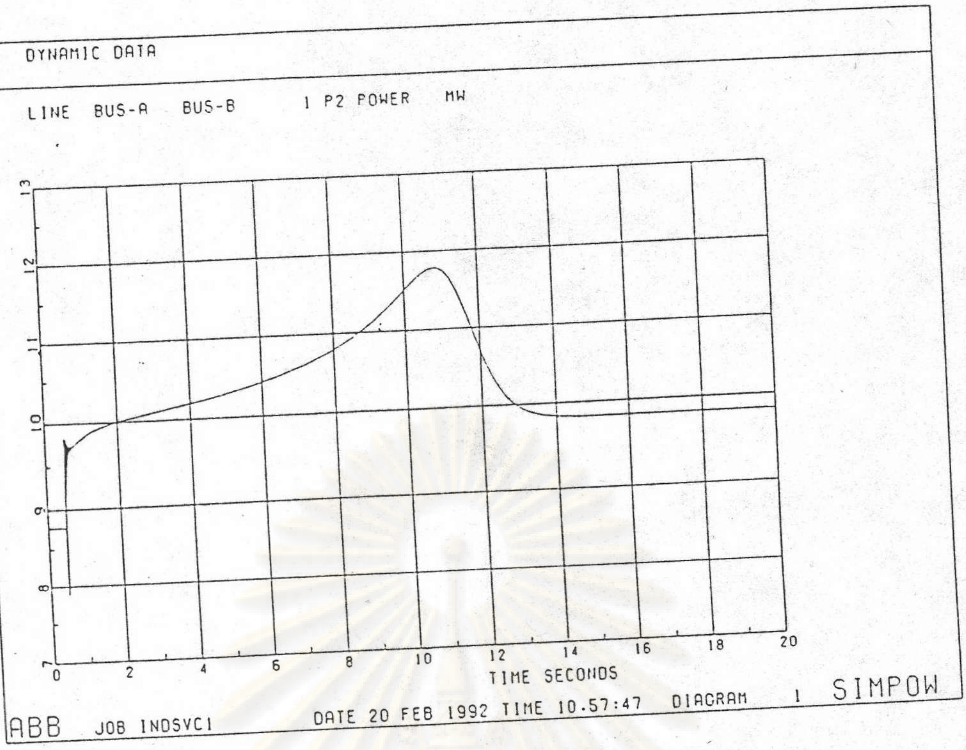


Figure A5.1 POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

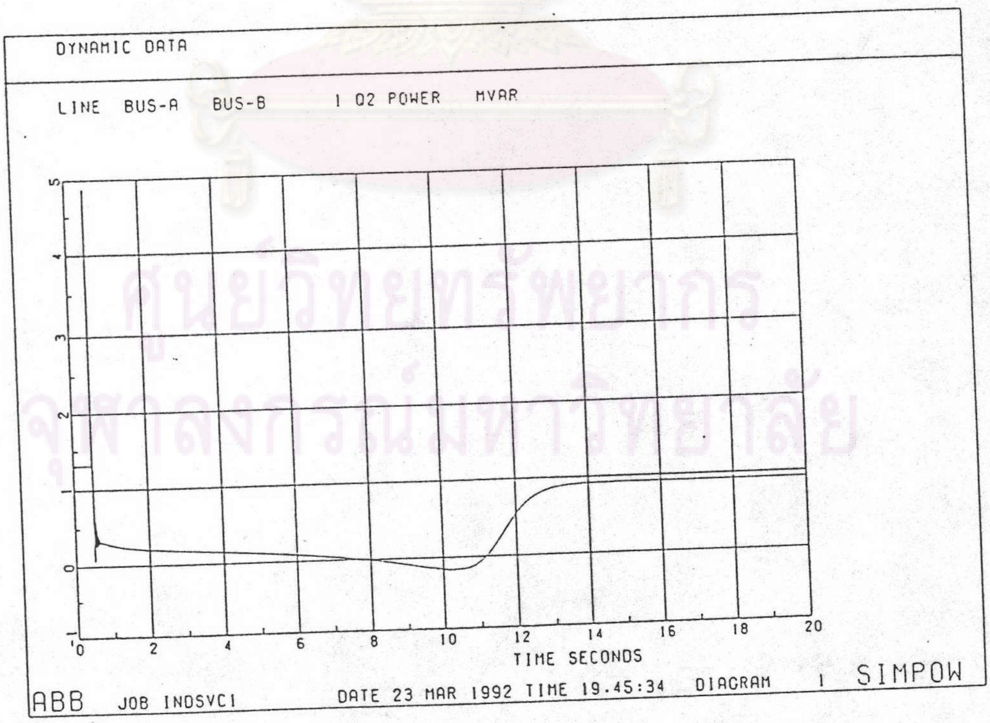


Figure A5.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

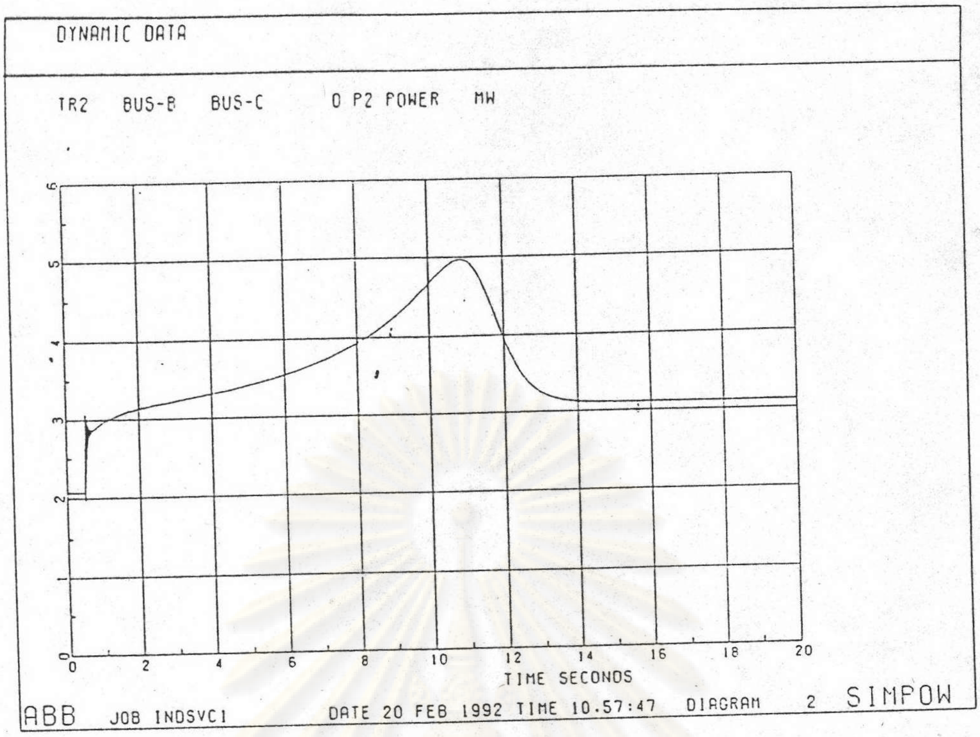


Figure A5.3 POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

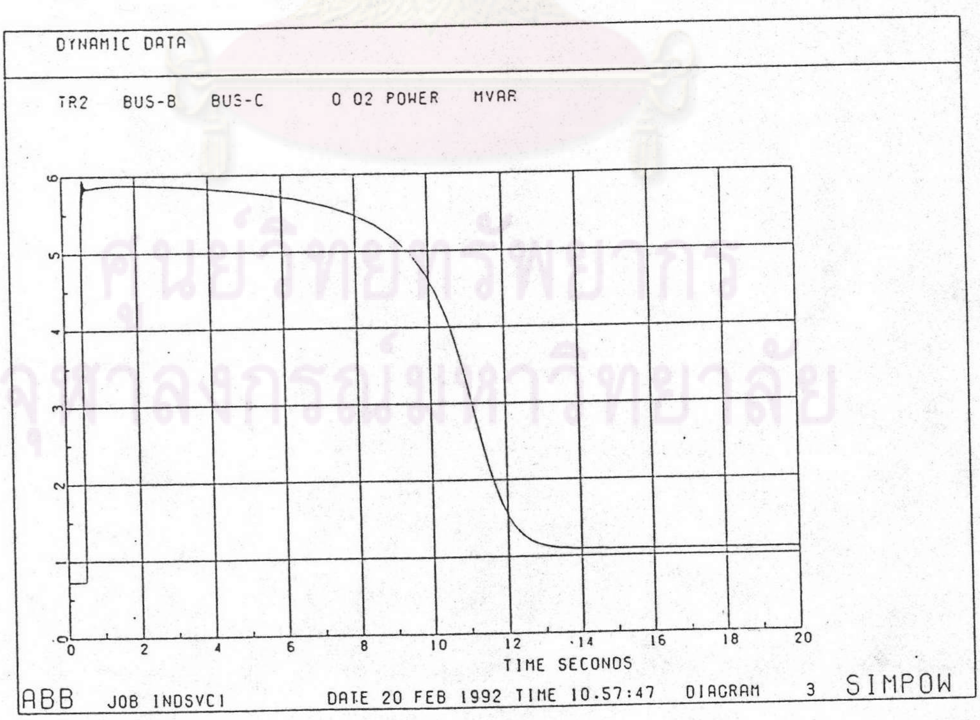


Figure A5.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

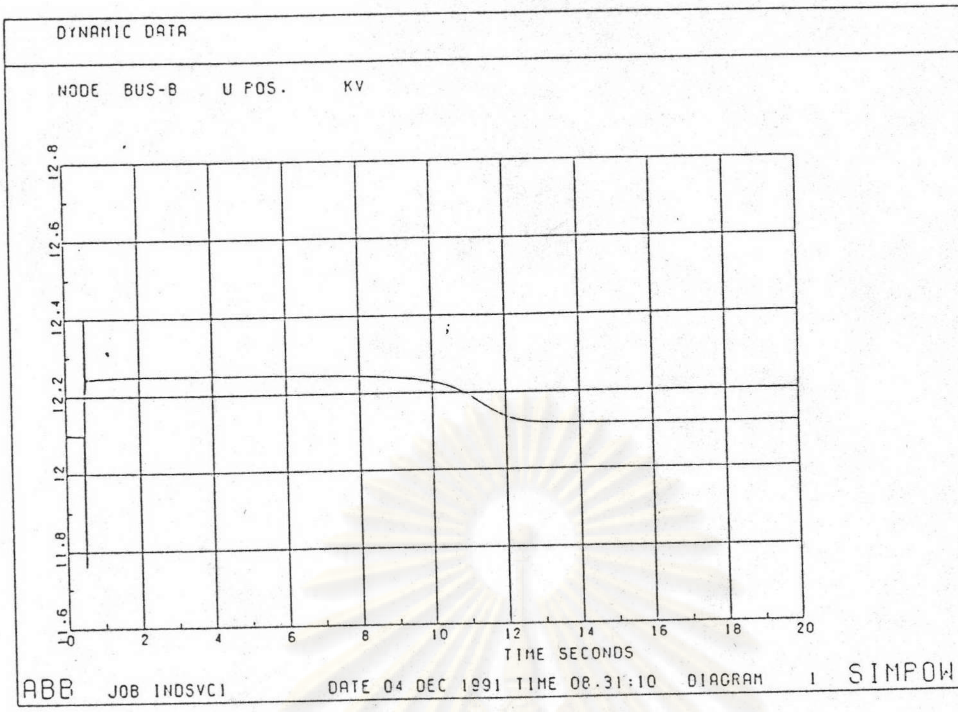


Figure A5.5 VOLTAGE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

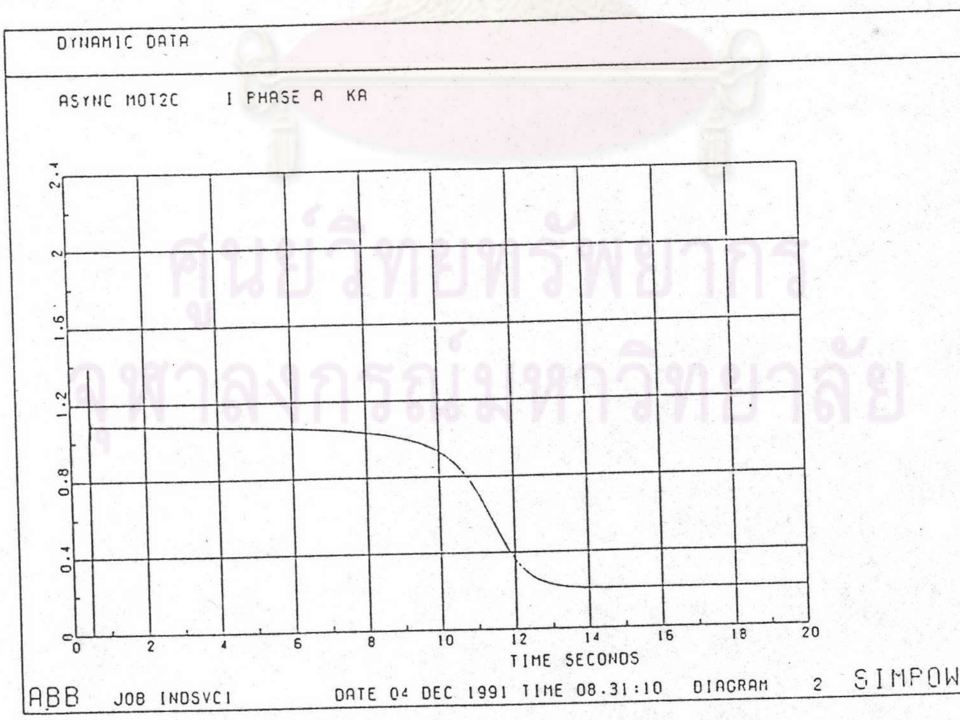


Figure A5.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

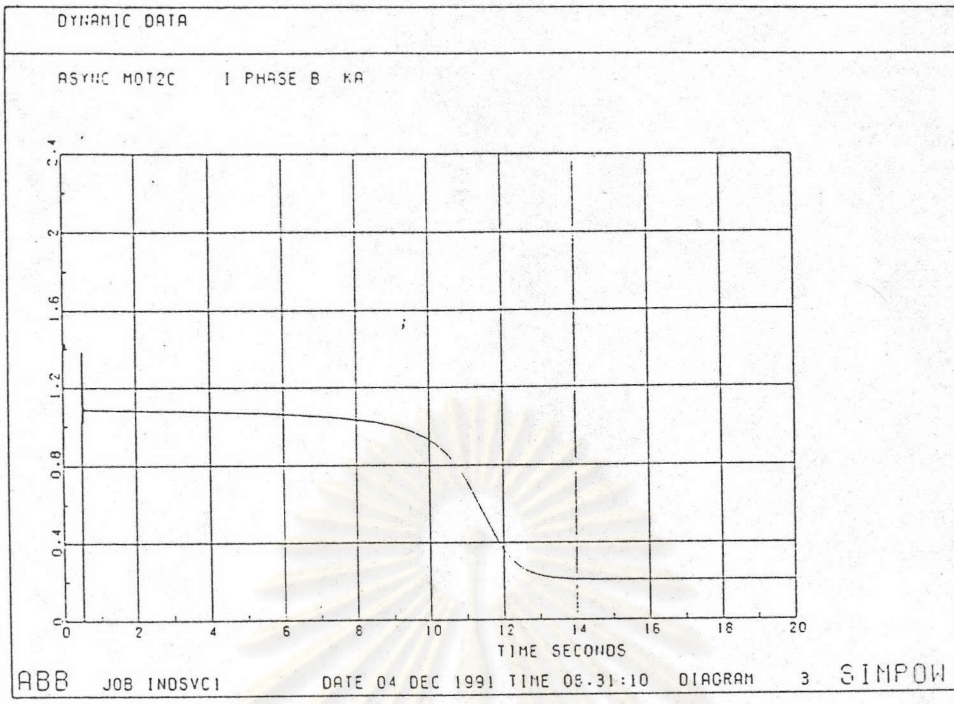


Figure A5.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

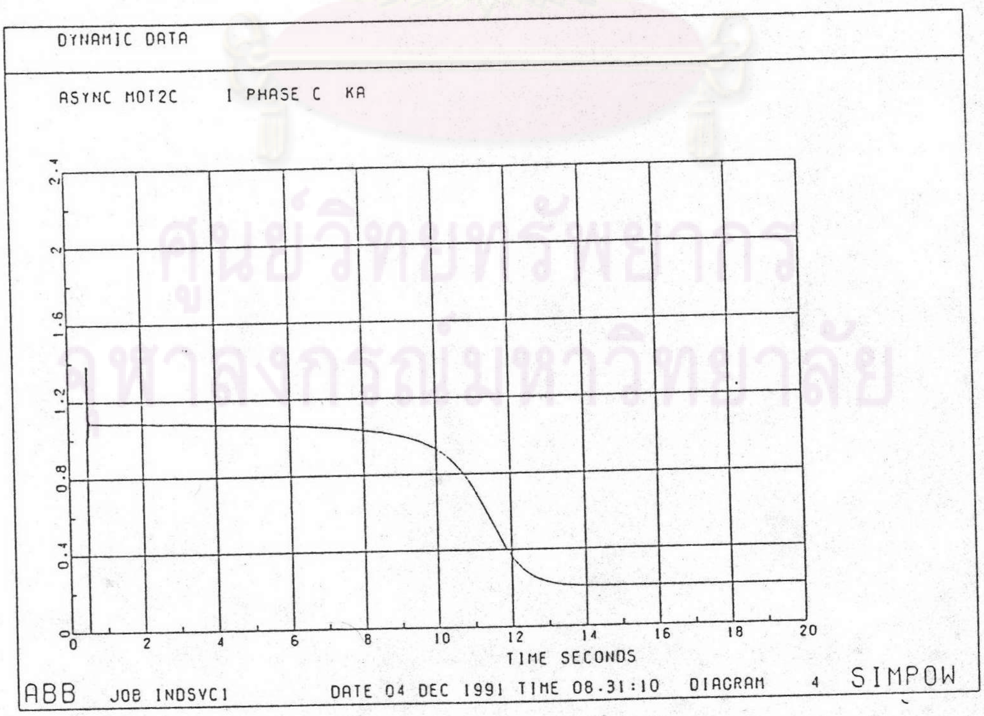


Figure A5.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

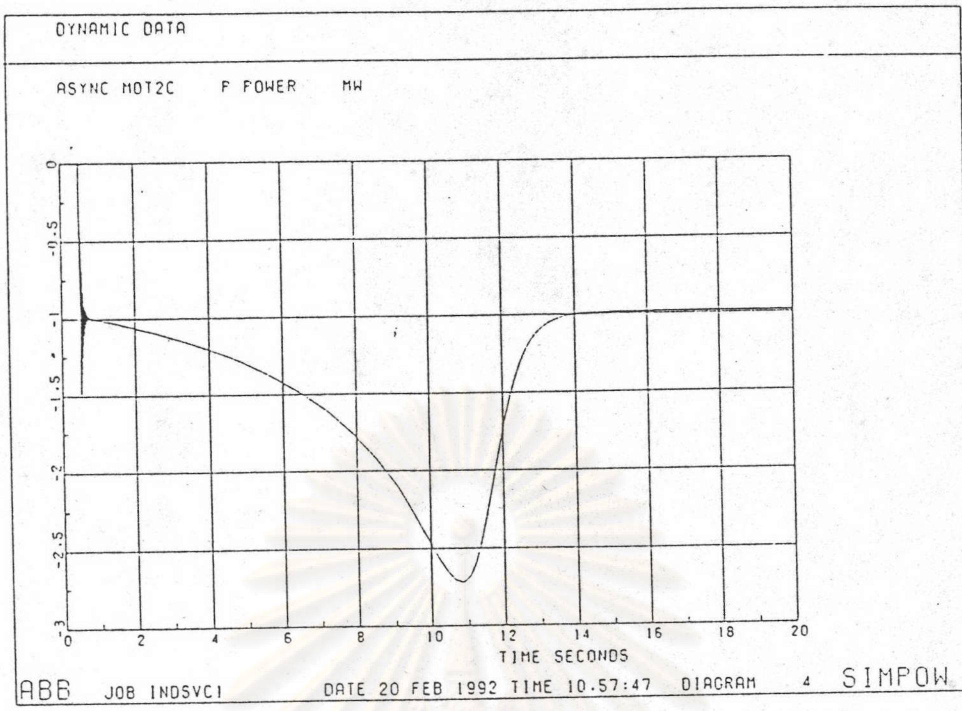


Figure A5.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

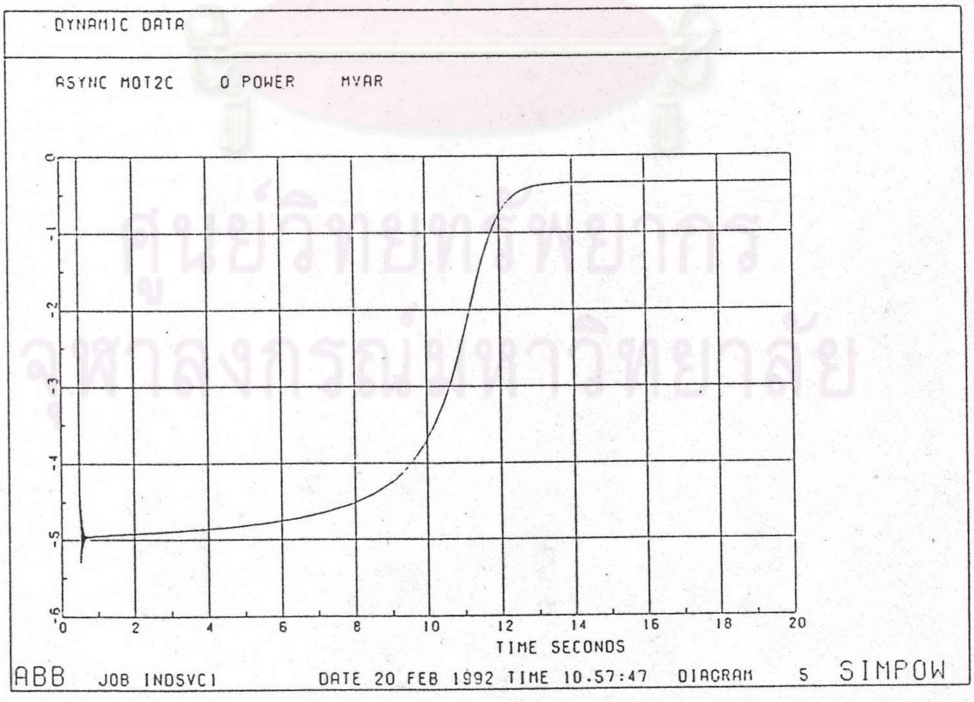


Figure A5.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 1 )

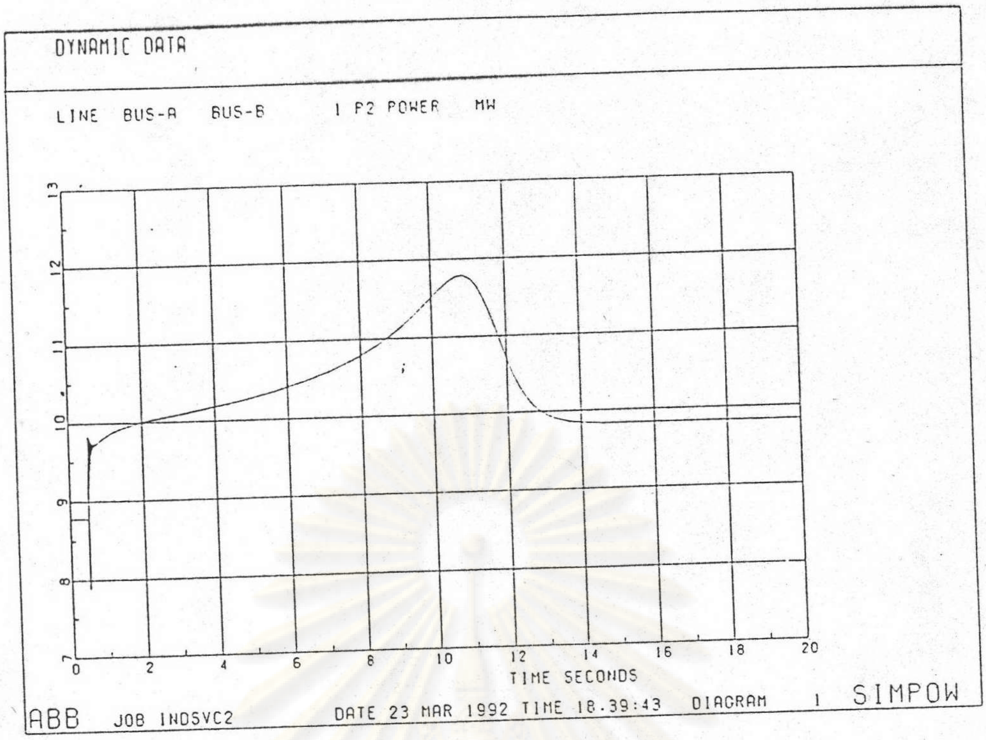


Figure A6.1 POWER INJECTION CURVE AT BUS-B (SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

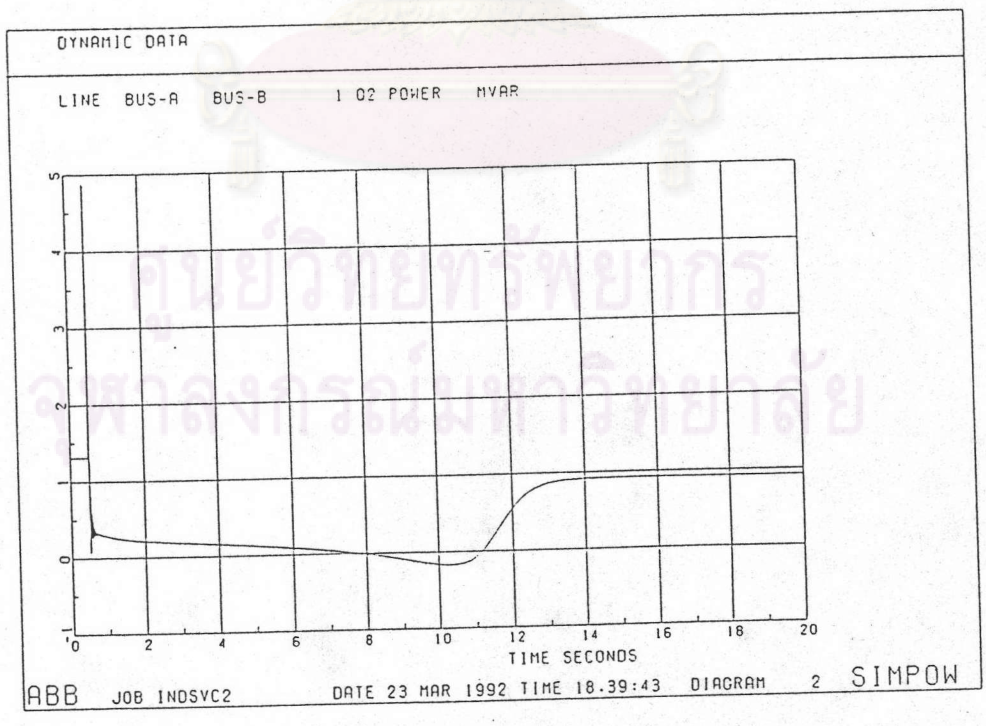


Figure A6.2 REACTIVE POWER INJECTION CURVE AT BUS-B (SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

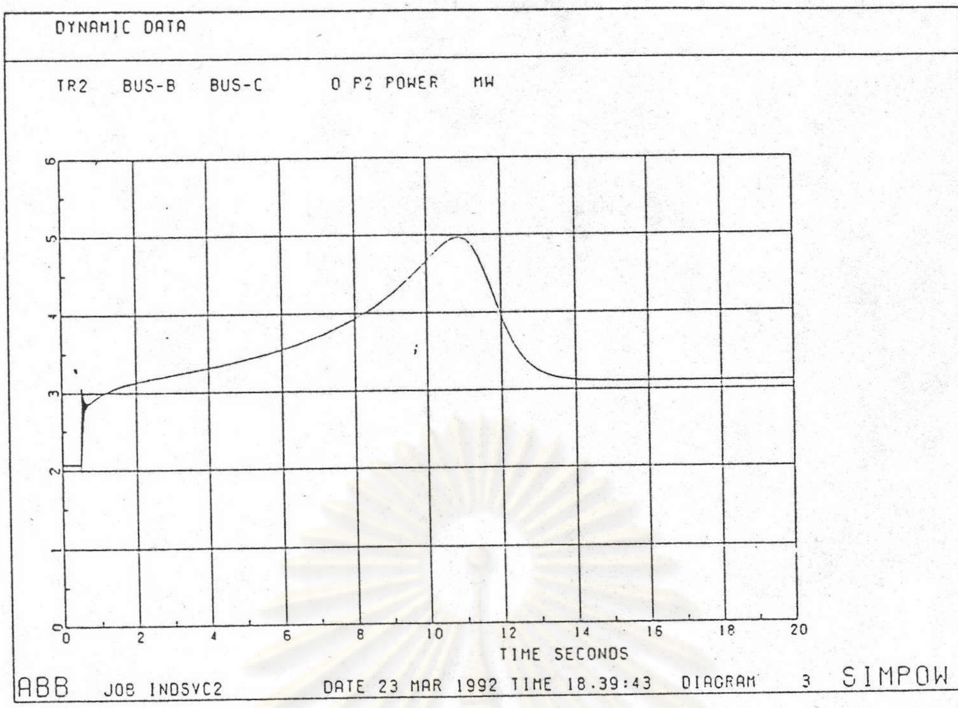


Figure A6.3 POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )


Figure A6.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

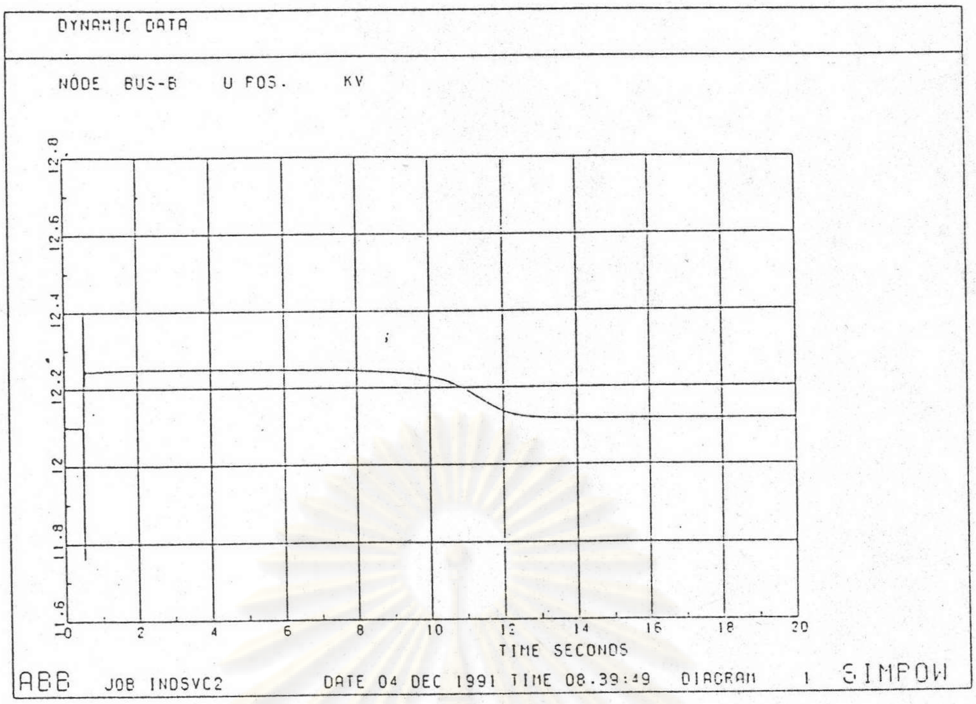


Figure A6.5 VOLTAGE AT BUS-B (SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

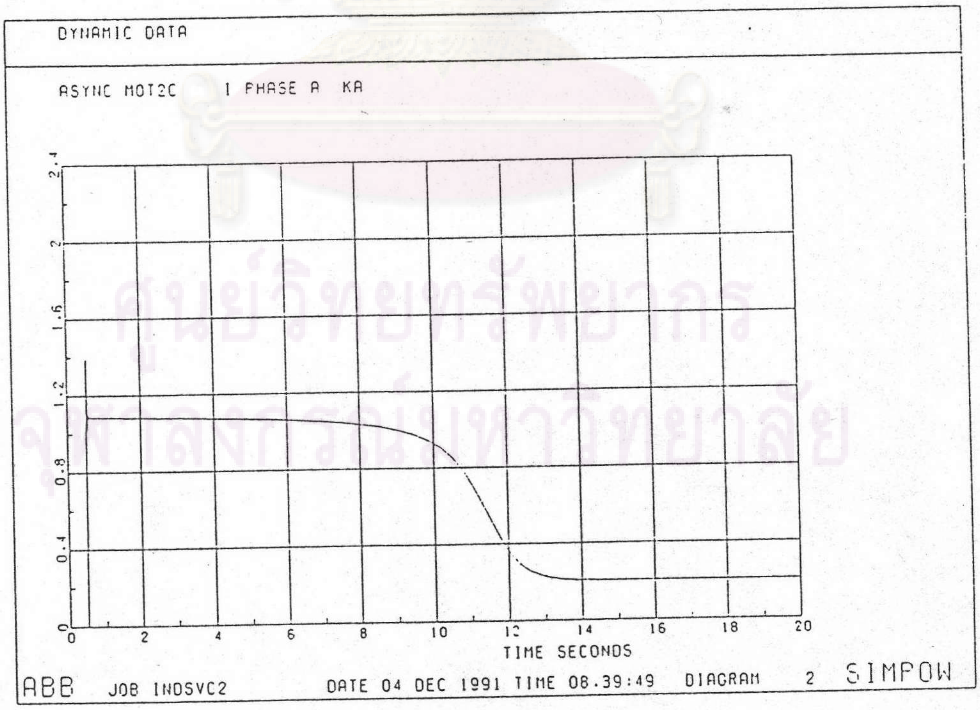


Figure A6.6 ASYNCHRONOUS MOTOR PHASE A CURRENT (SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

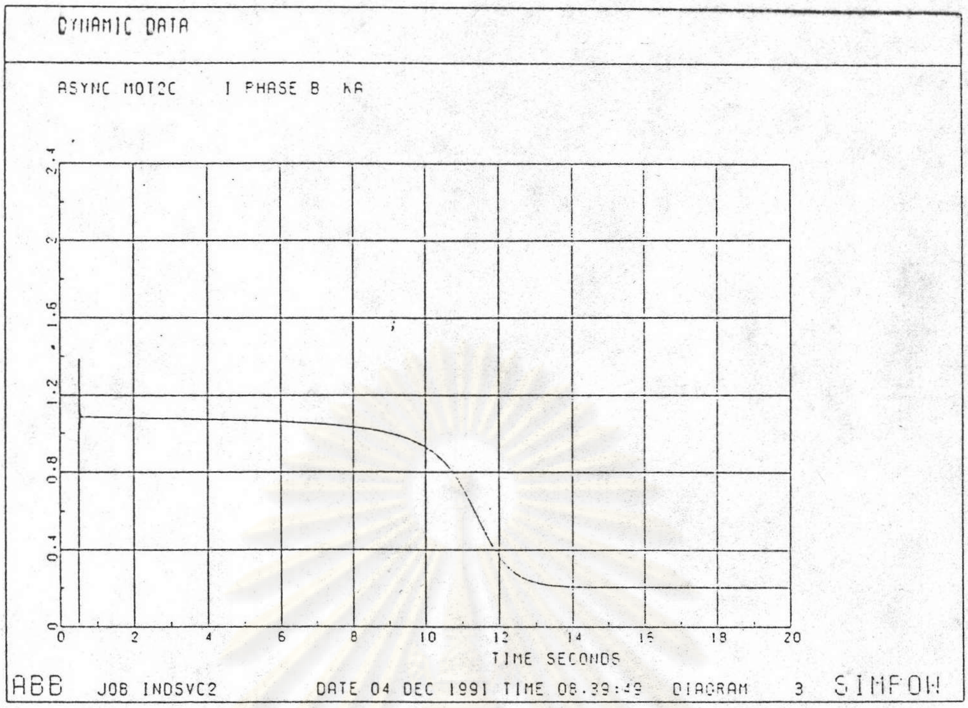


Figure A6.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

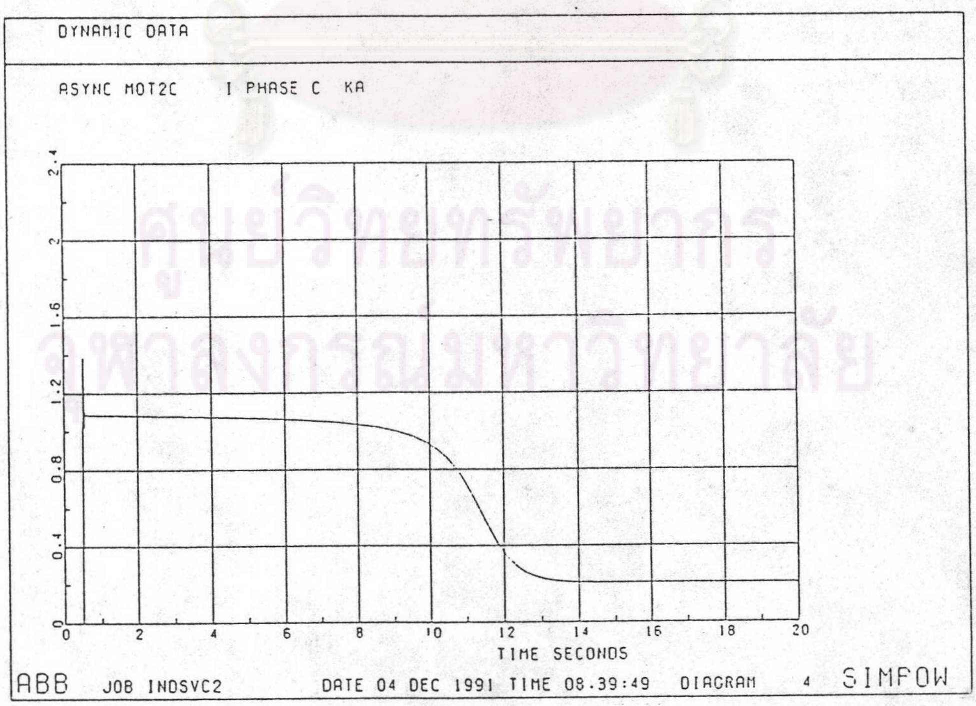


Figure A6.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

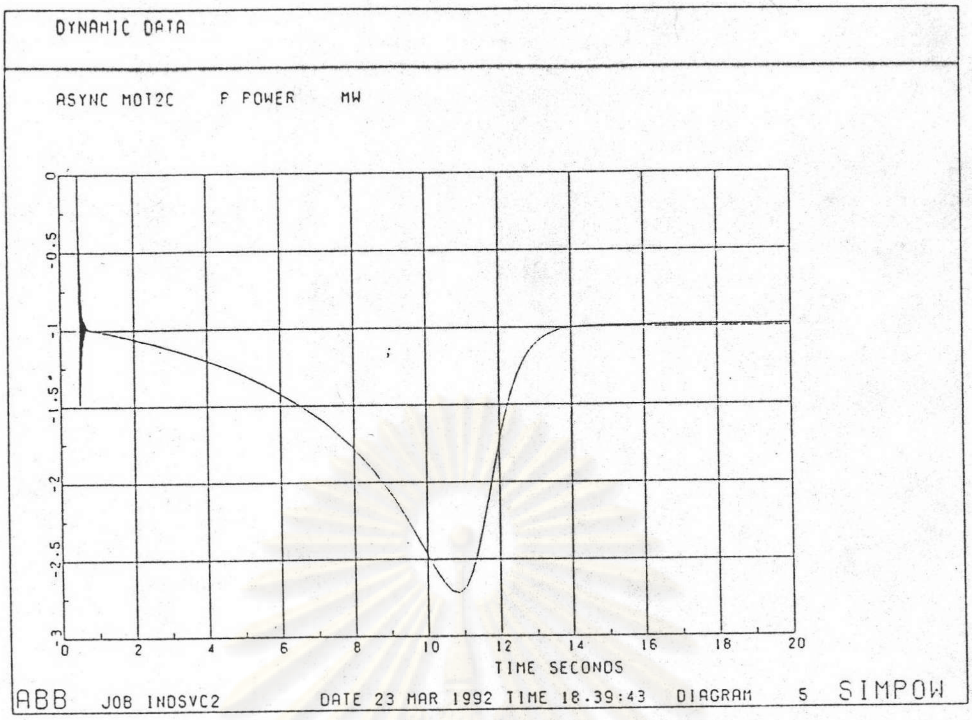


Figure A6.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT (SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

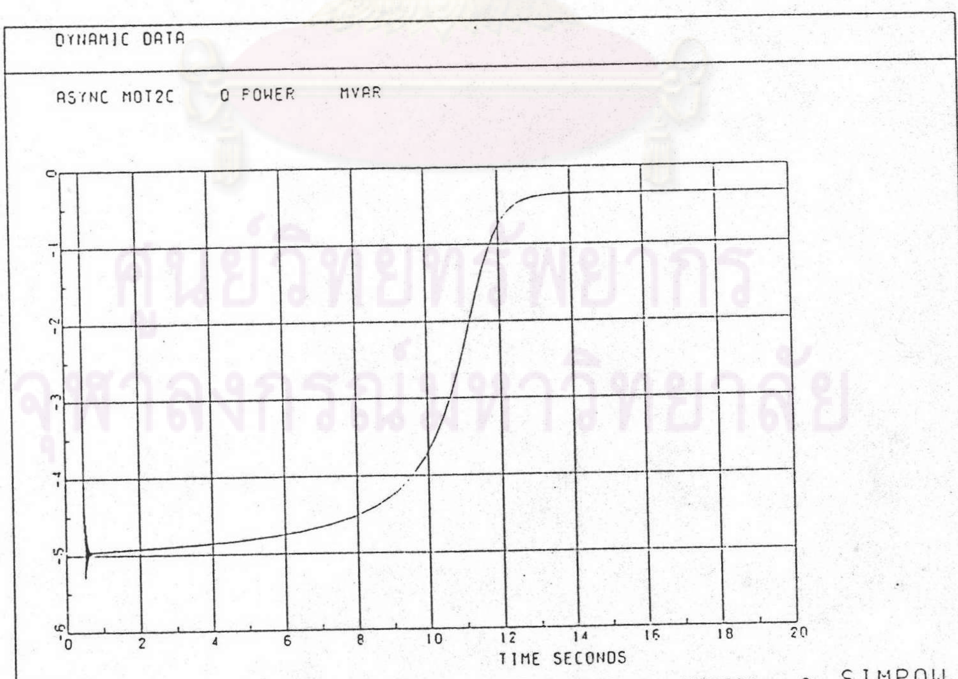


Figure A6.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT (SINGLE DISTRIBUTION LINE WITH SVC TYPE 2 )

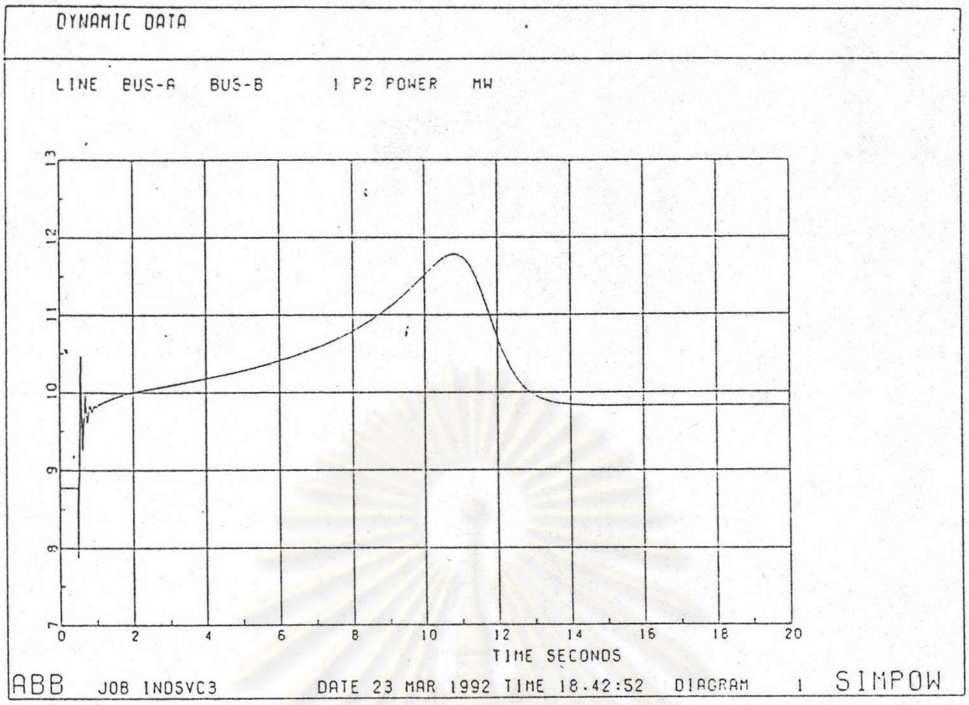


Figure A7.1 POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

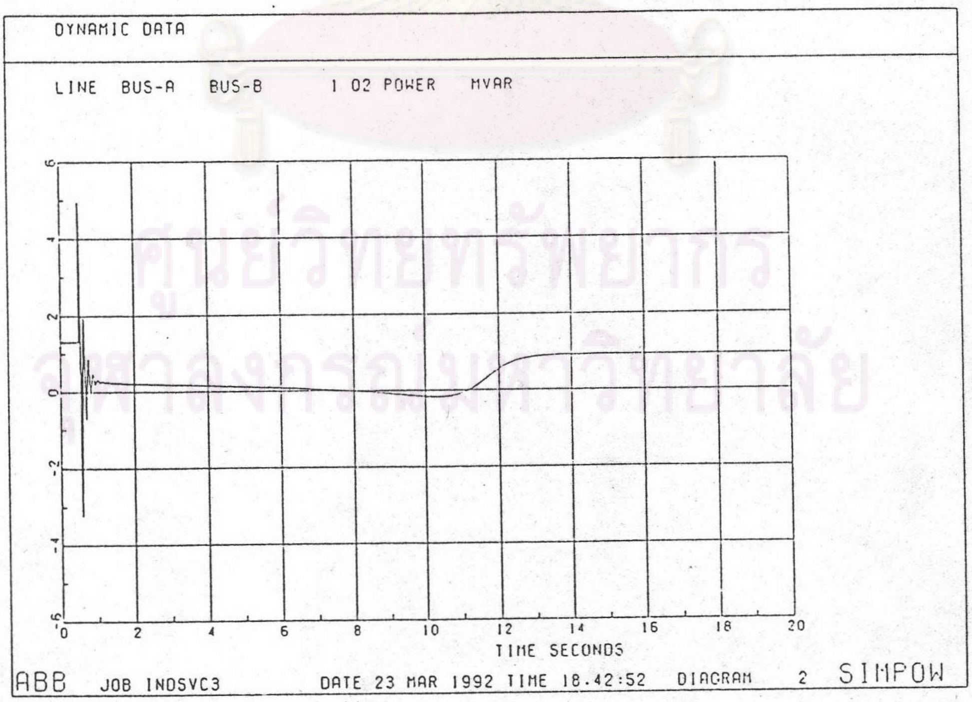


Figure A7.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

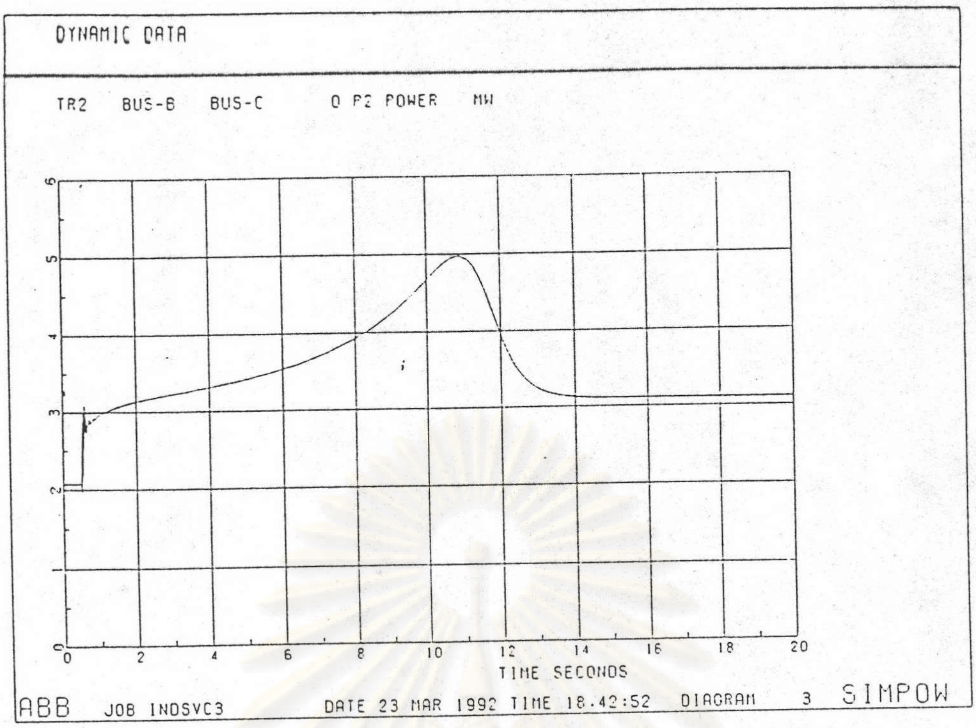


Figure A7.3 POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

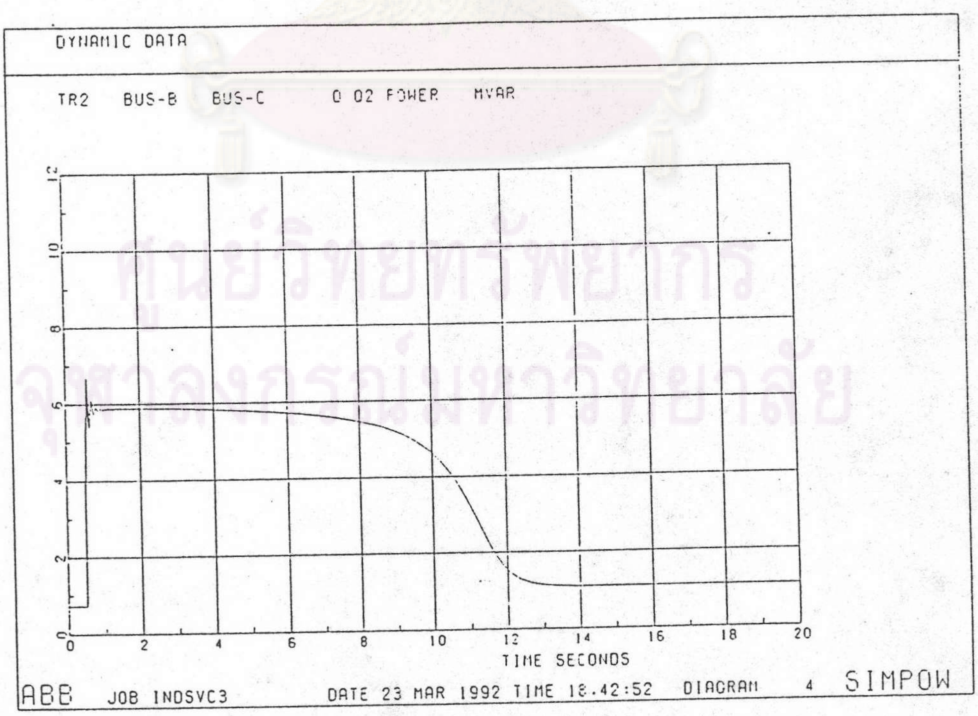


Figure A7.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

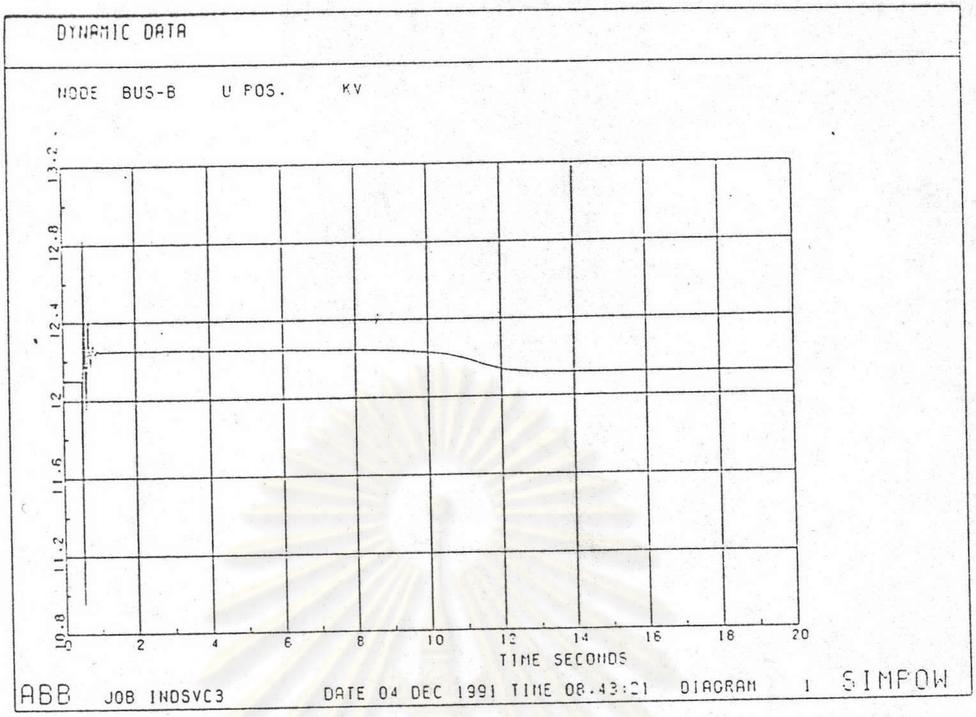


Figure A7.5 VOLTAGE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

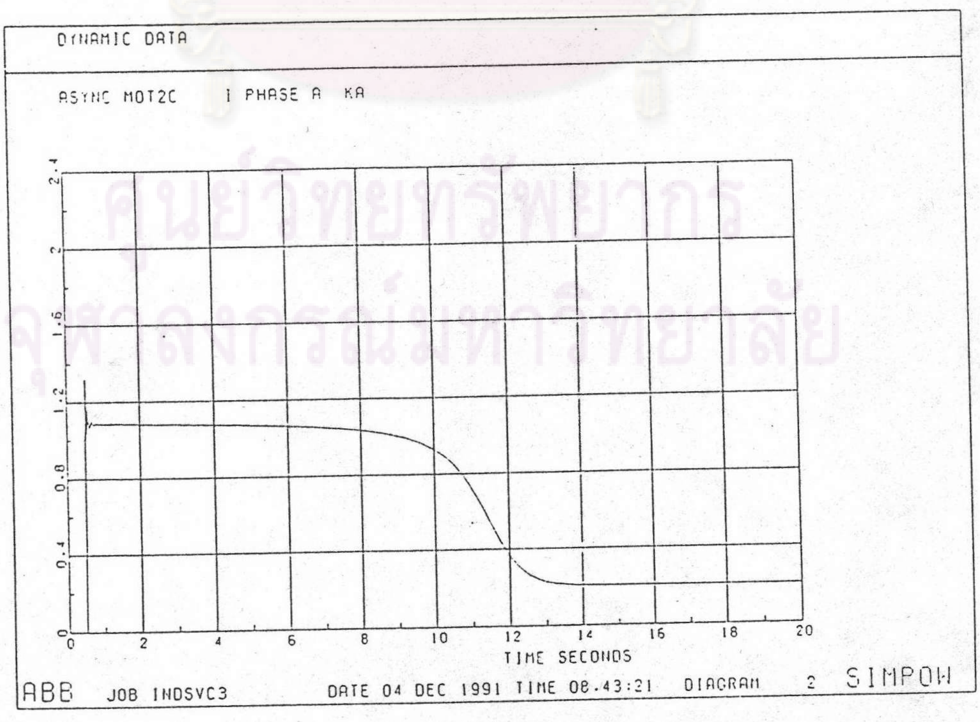


Figure A7.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

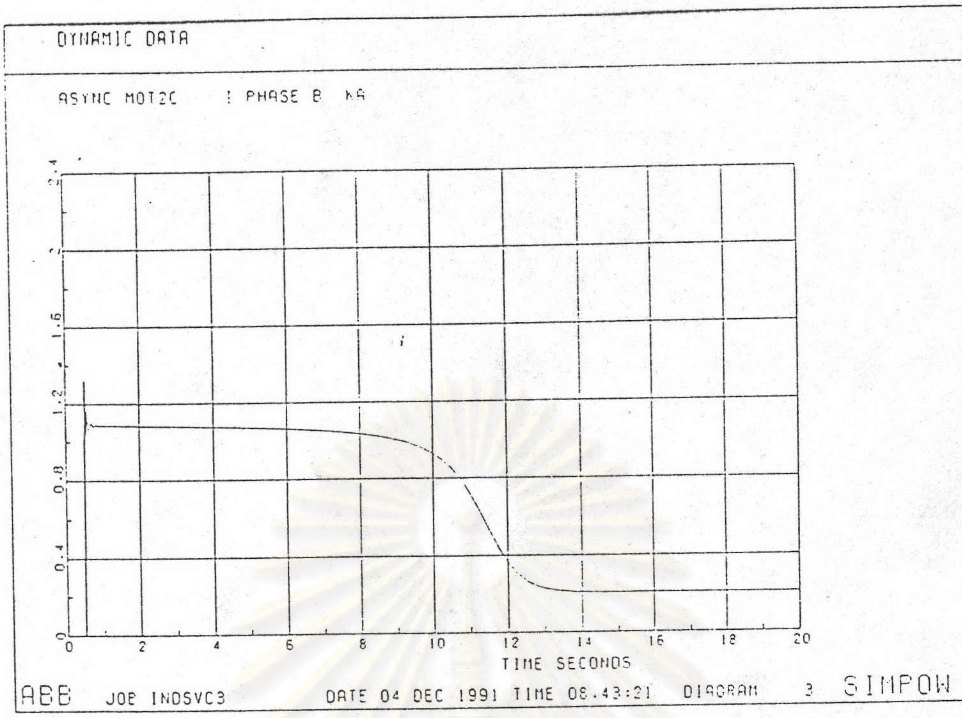


Figure A7.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

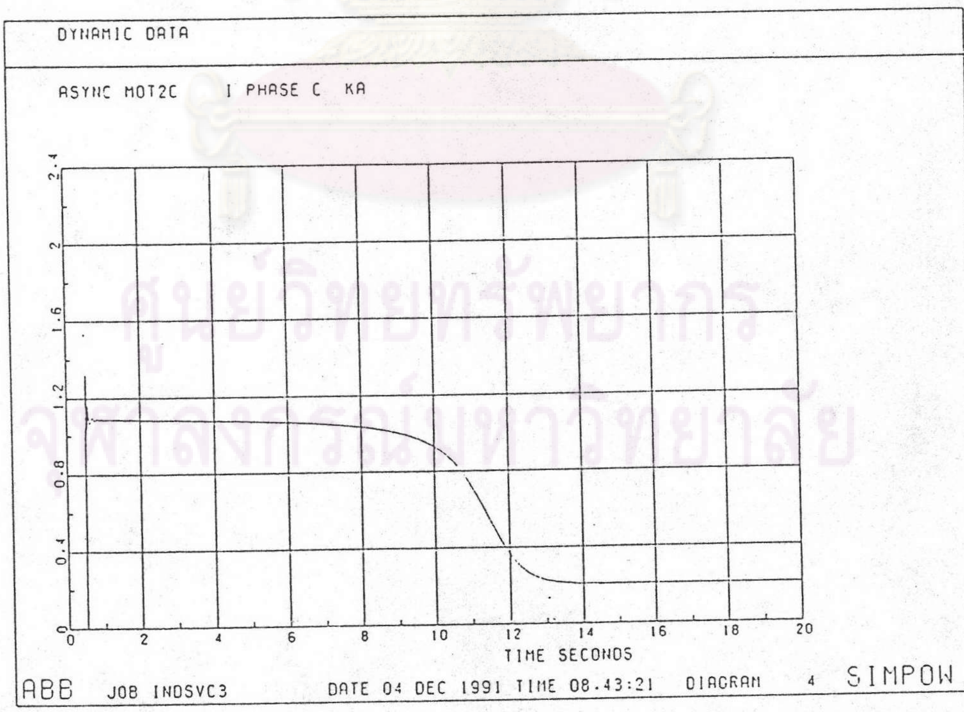


Figure A7.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

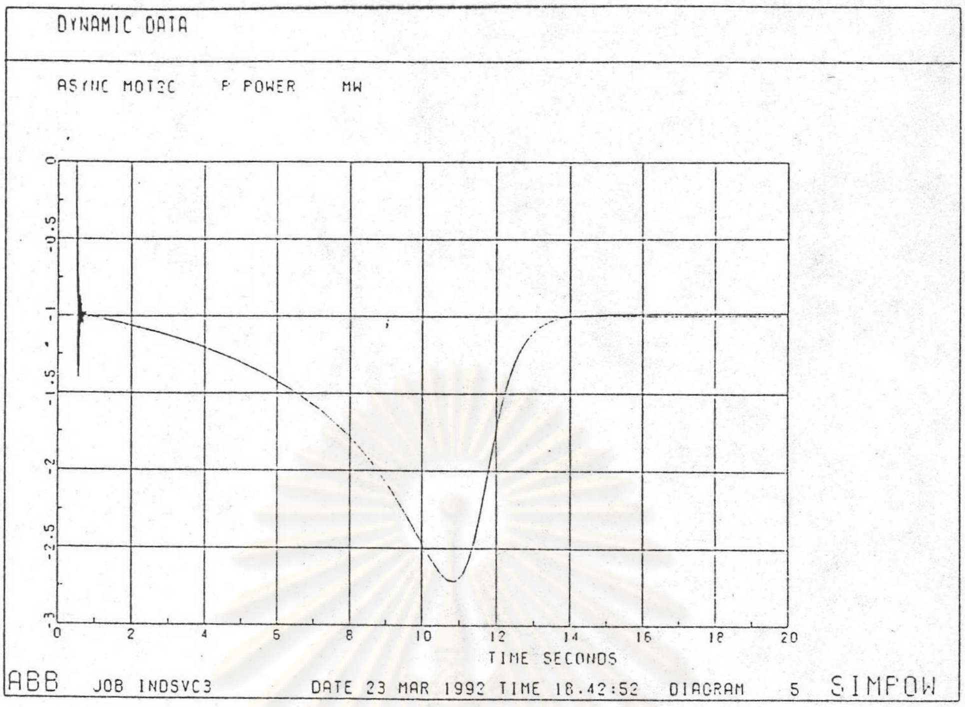


Figure A7.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

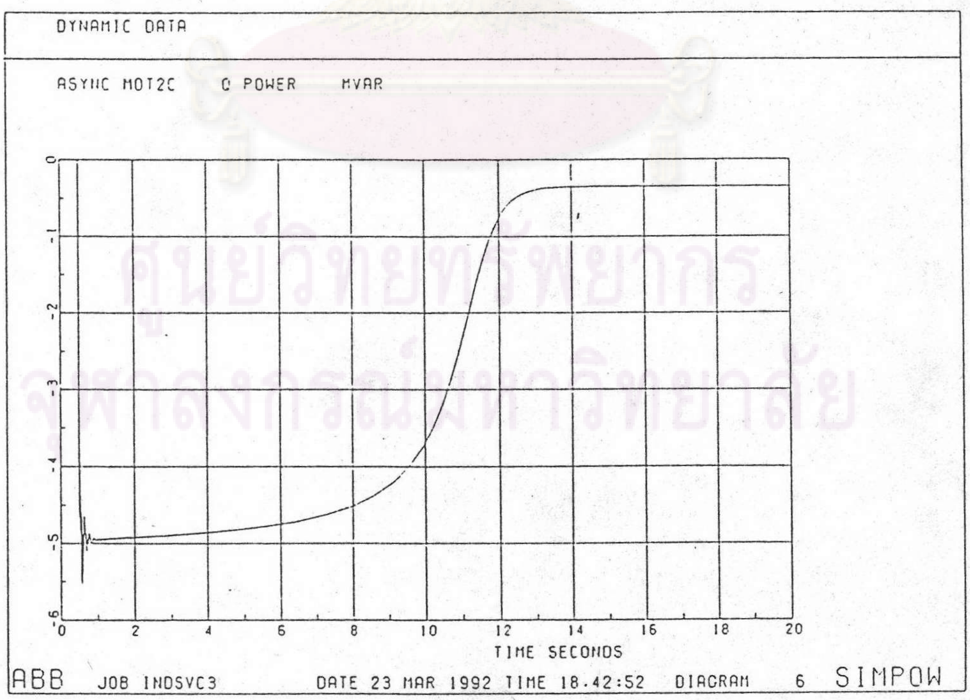


Figure A7.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 3 )

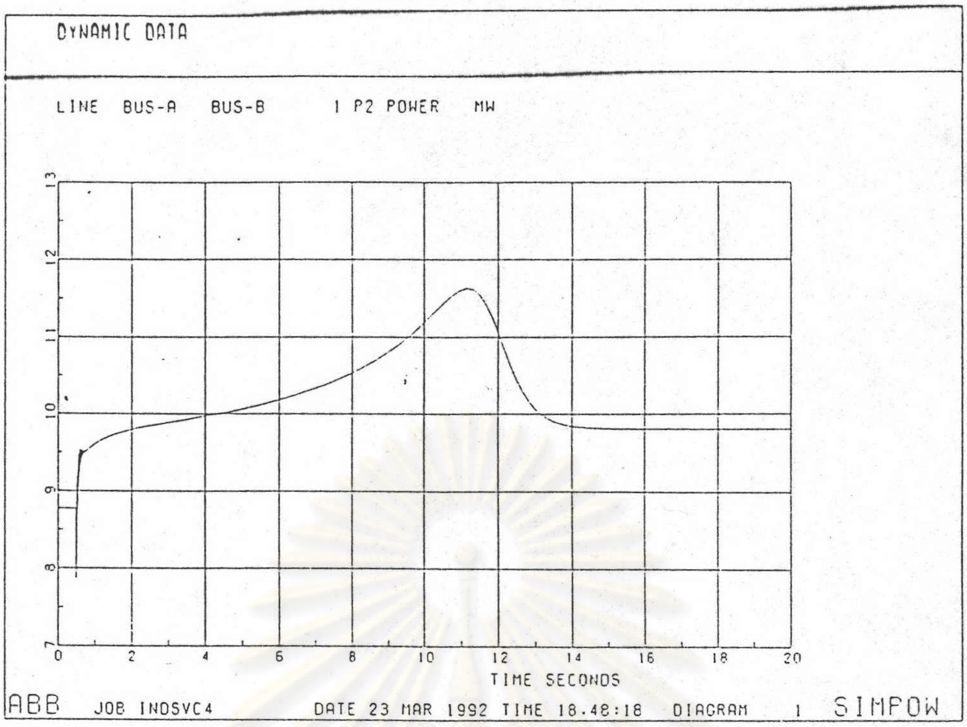


Figure A8.1 POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

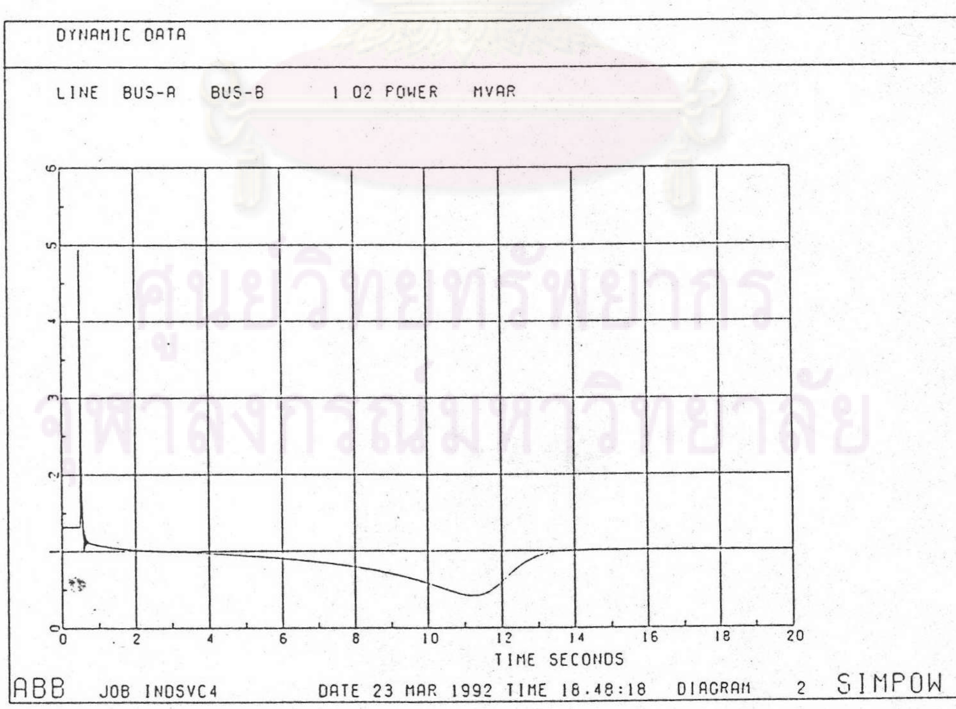


Figure A8.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

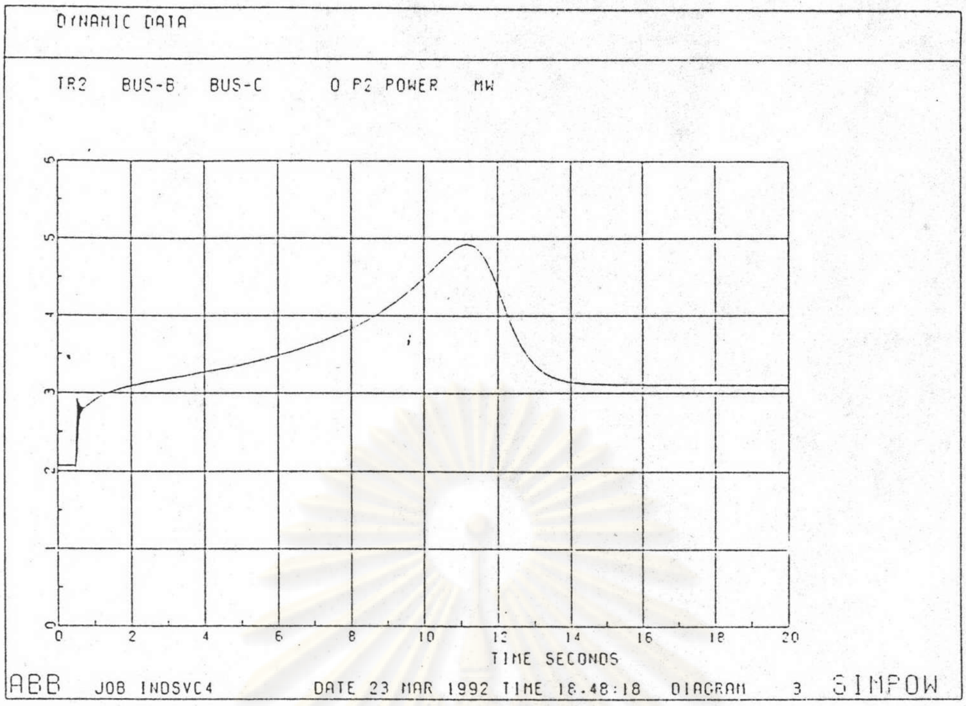


Figure A8.3 POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

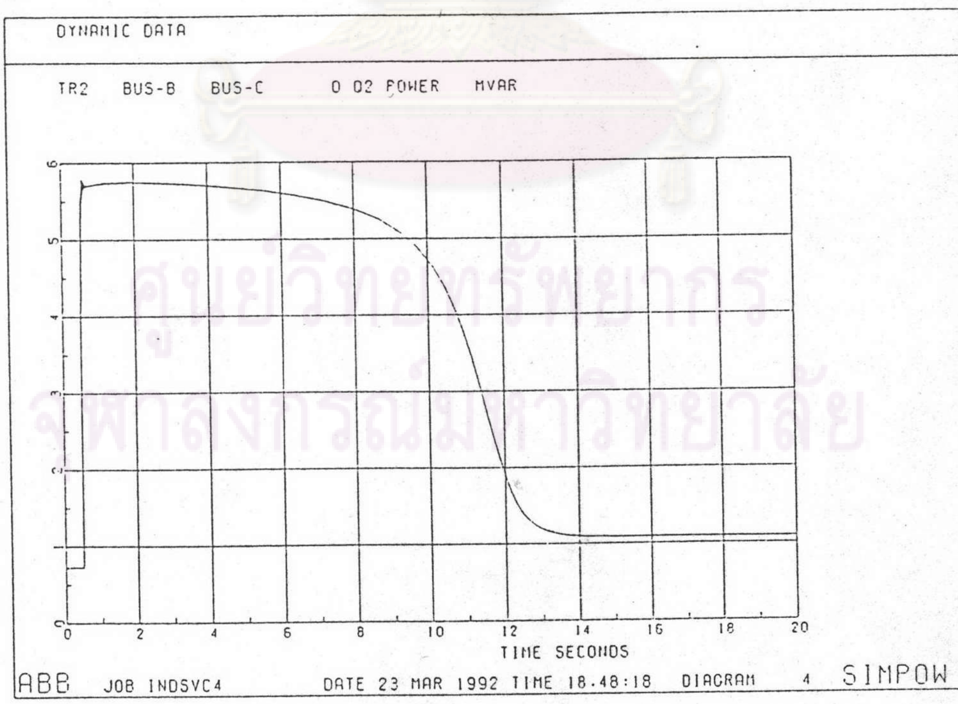


Figure A8.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

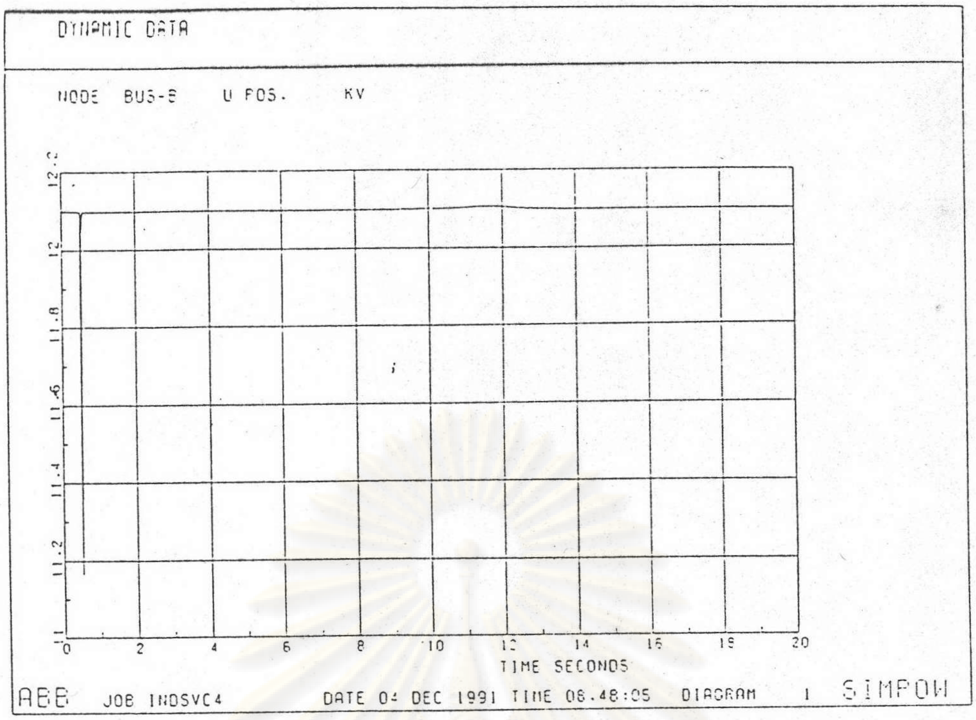


Figure A8.5 VOLTAGE AT BUS-B
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

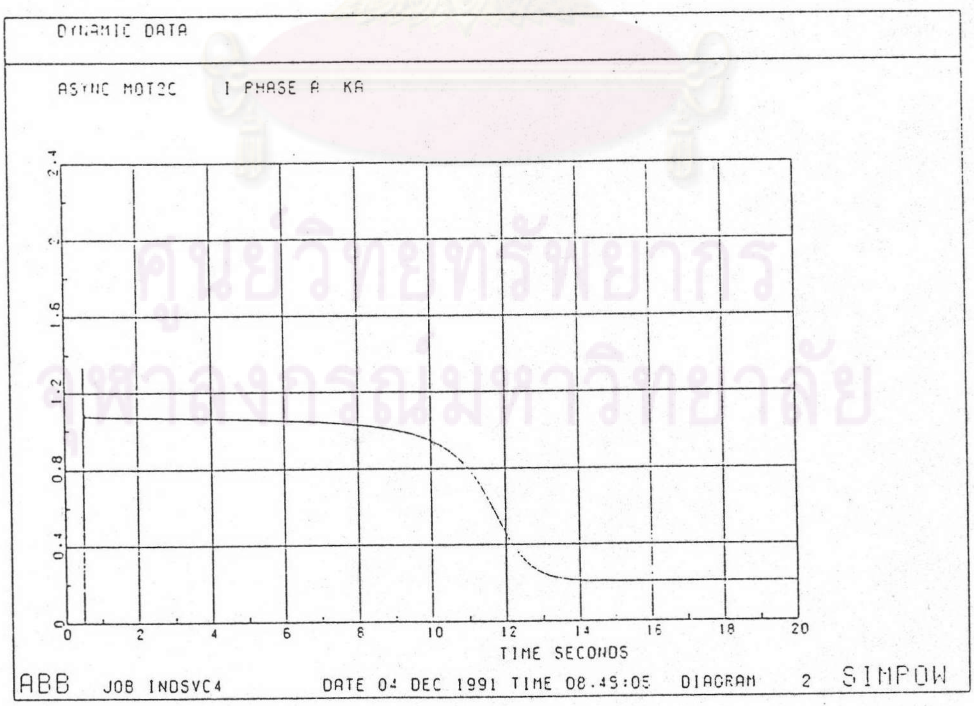


Figure A8.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

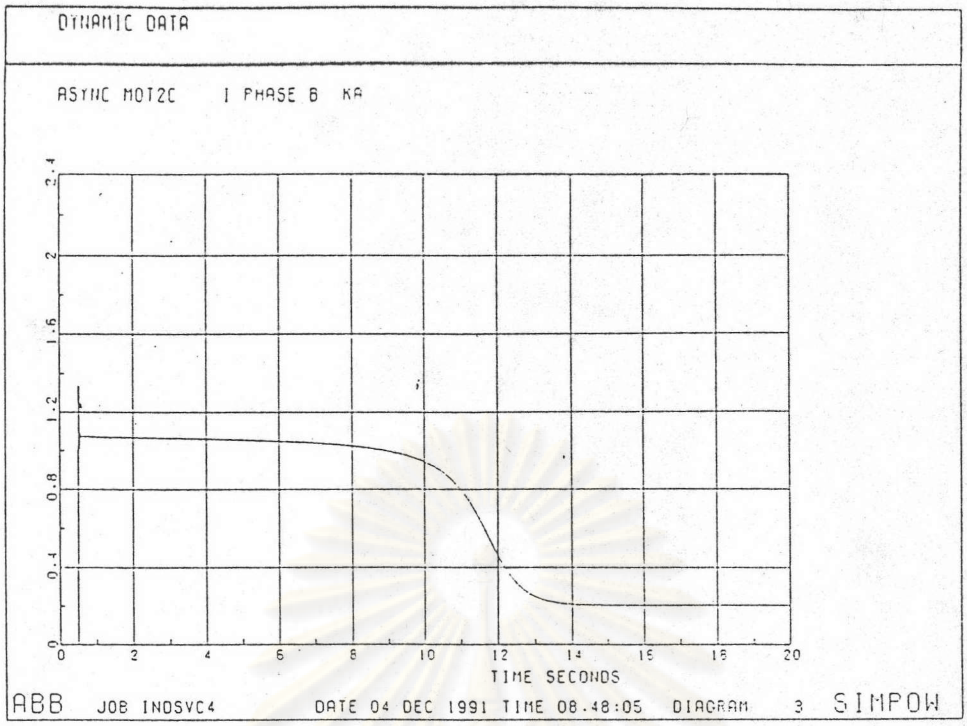


Figure A8.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

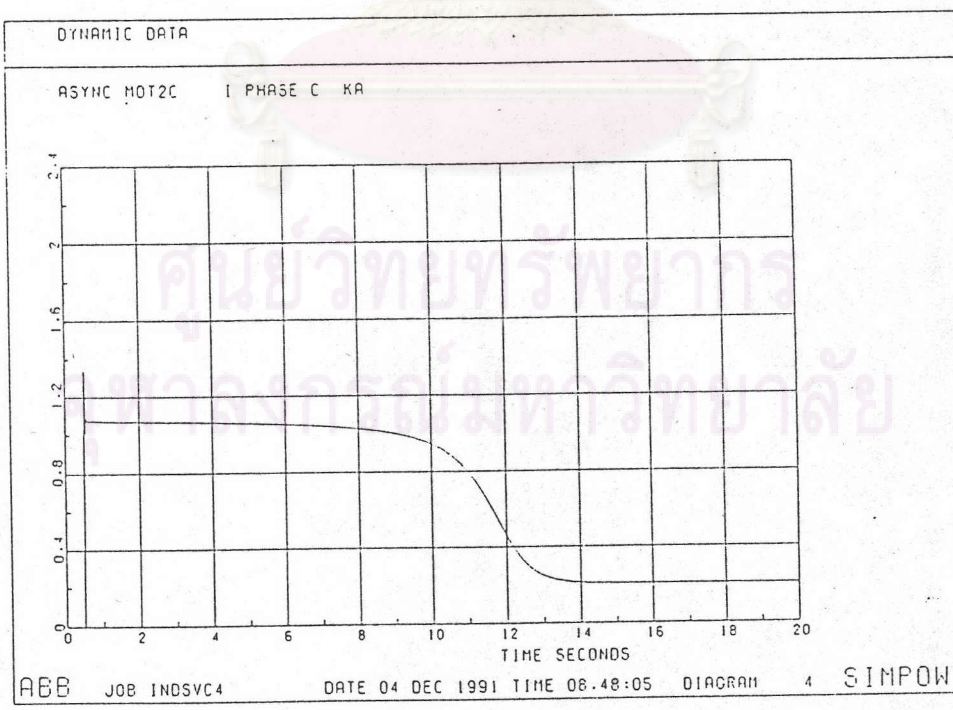




Figure A8.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

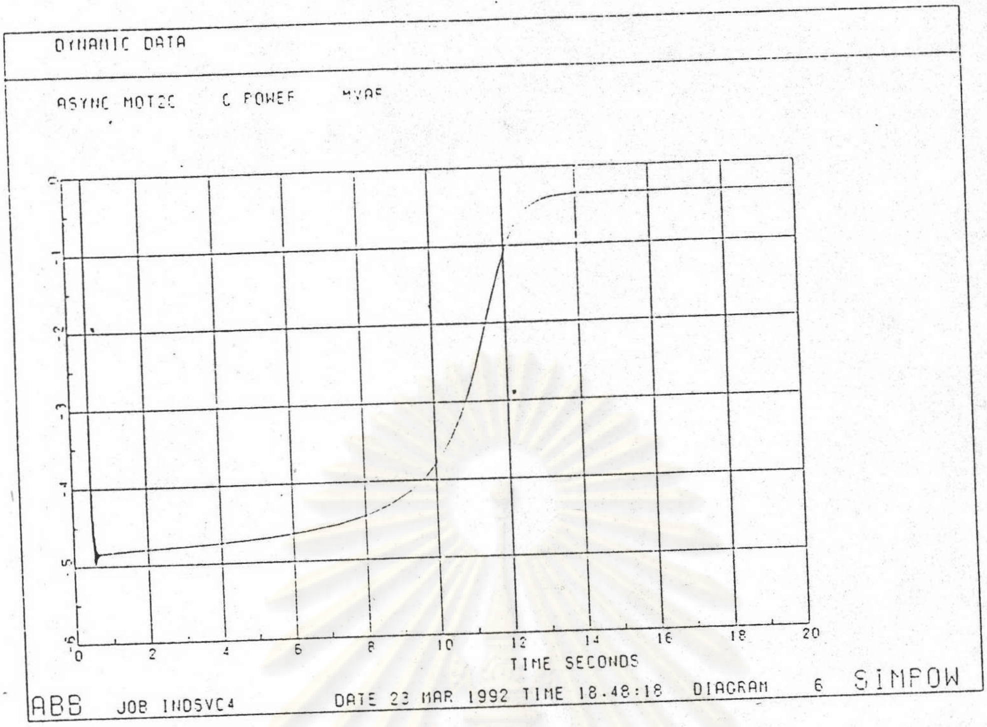


Figure A8.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

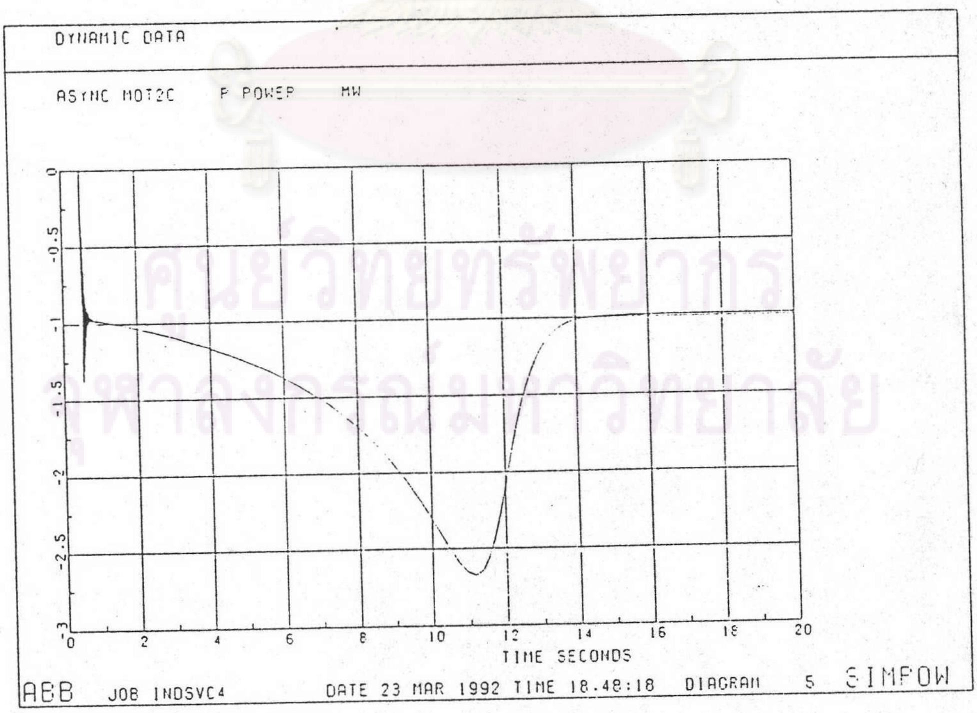


Figure A8.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(SINGLE DISTRIBUTION LINE WITH SVC TYPE 4 )

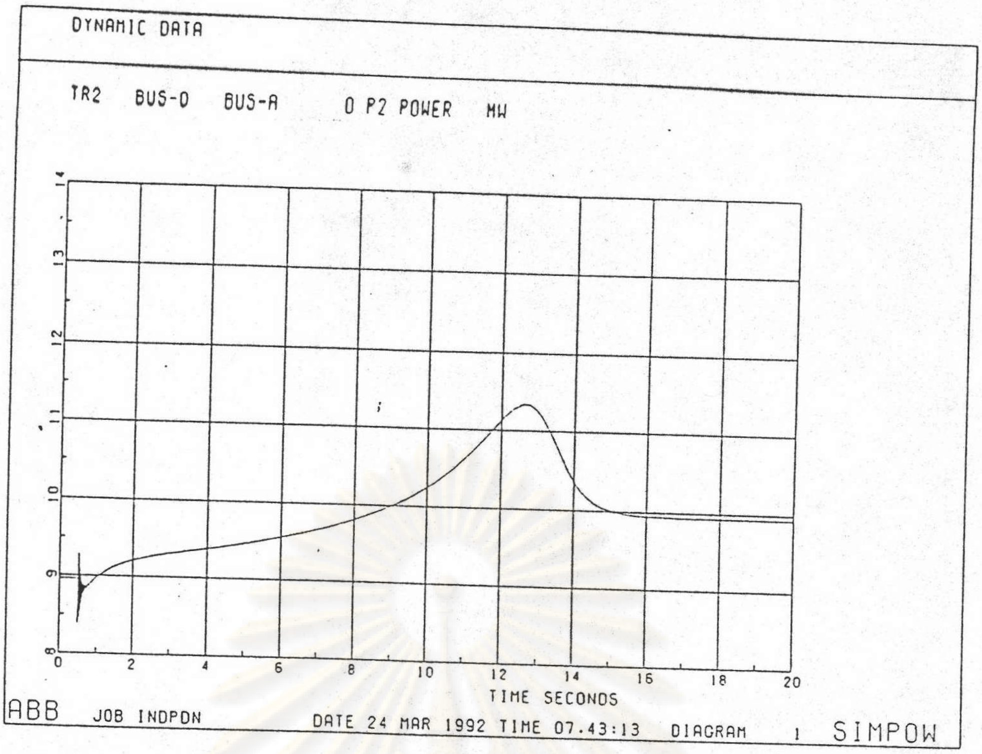


Figure A9.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)

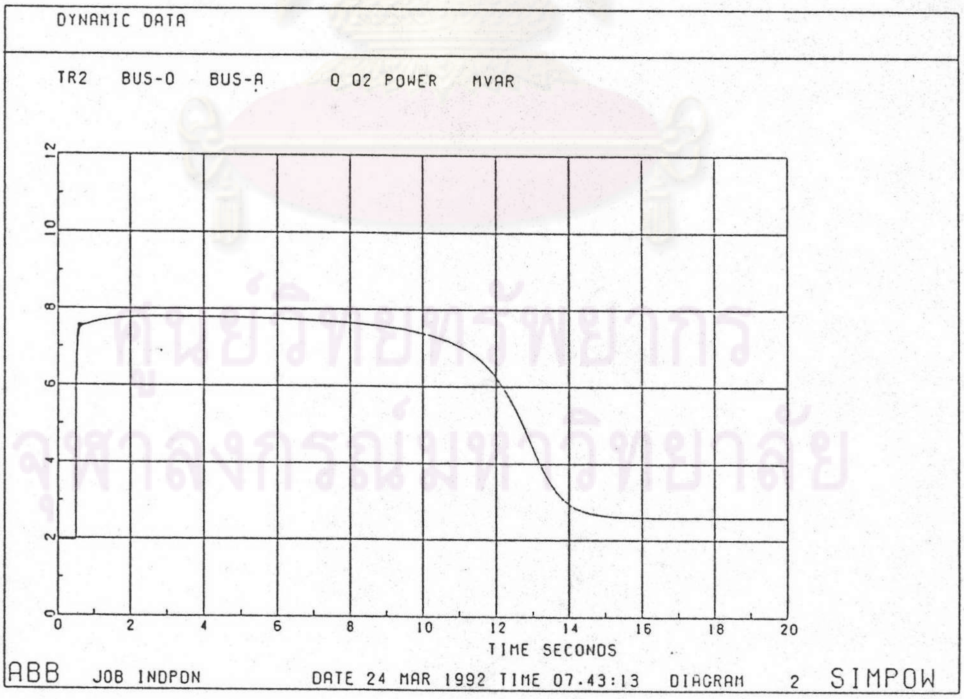


Figure A9.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)

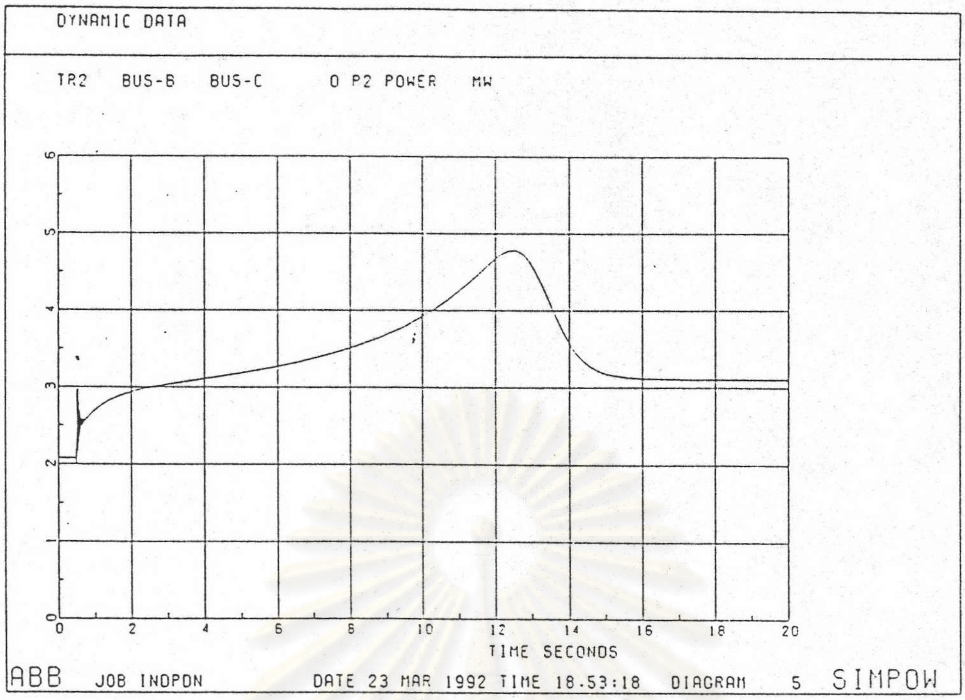


Figure A9.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)


Figure A9.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)

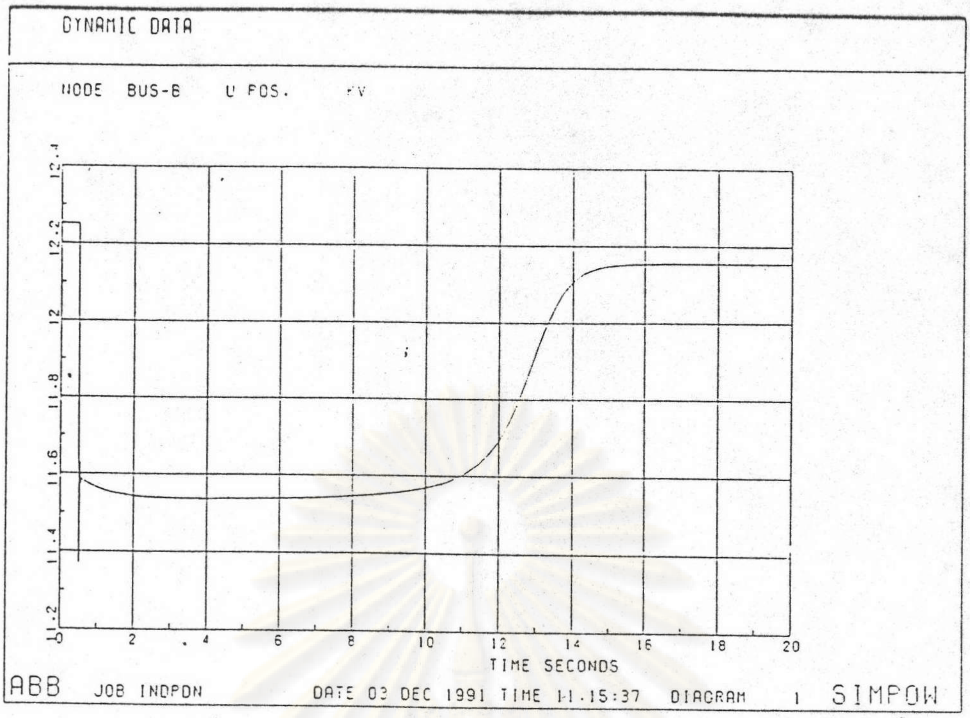


Figure A9.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)

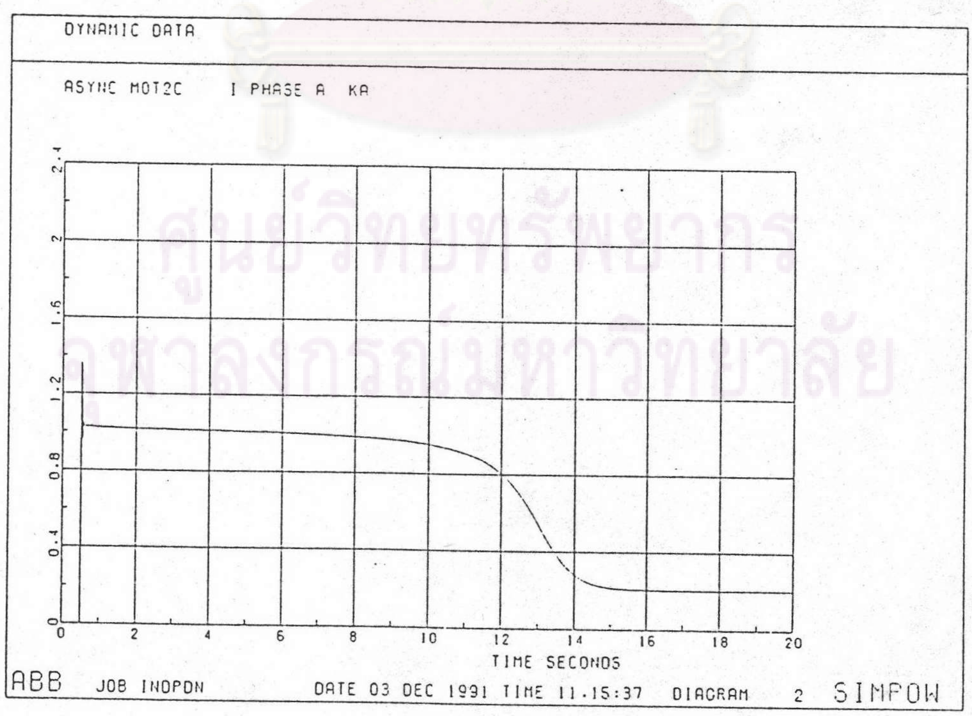


Figure A9.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)

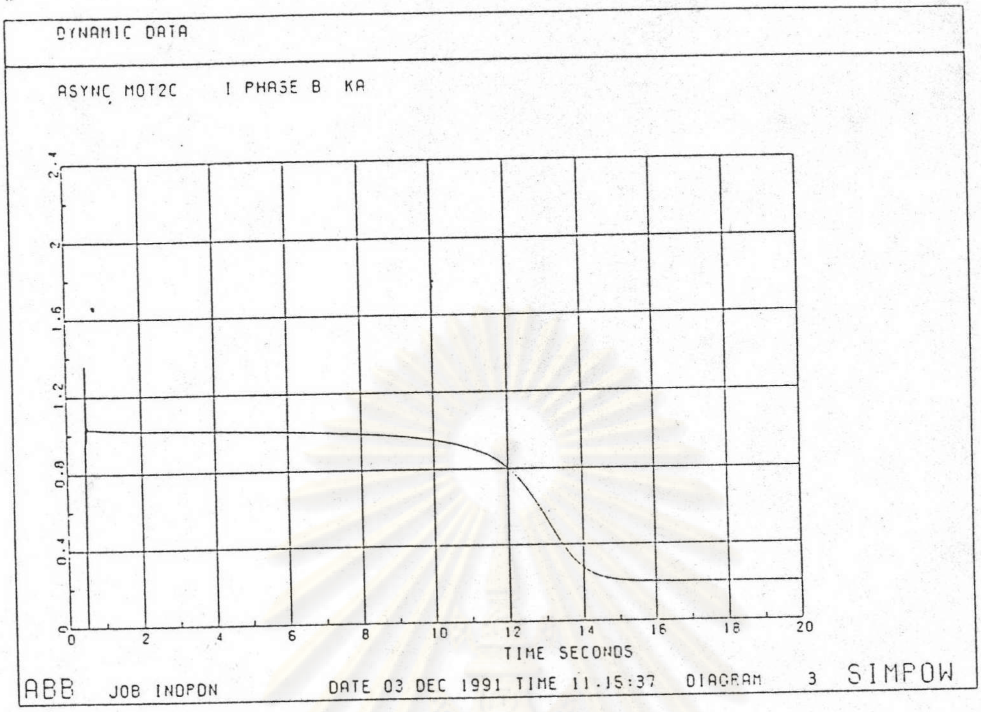


Figure A9.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)



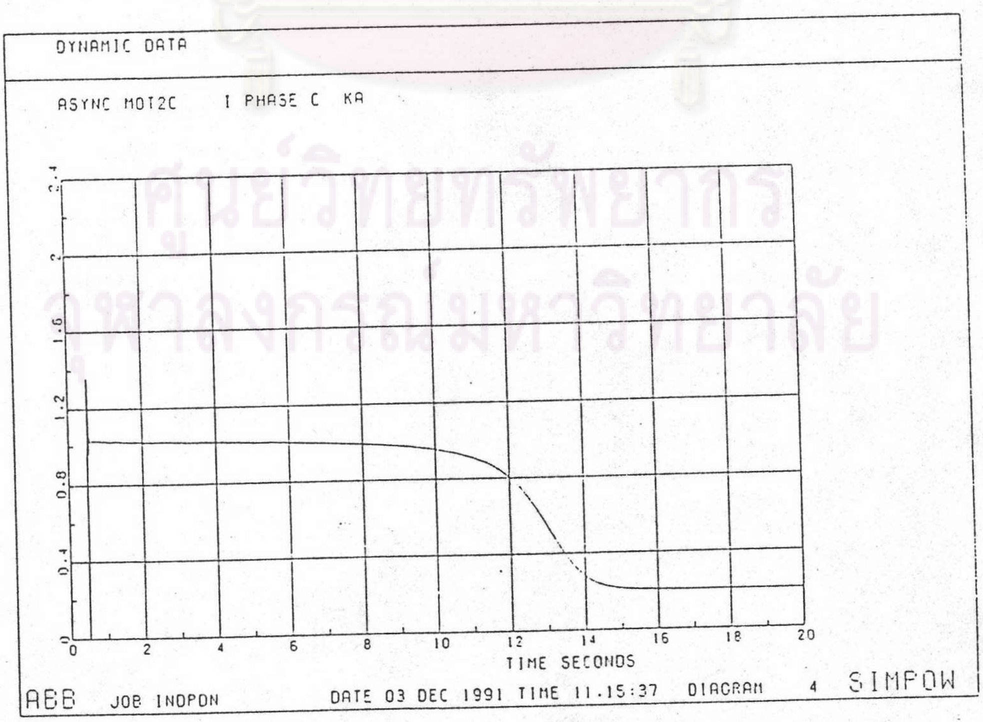


Figure A9.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(DOUBLE DISTRIBUTION LINE USING DOL STARTING)

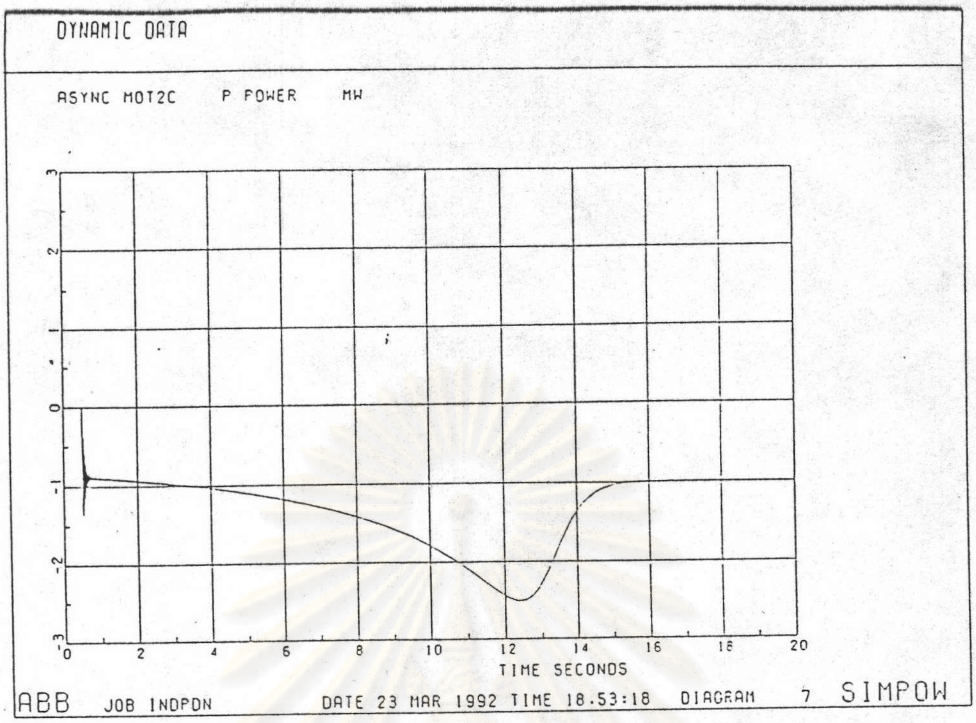


Figure A9.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT (DOUBLE DISTRIBUTION LINE USING DOL STARTING)

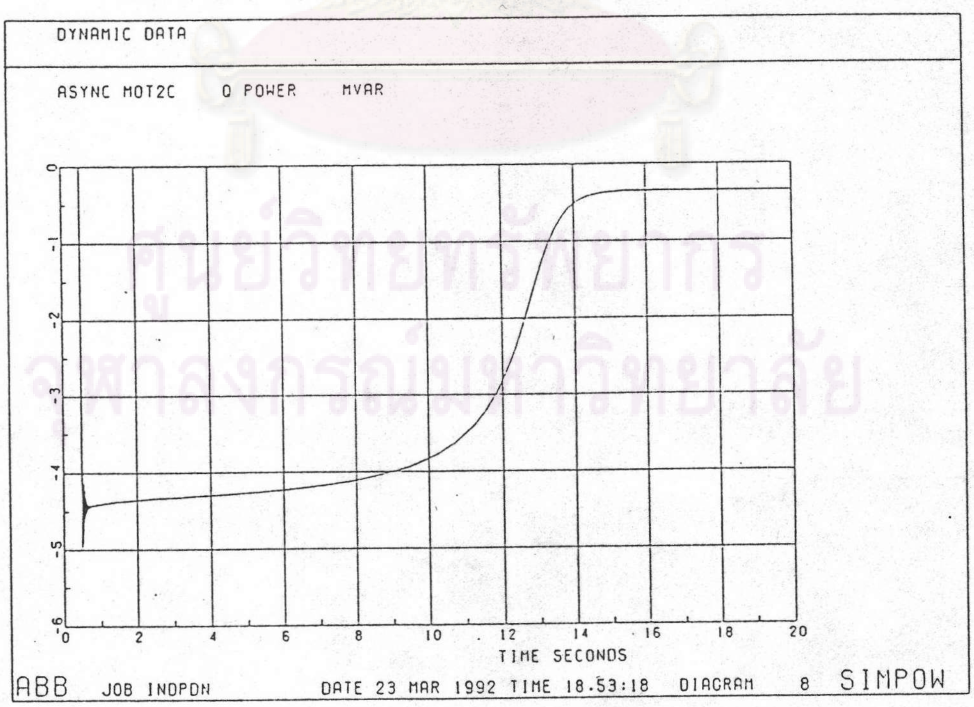


Figure A9.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT (DOUBLE DISTRIBUTION LINE USING DOL STARTING)

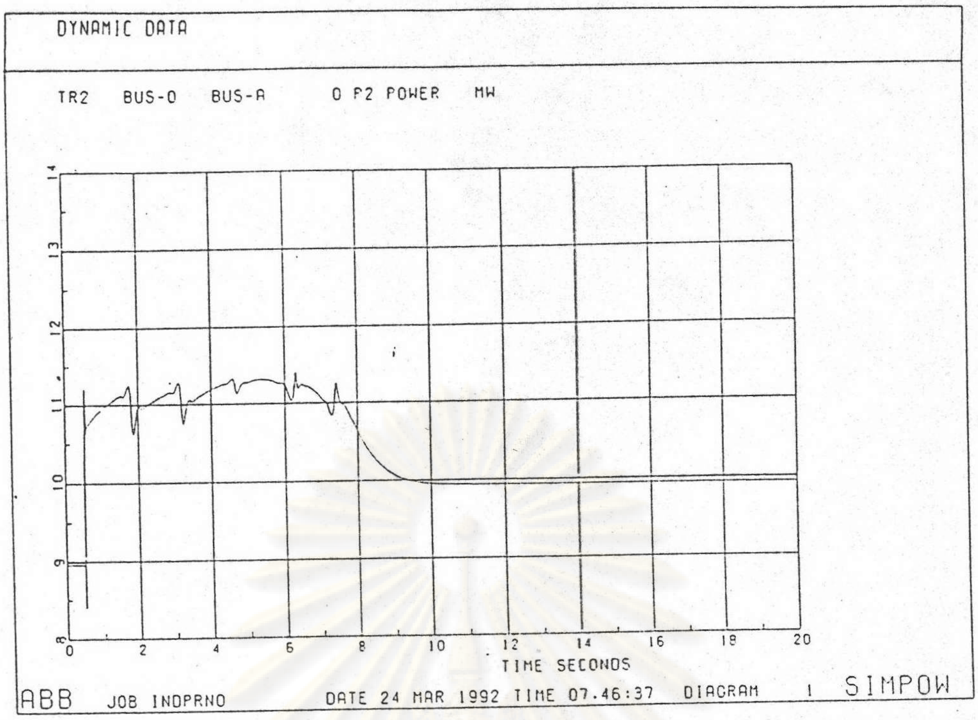


Figure A10.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

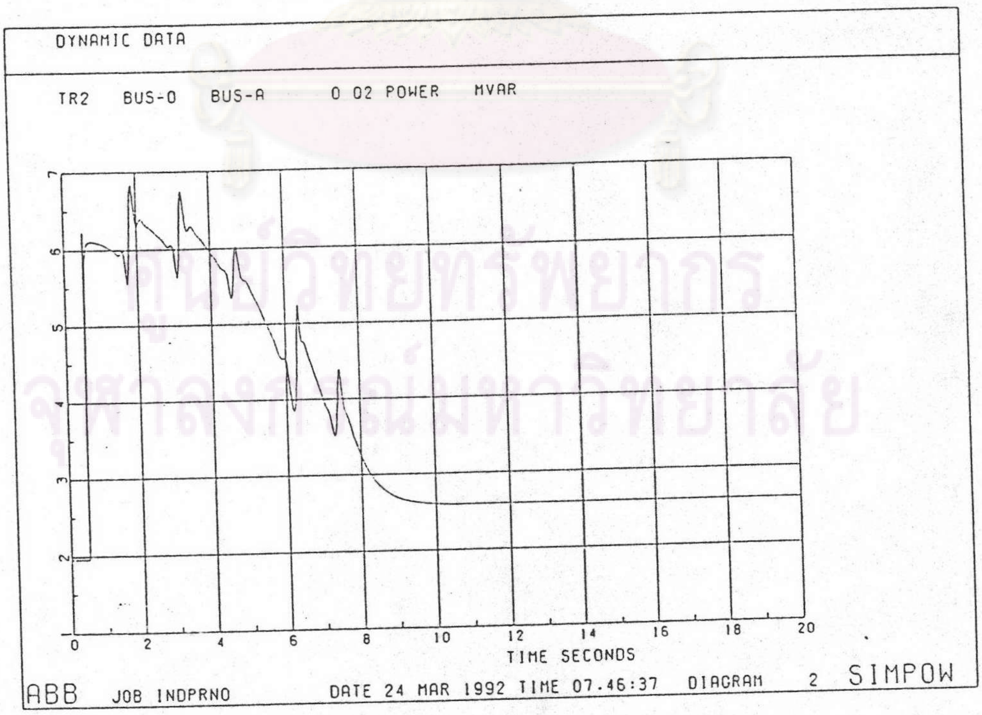


Figure A10.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

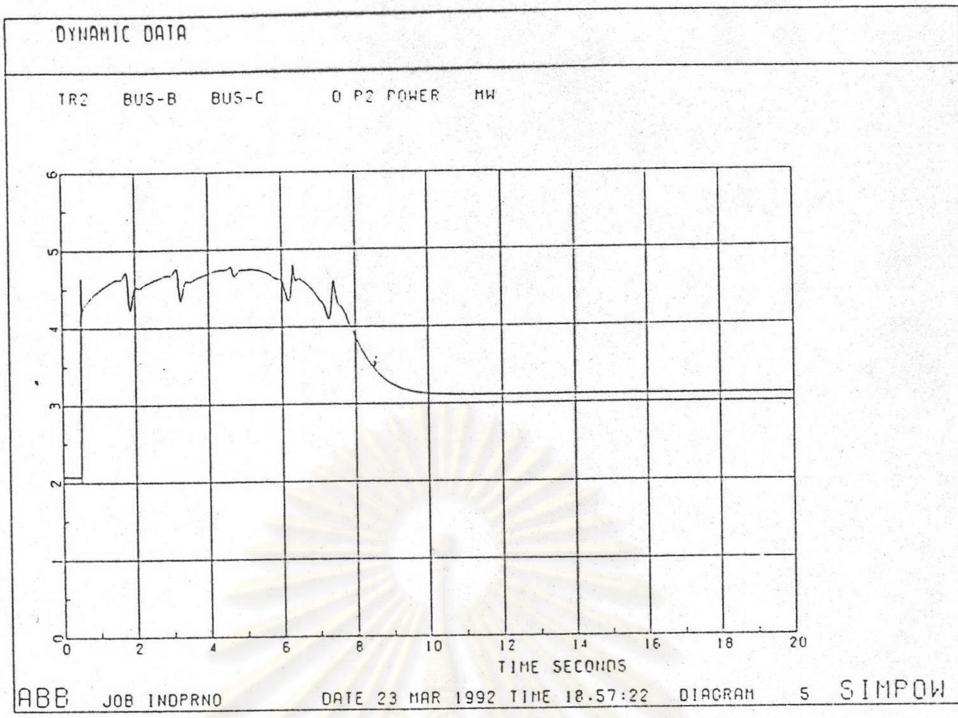


Figure A10.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

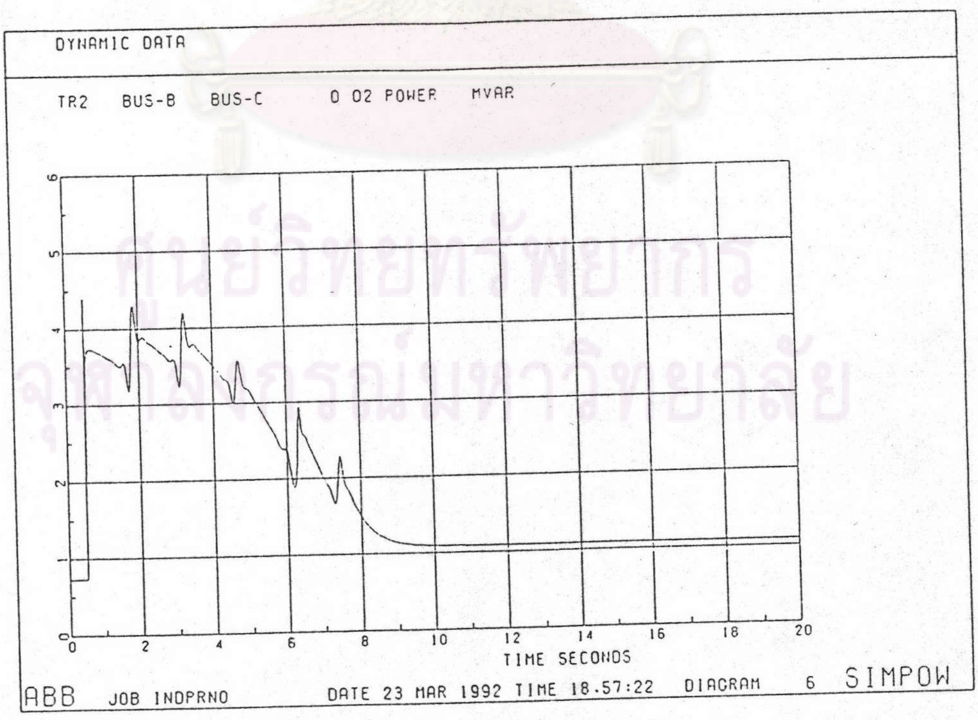


Figure A10.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

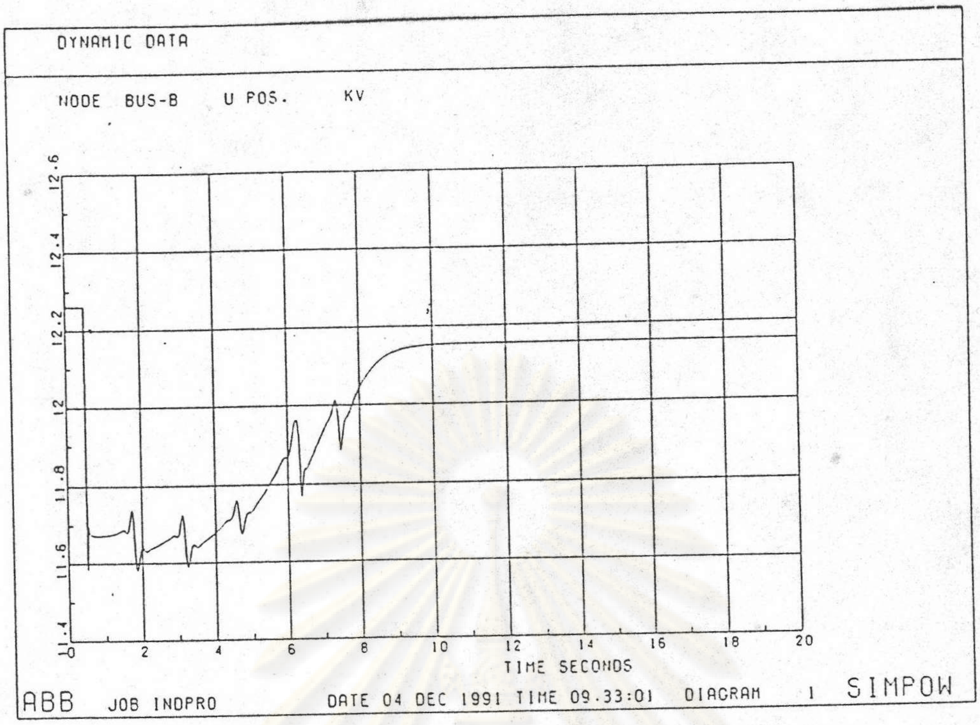


Figure A10.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

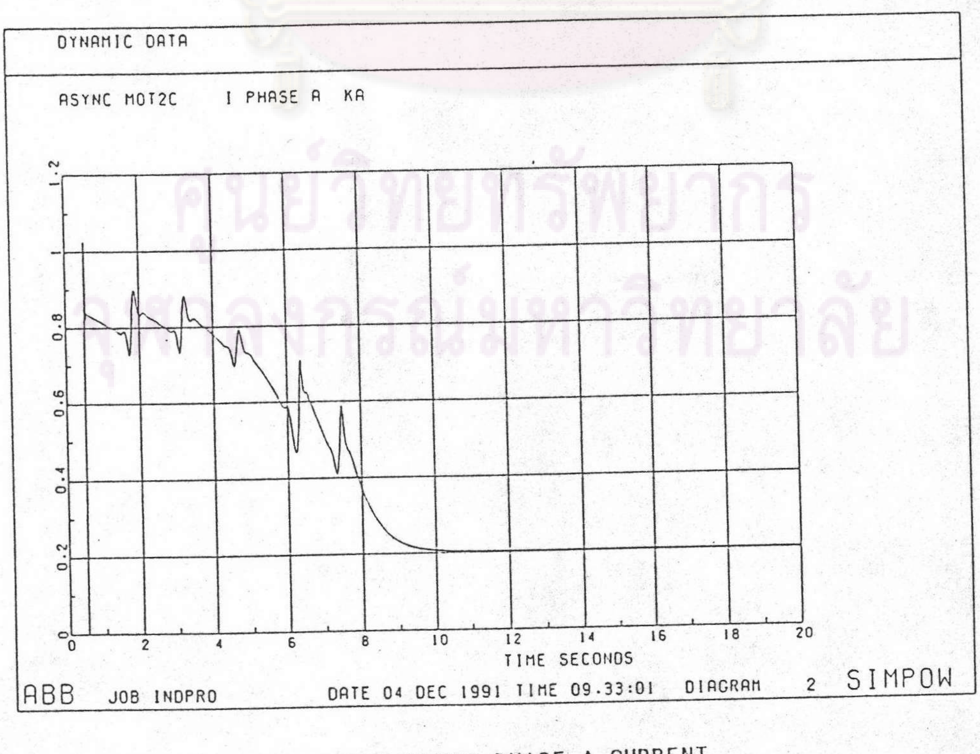


Figure A10.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

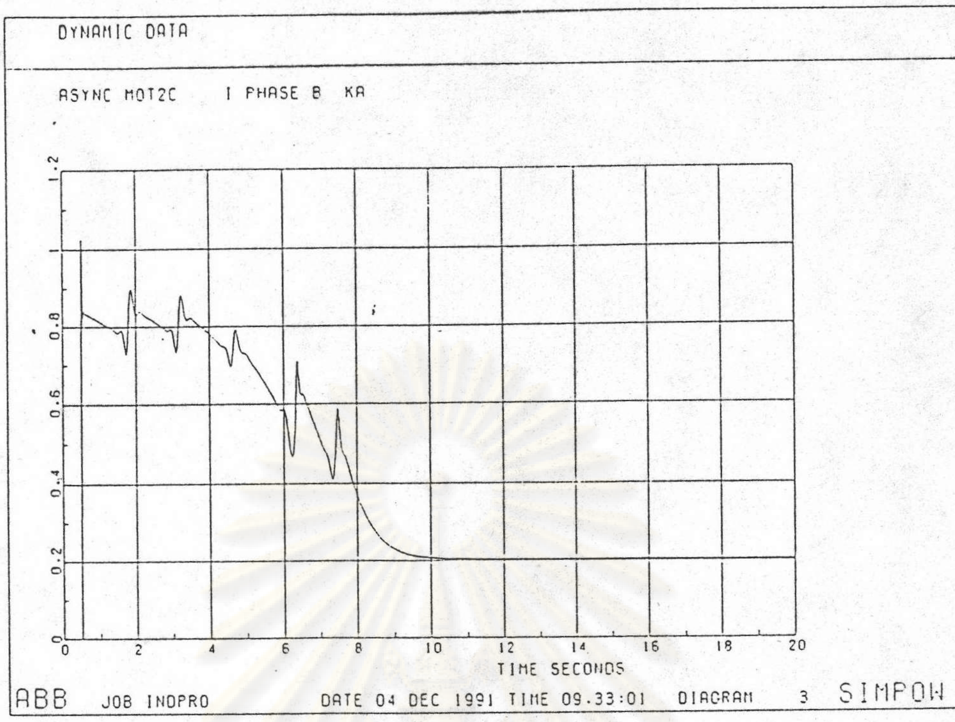


Figure A10.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

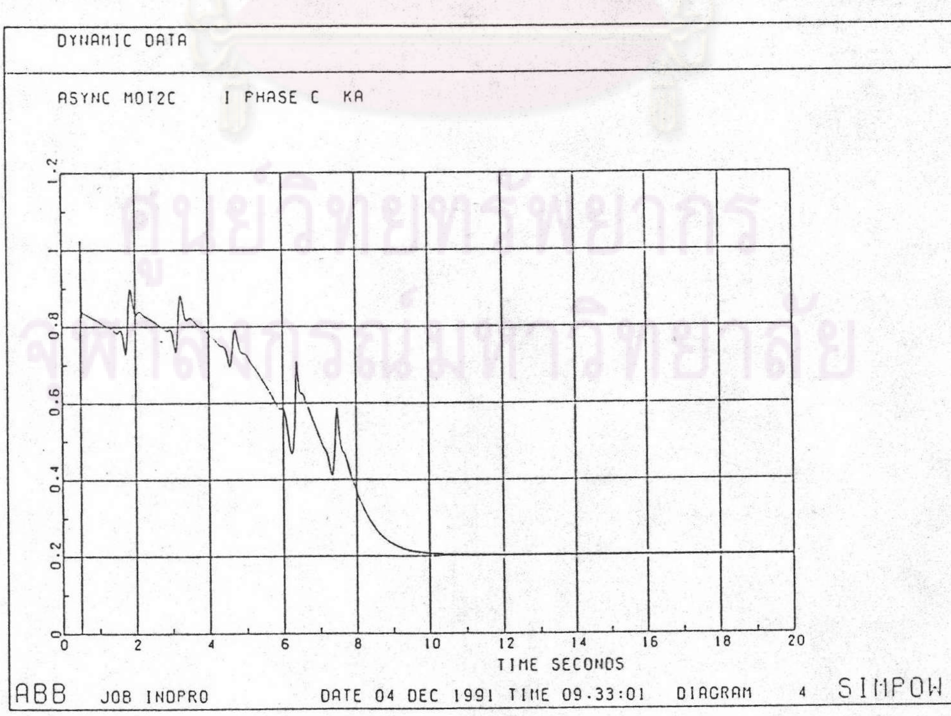


Figure A10.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

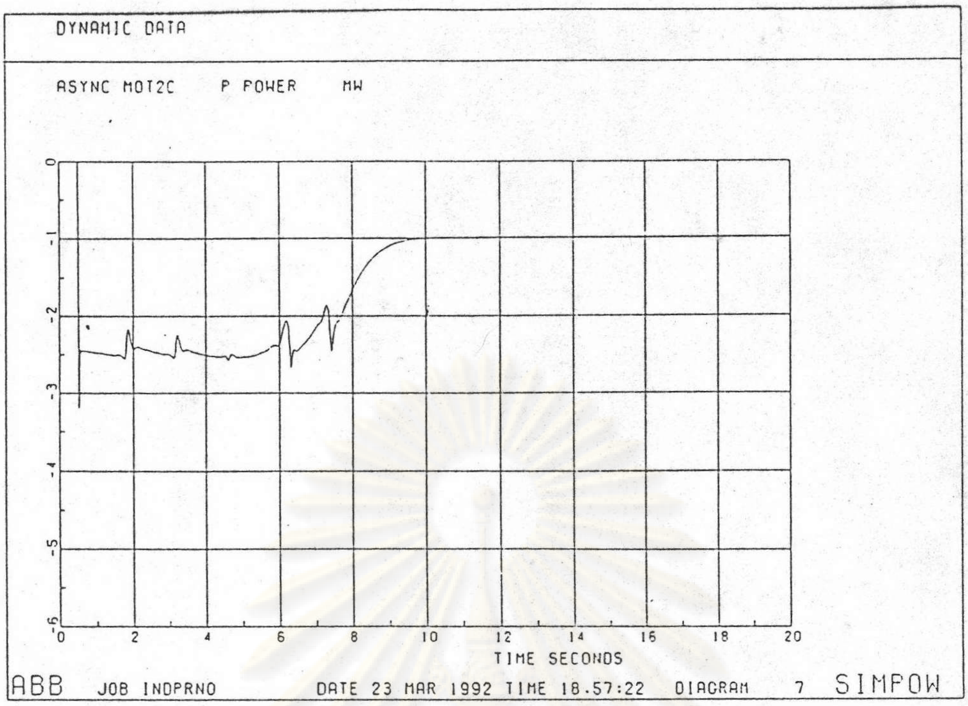


Figure A10.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

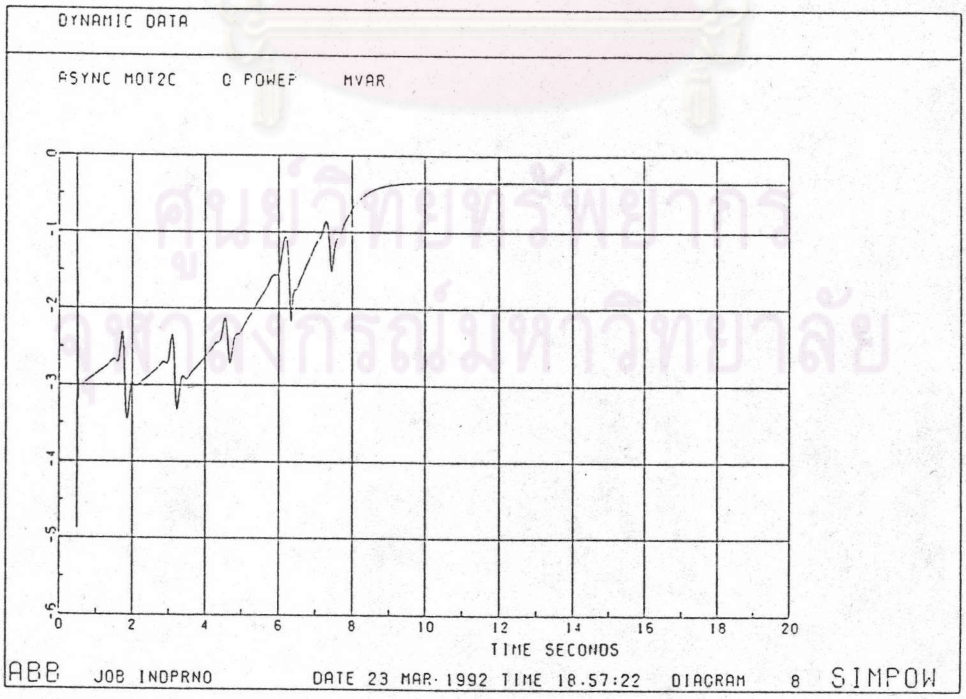


Figure A10.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

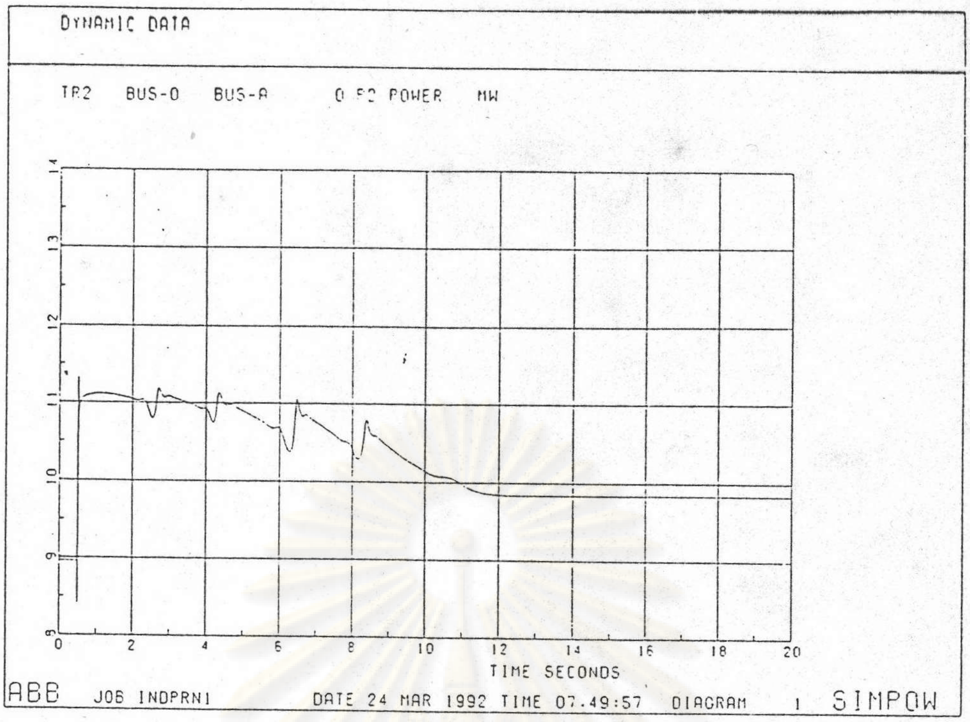


Figure A11.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

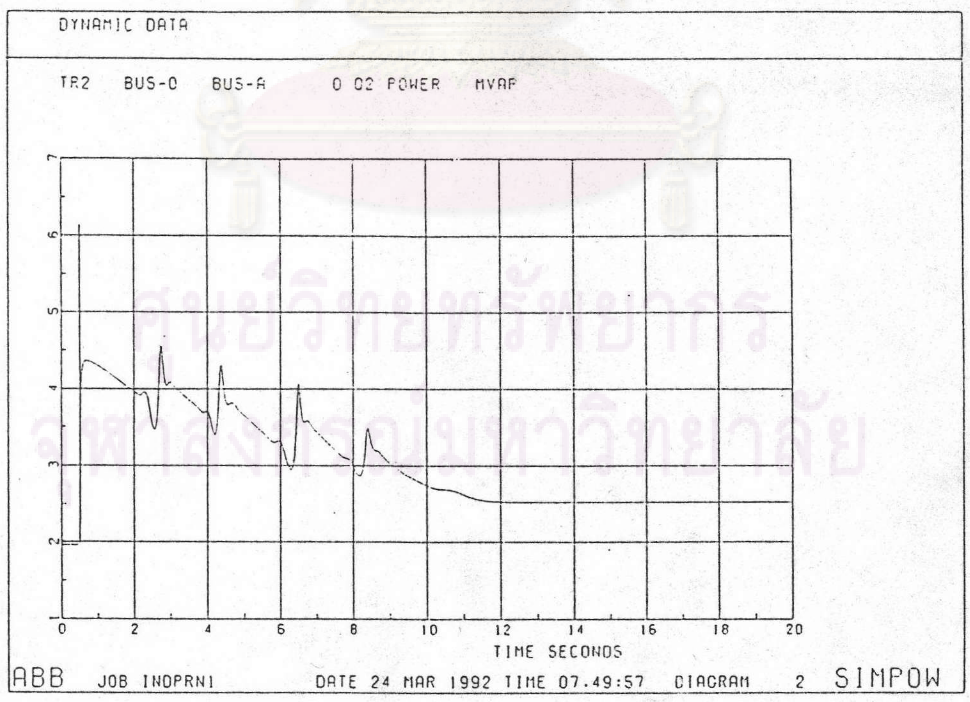


Figure A11.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

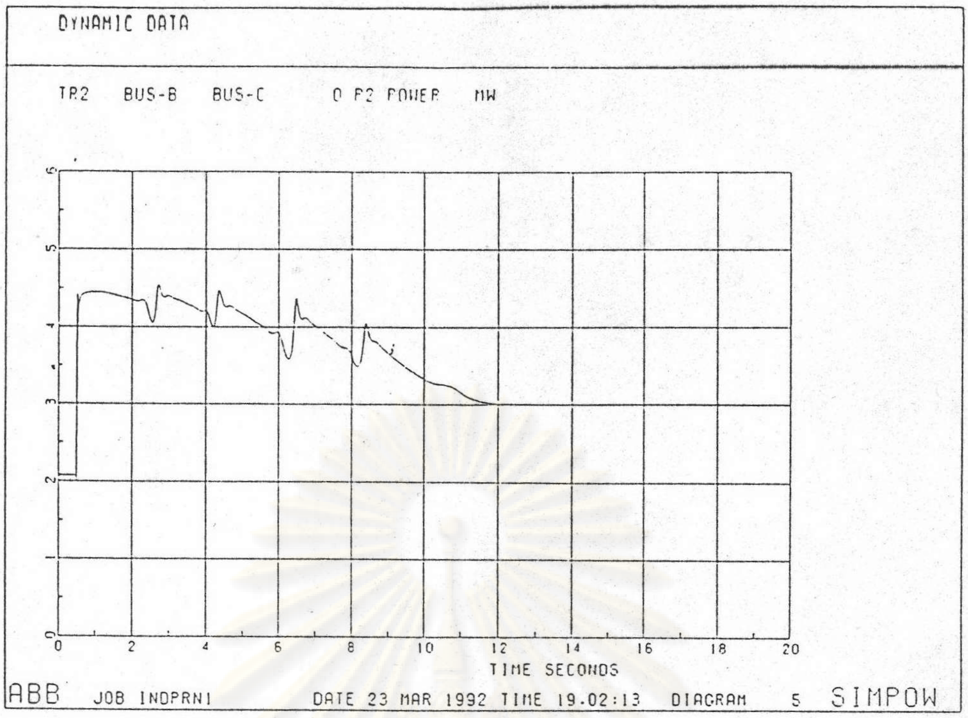


Figure A11.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

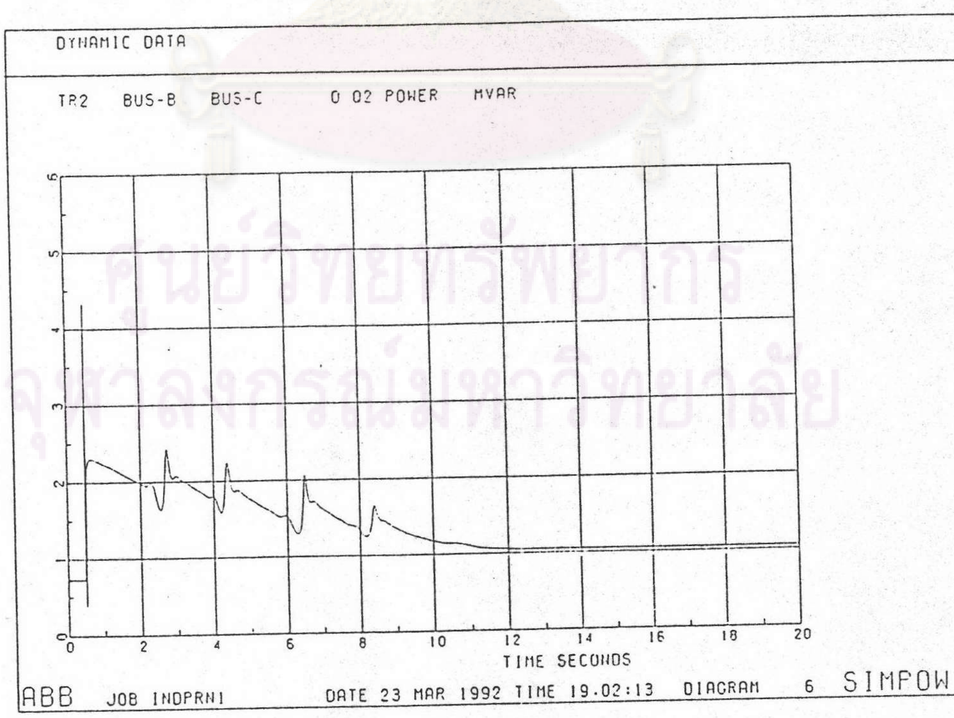




Figure A11.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

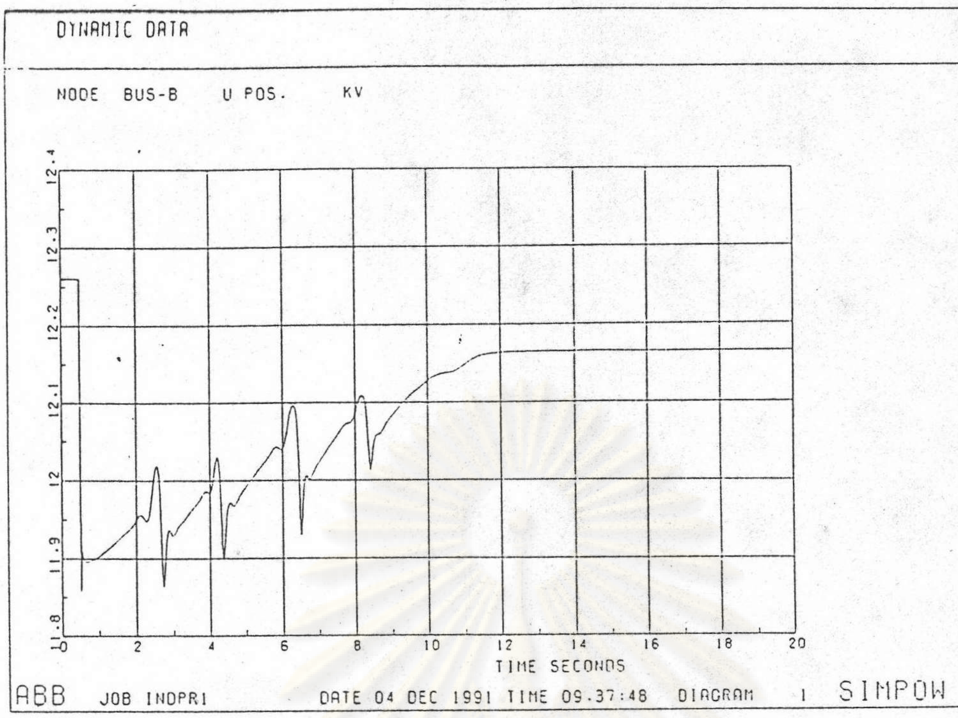


Figure A11.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

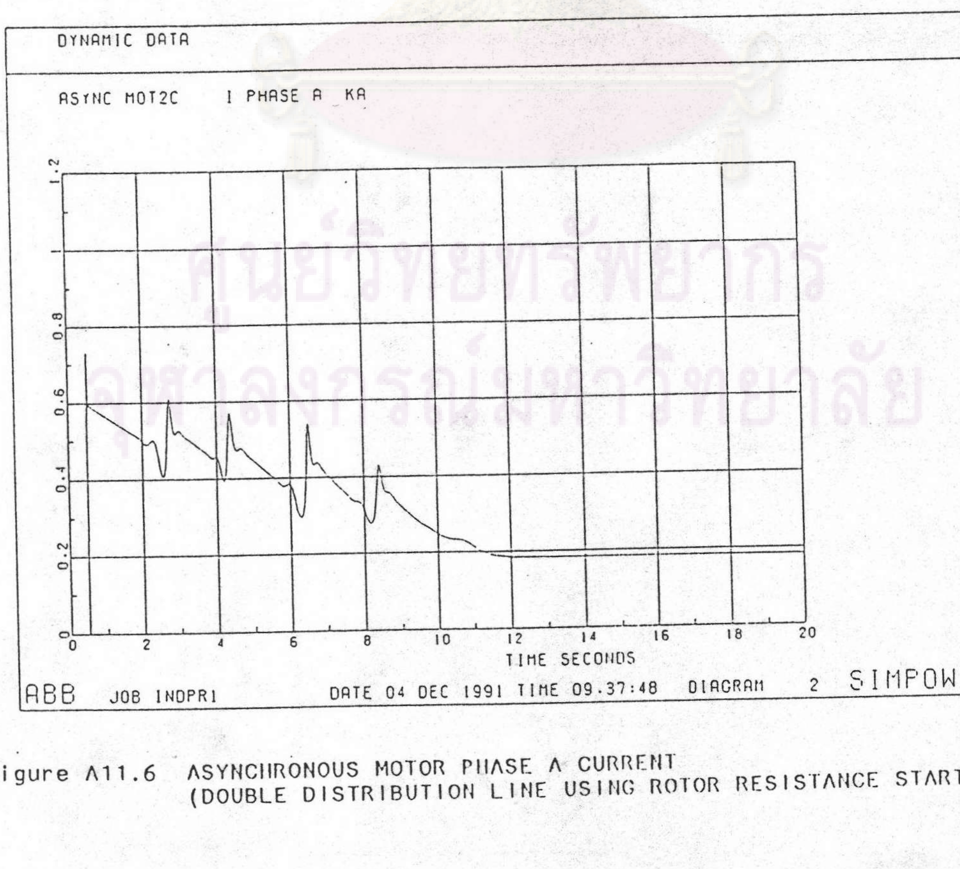


Figure A11.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

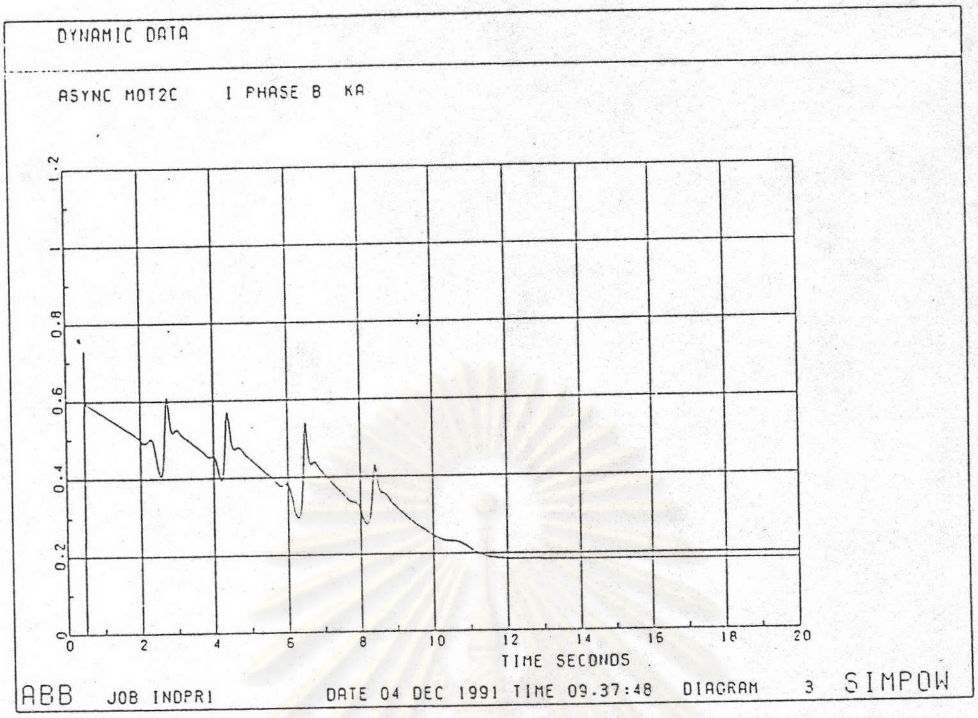


Figure A11.7 ASYNCHRONOUS MOTOR PHASE B CURRENT (DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

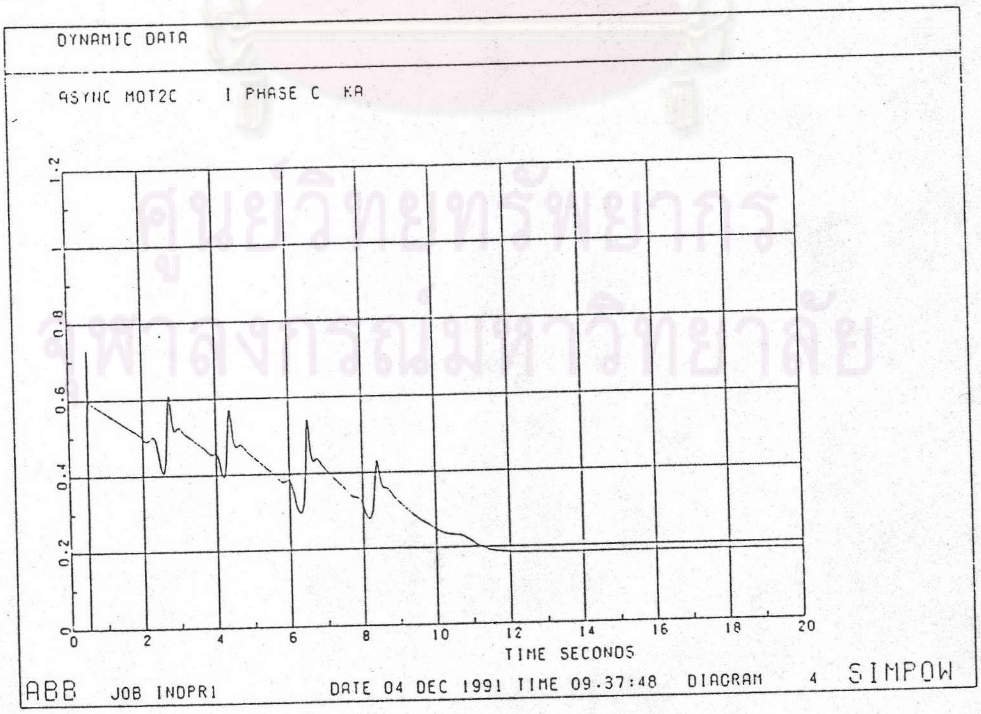


Figure A11.8 ASYNCHRONOUS MOTOR PHASE C CURRENT (DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

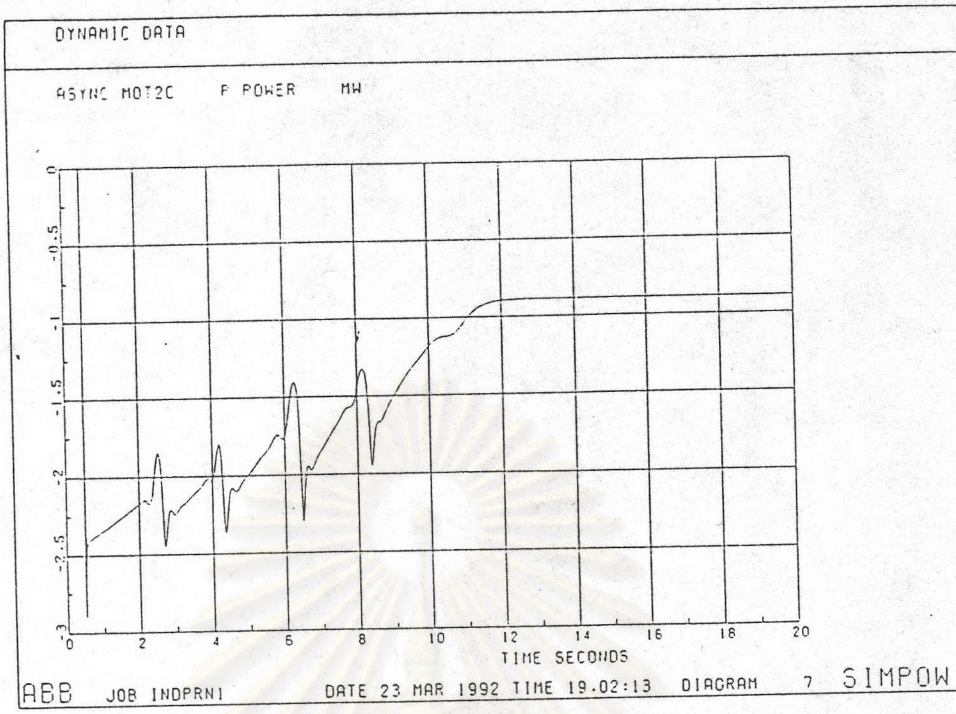


Figure A11.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

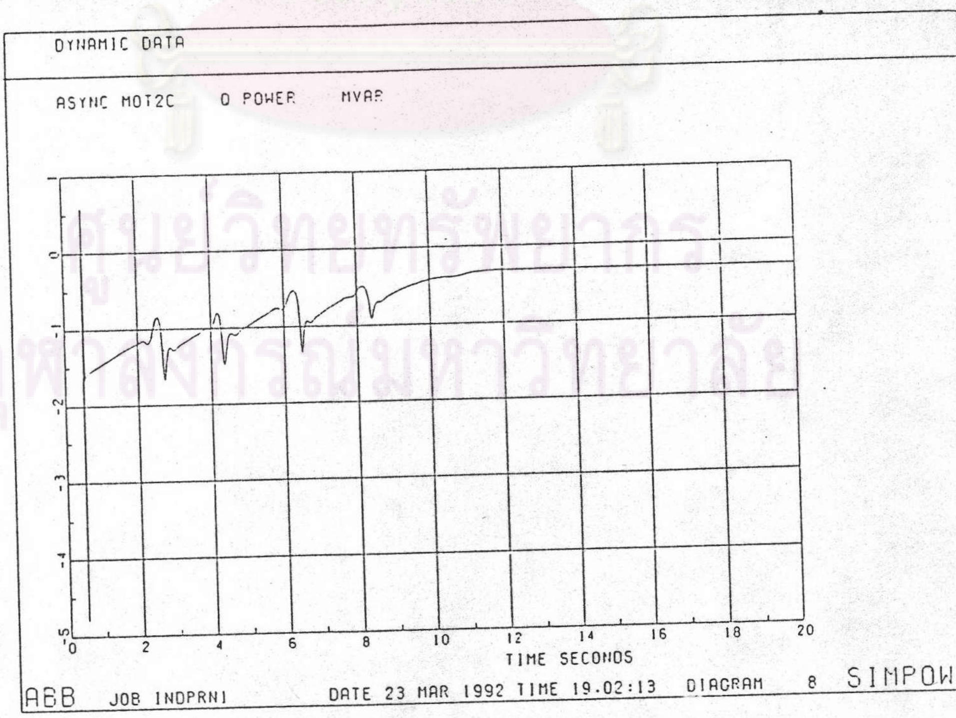


Figure A11.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE USING ROTOR RESISTANCE STARTING)

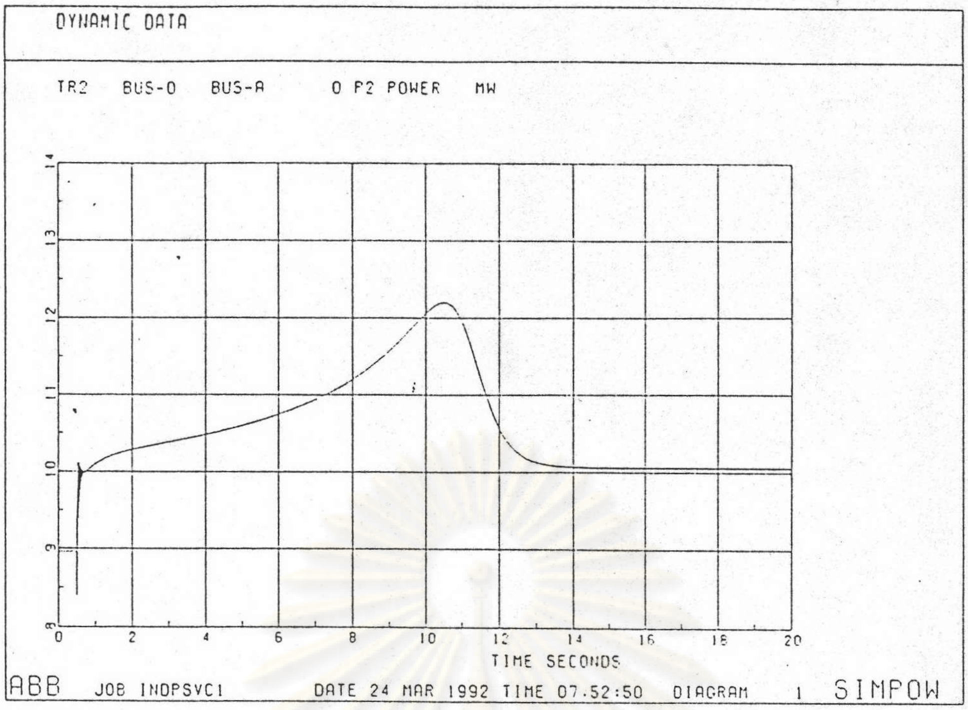


Figure A12.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

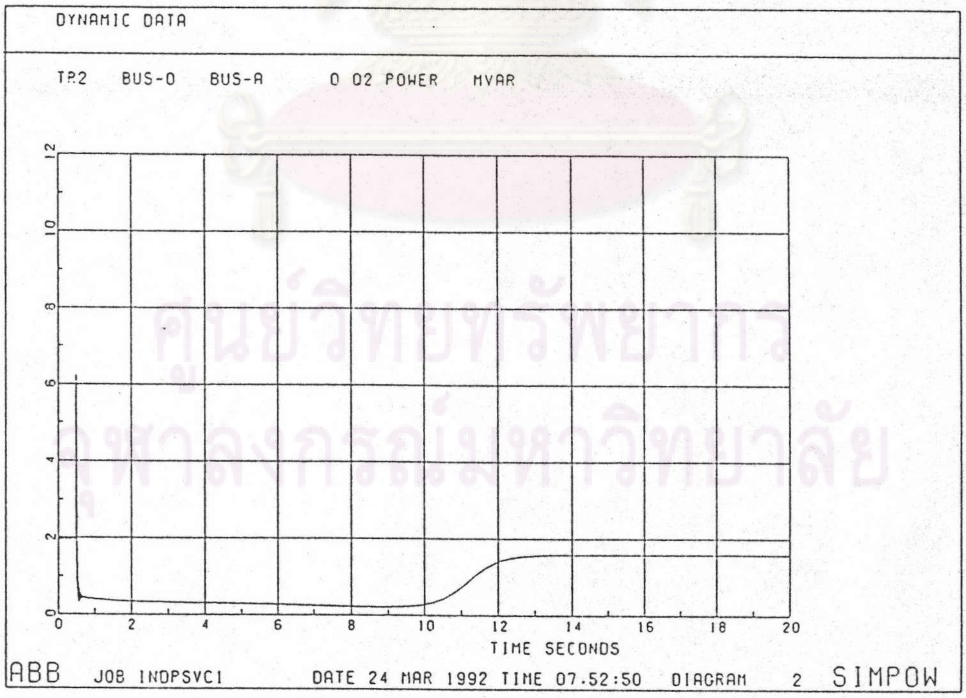


Figure A12.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

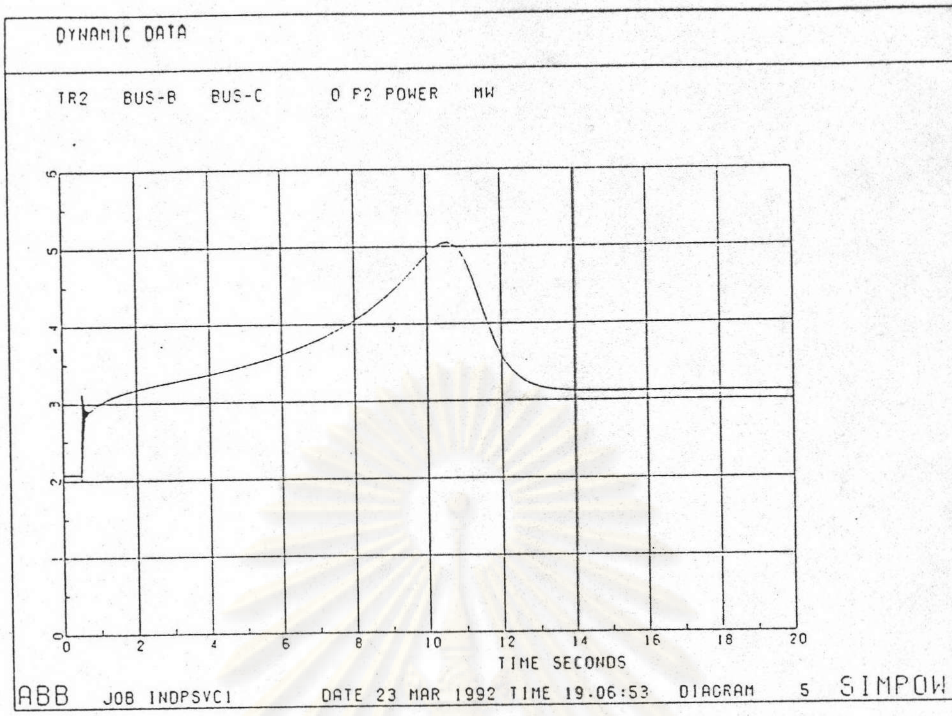


Figure A12.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

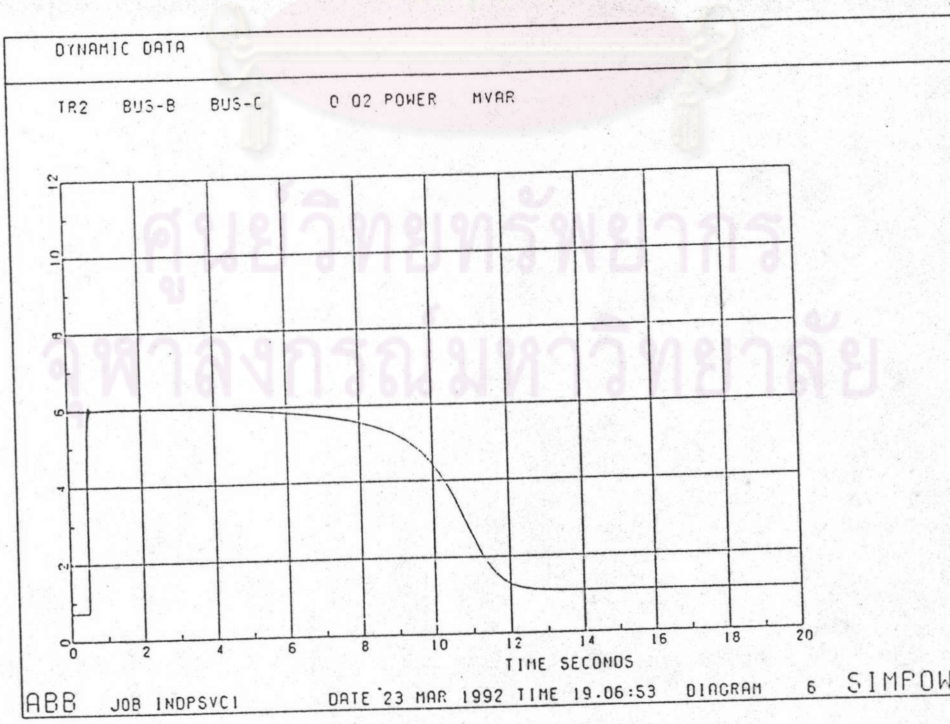


Figure A12.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

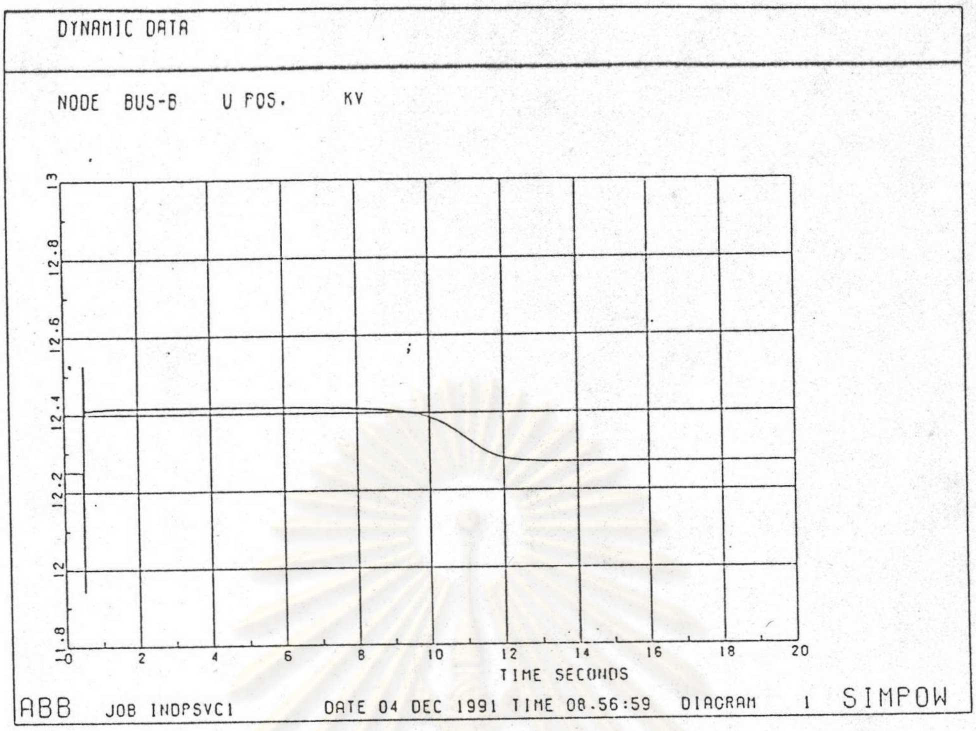


Figure A12.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

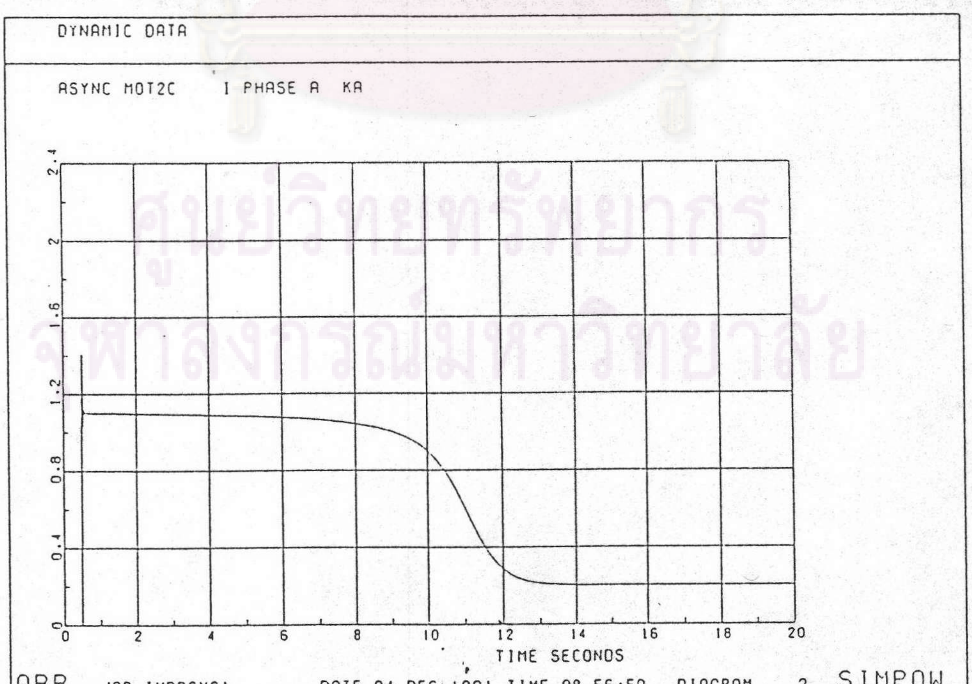


Figure A12.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

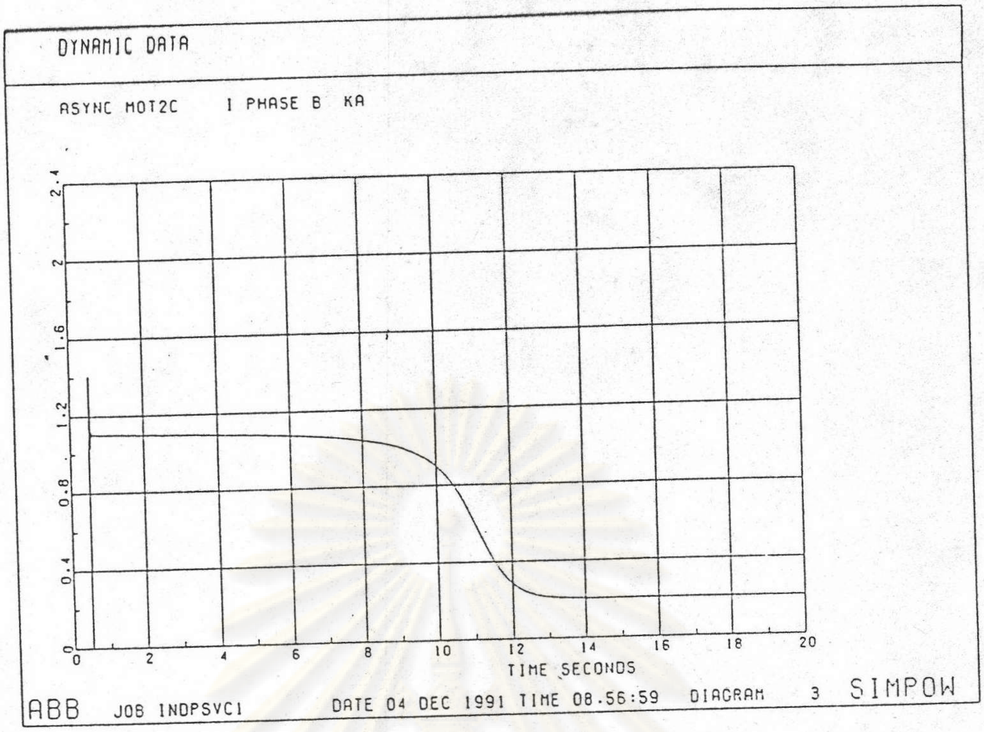


Figure A12.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

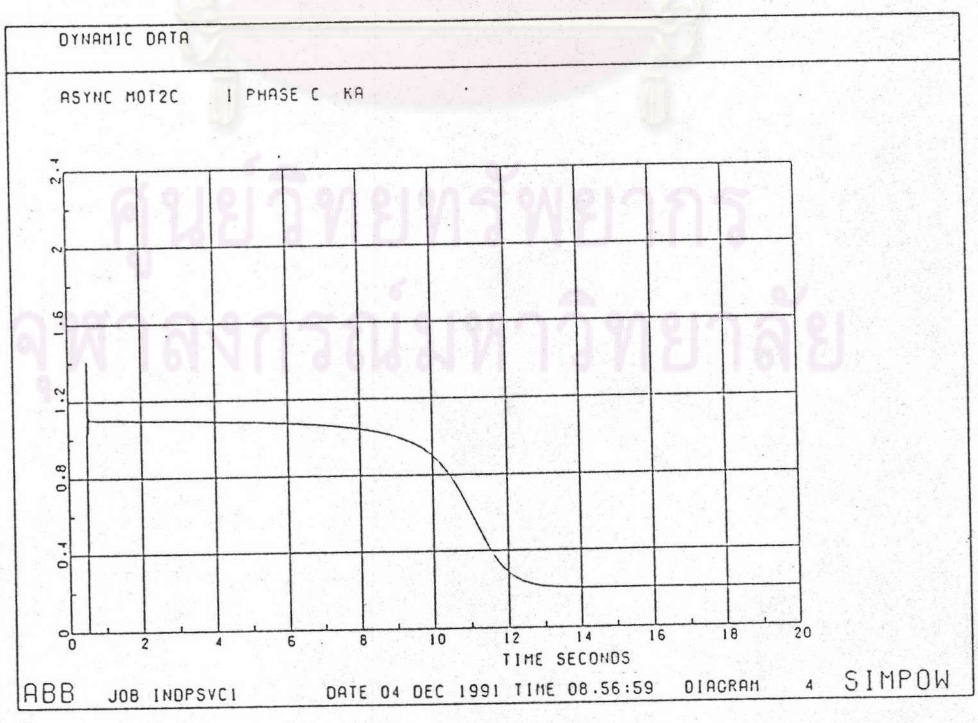


Figure A12.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

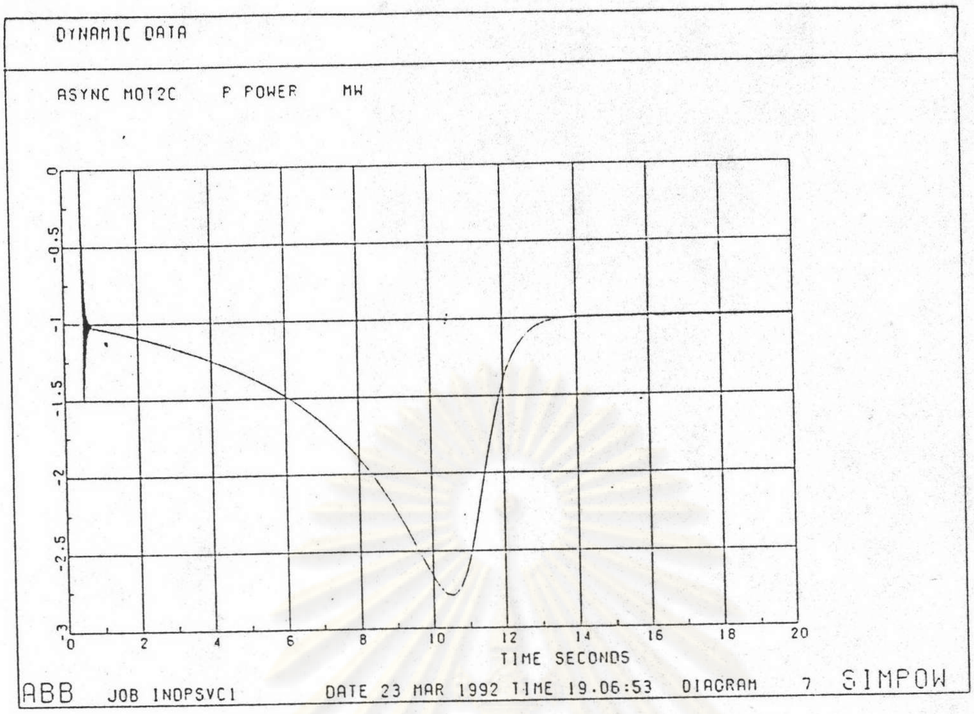


Figure A12.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

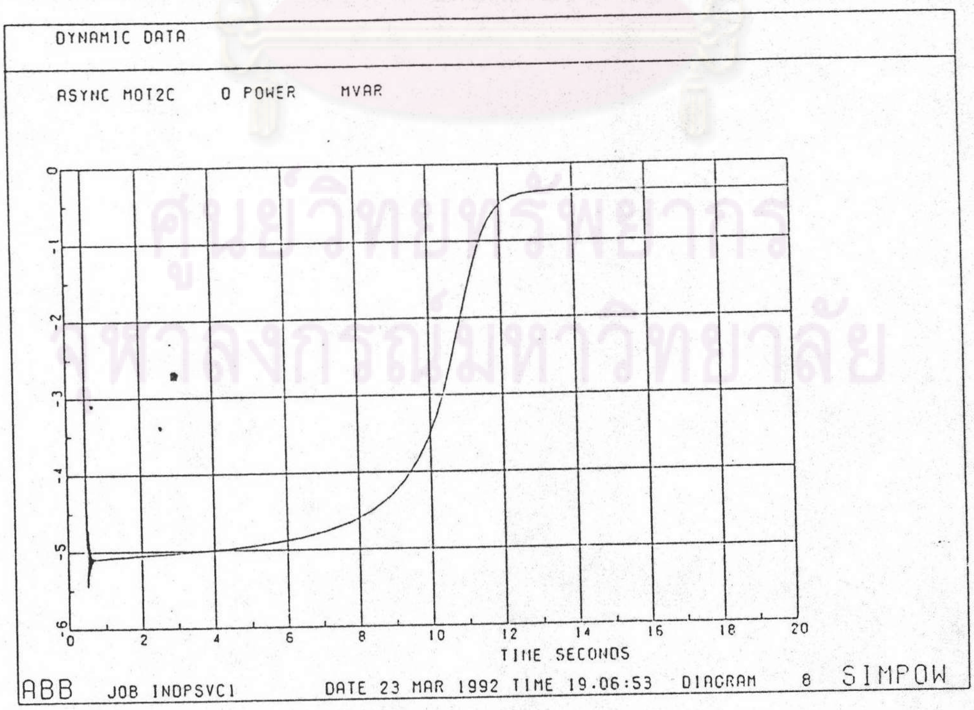


Figure A12.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 1 )

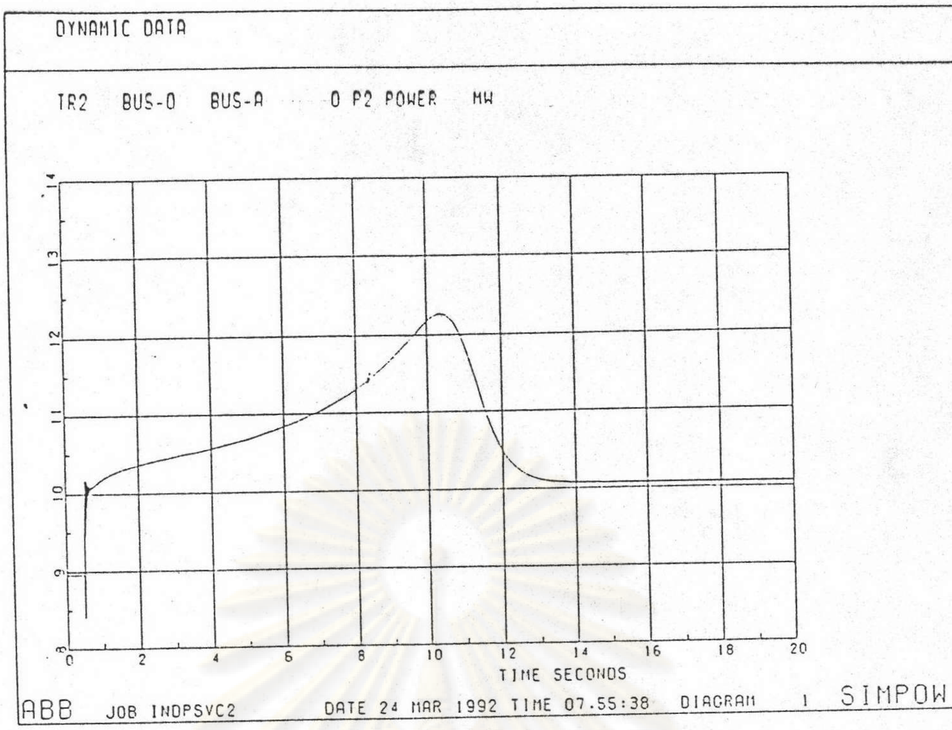


Figure A13.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

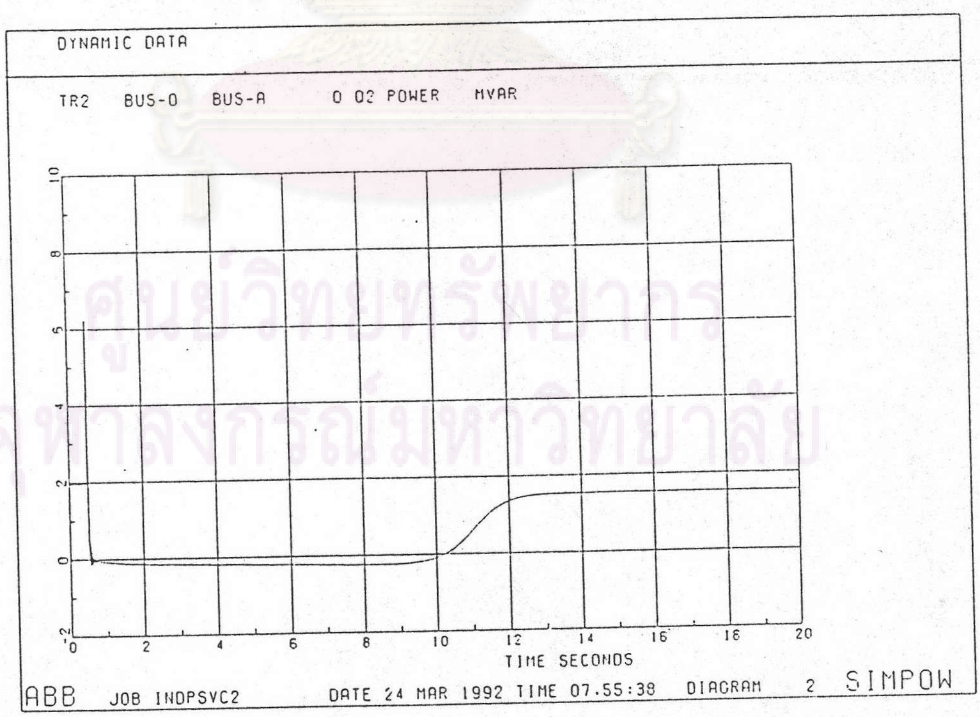


Figure A13.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

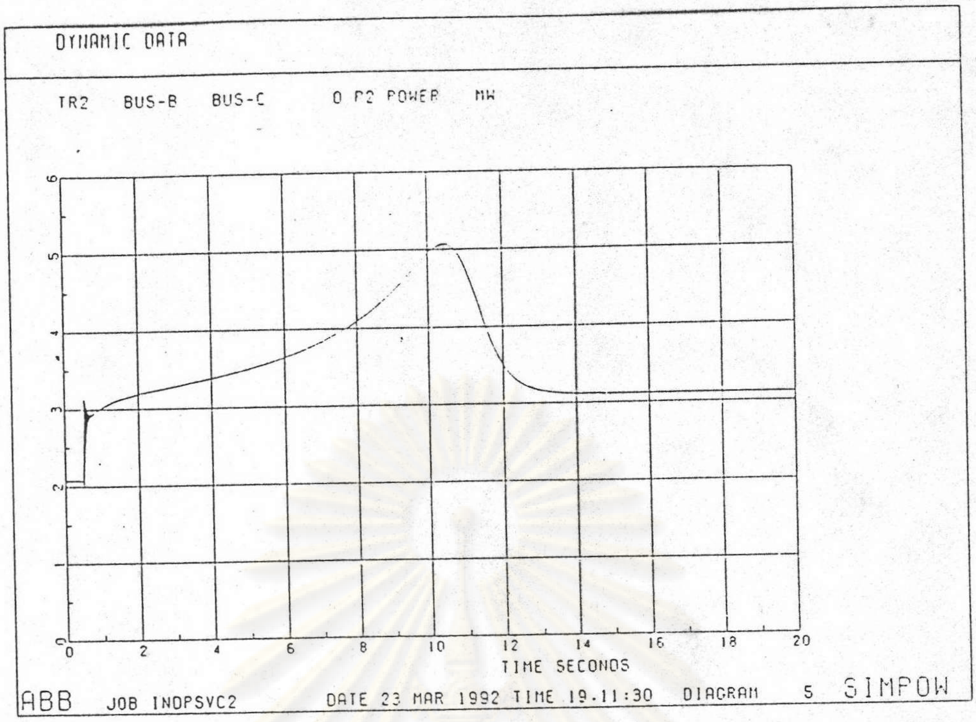


Figure A13.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

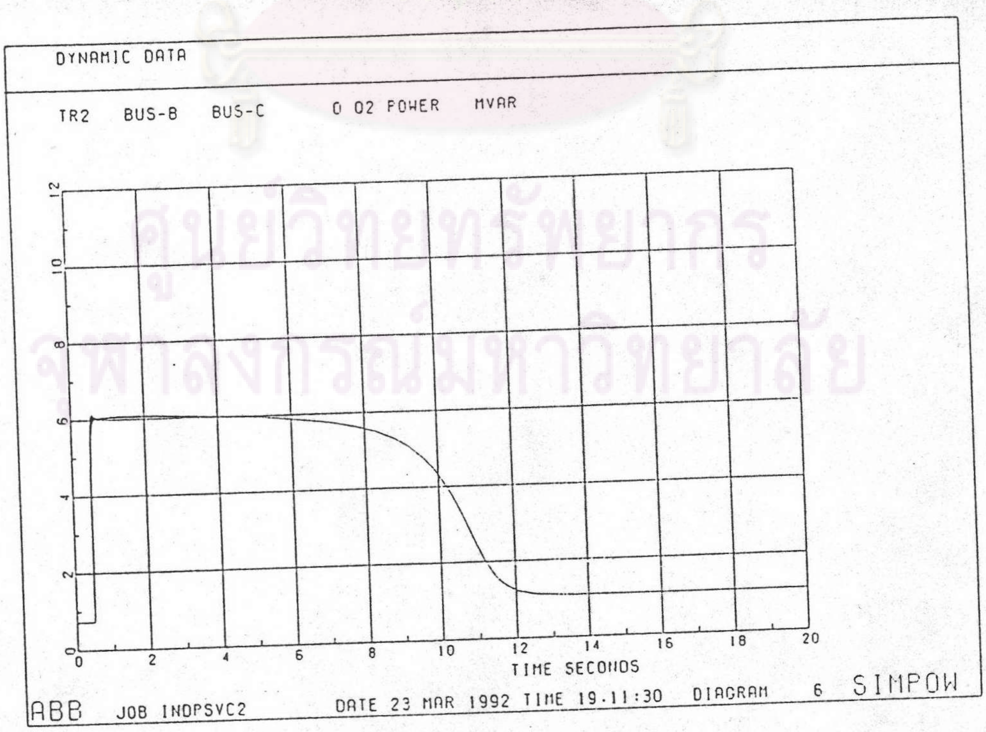


Figure A13.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

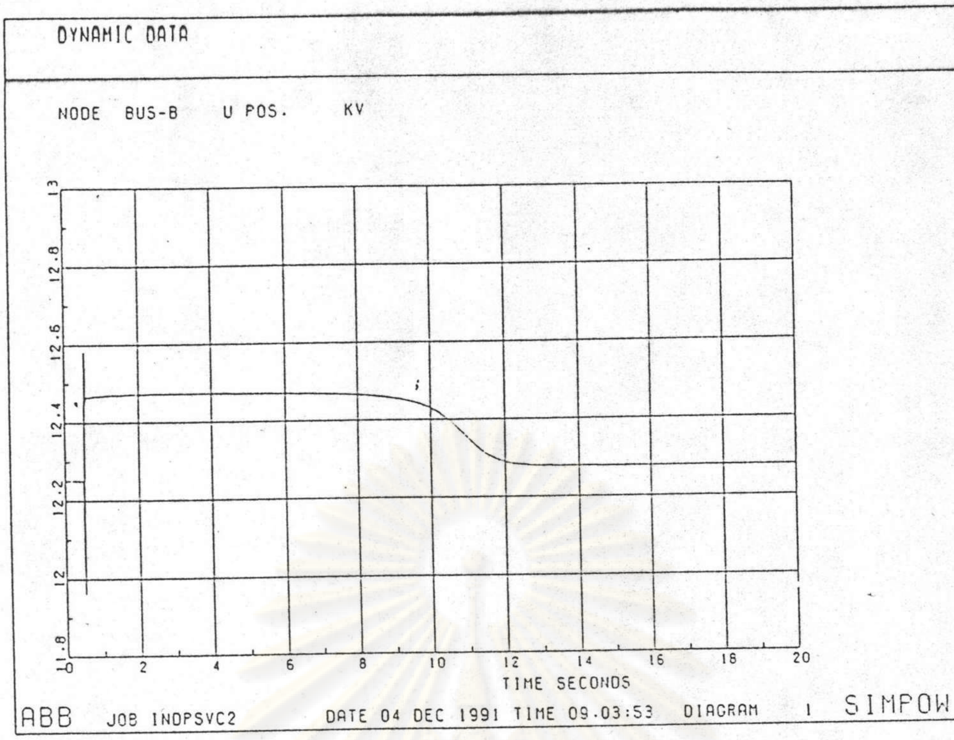


Figure A13.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

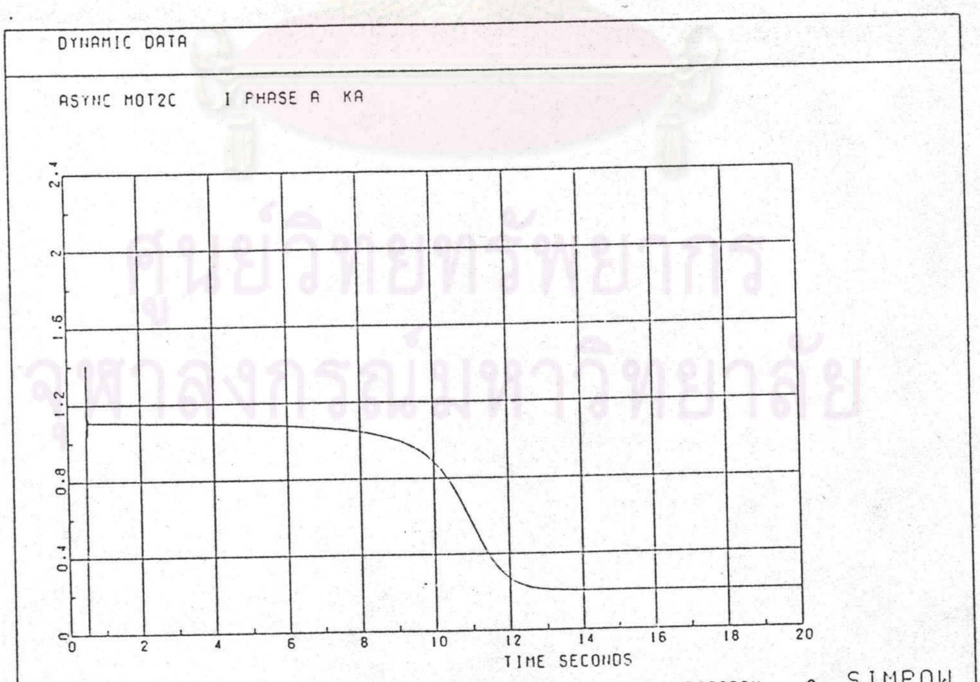


Figure A13.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

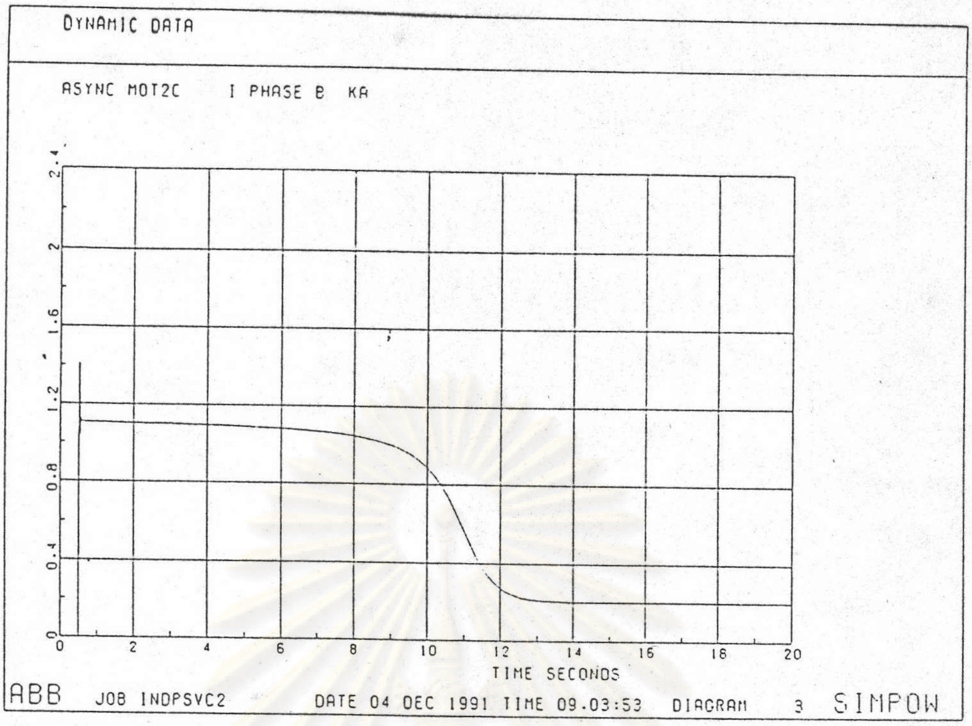


Figure A13.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

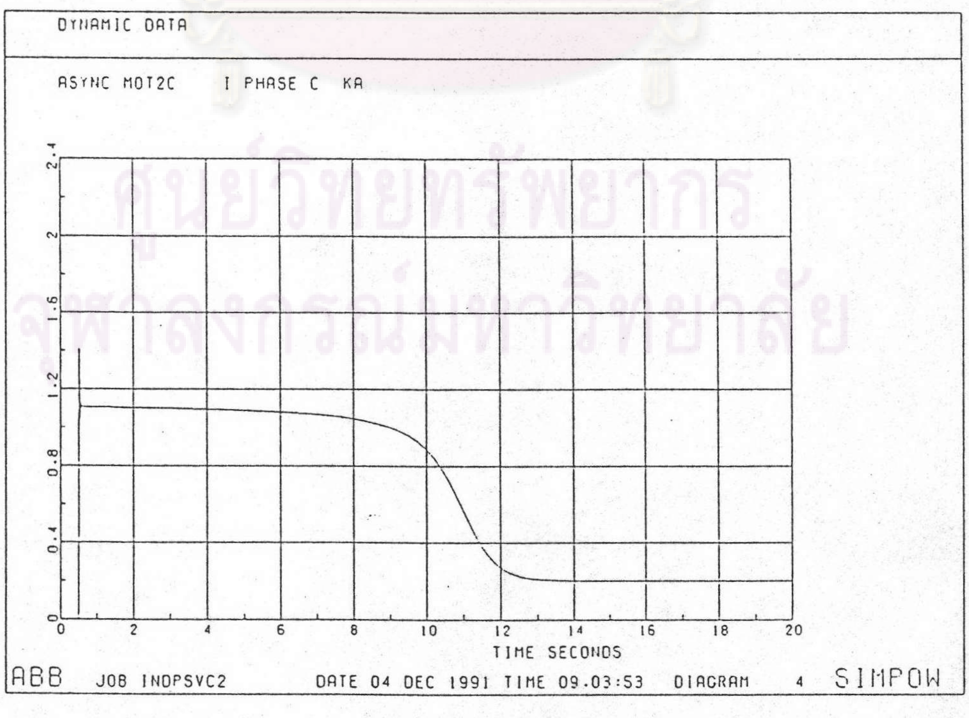


Figure A13.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

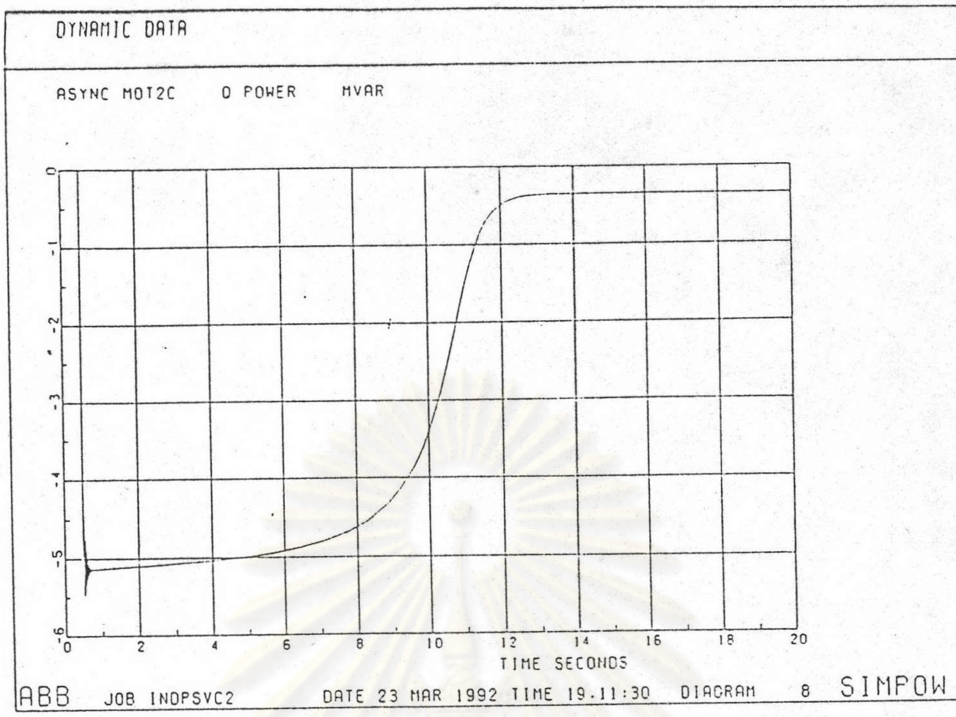


Figure A13.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

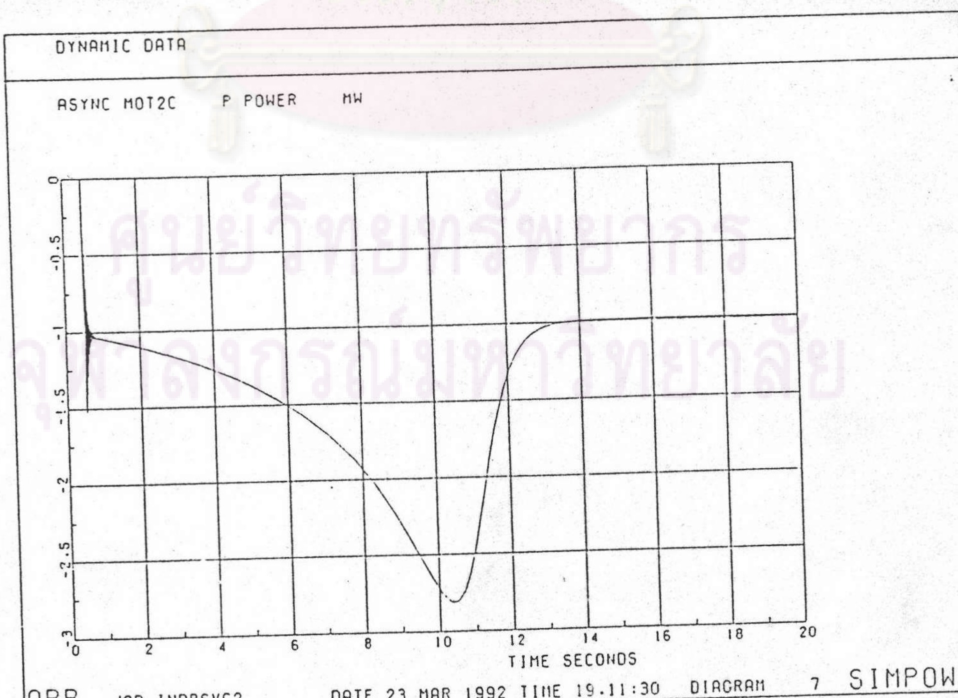


Figure A13.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 2 )

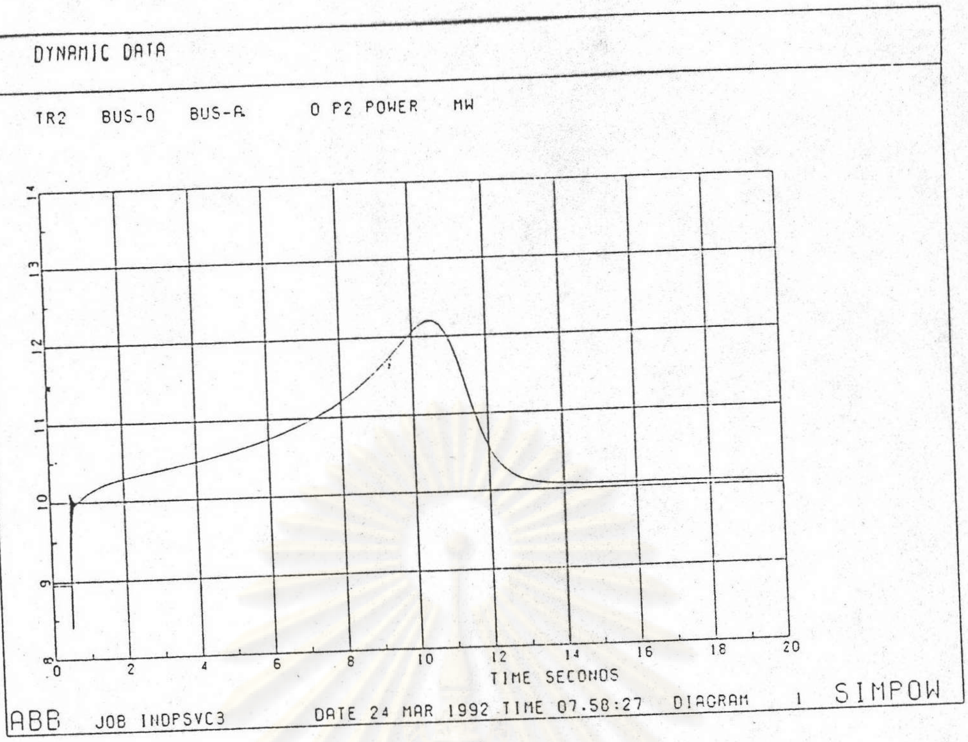


Figure A14.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

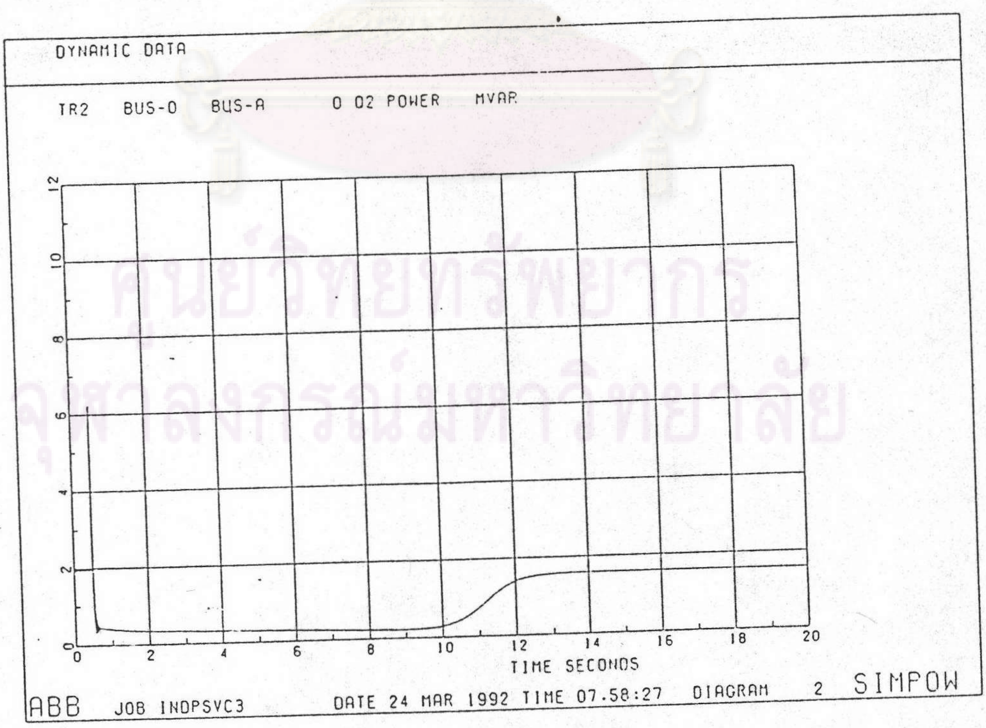


Figure A14.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

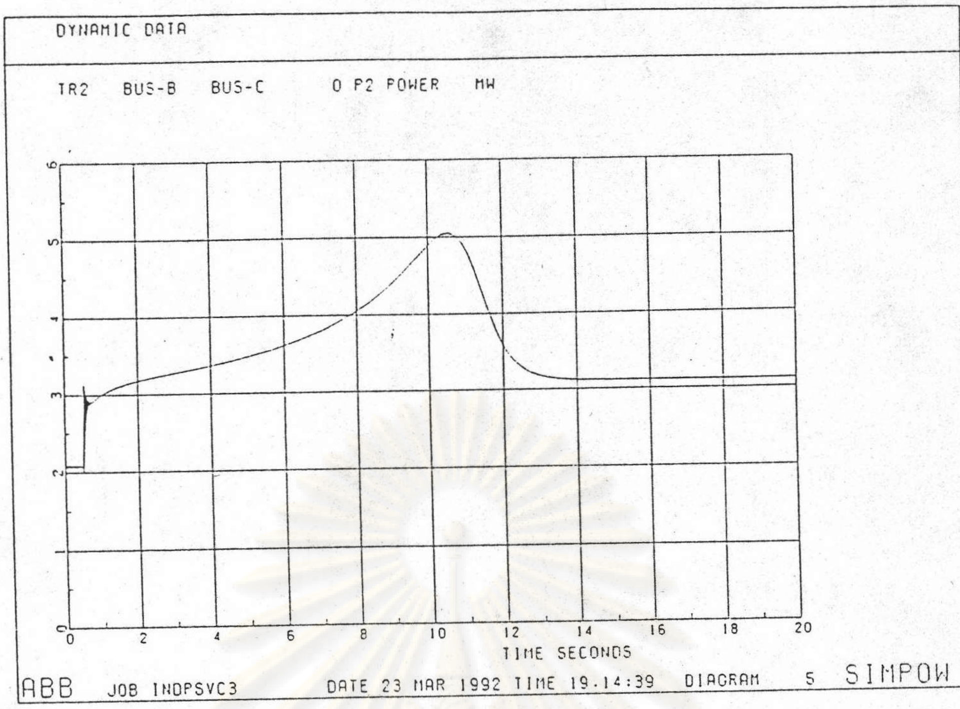


Figure A14.3 POWER INJECTION CURVE AT BUS-C (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

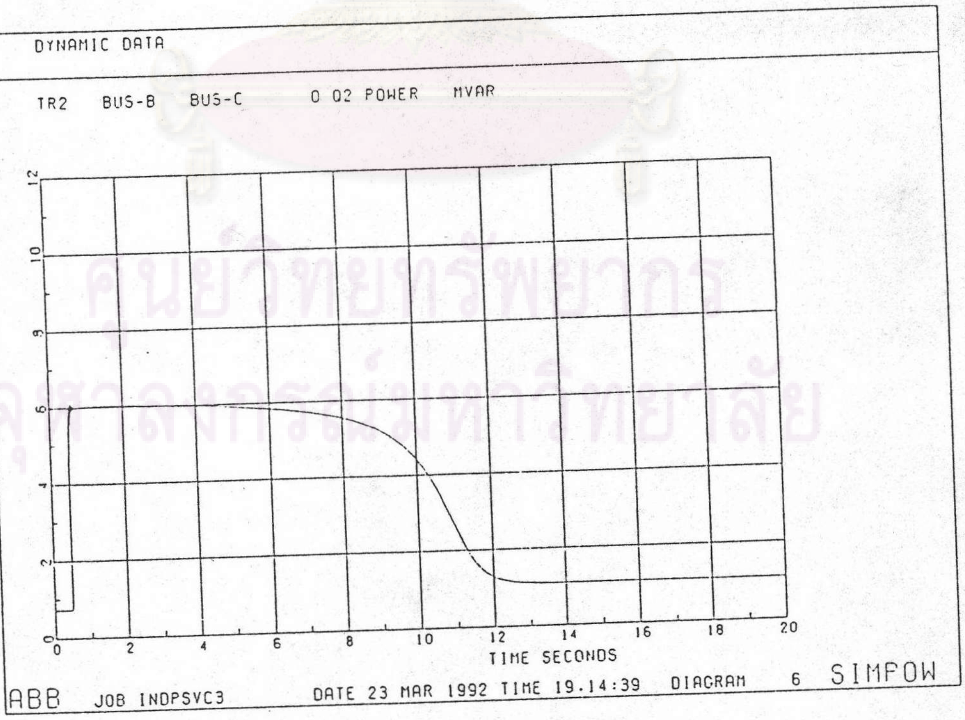


Figure A14.4 REACTIVE POWER INJECTION CURVE AT BUS-C (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

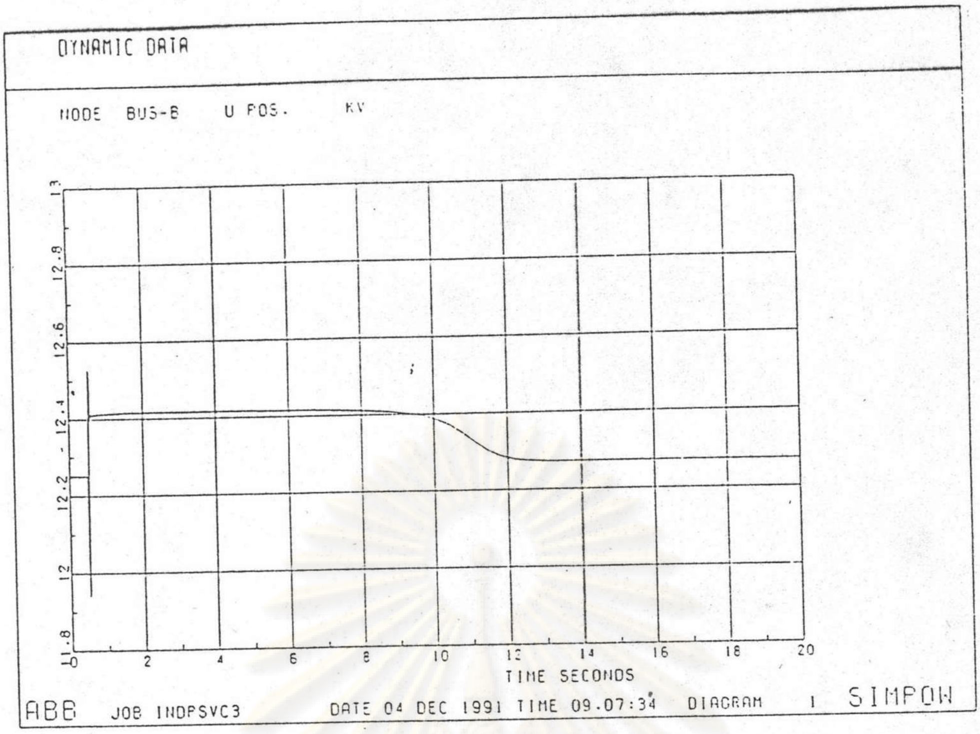


Figure A14.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

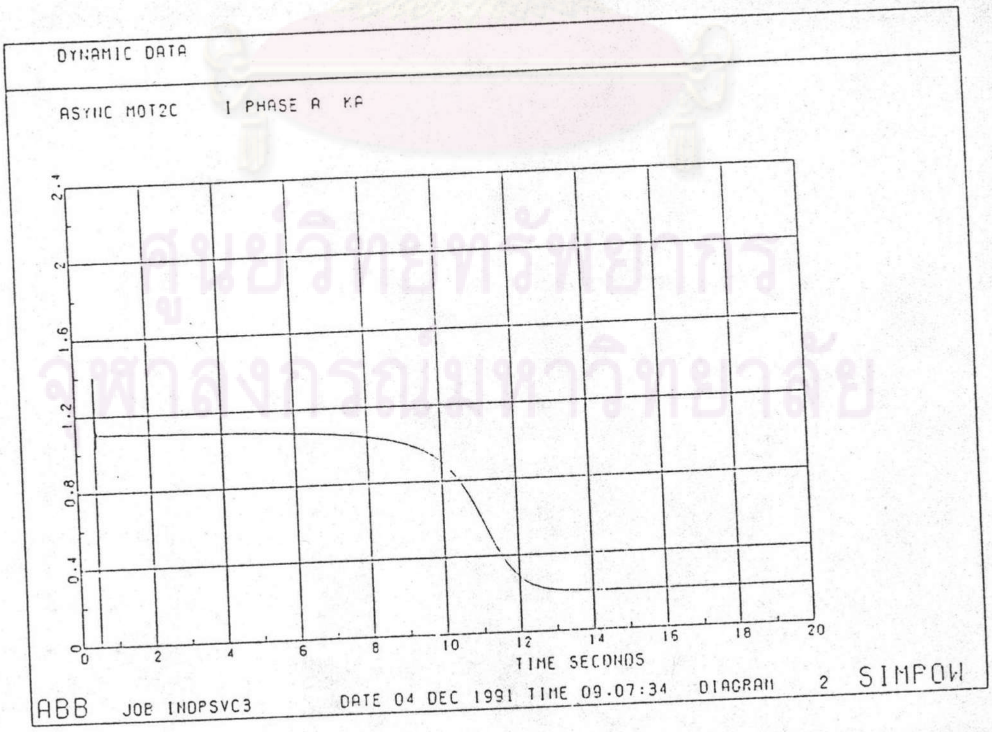


Figure A14.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

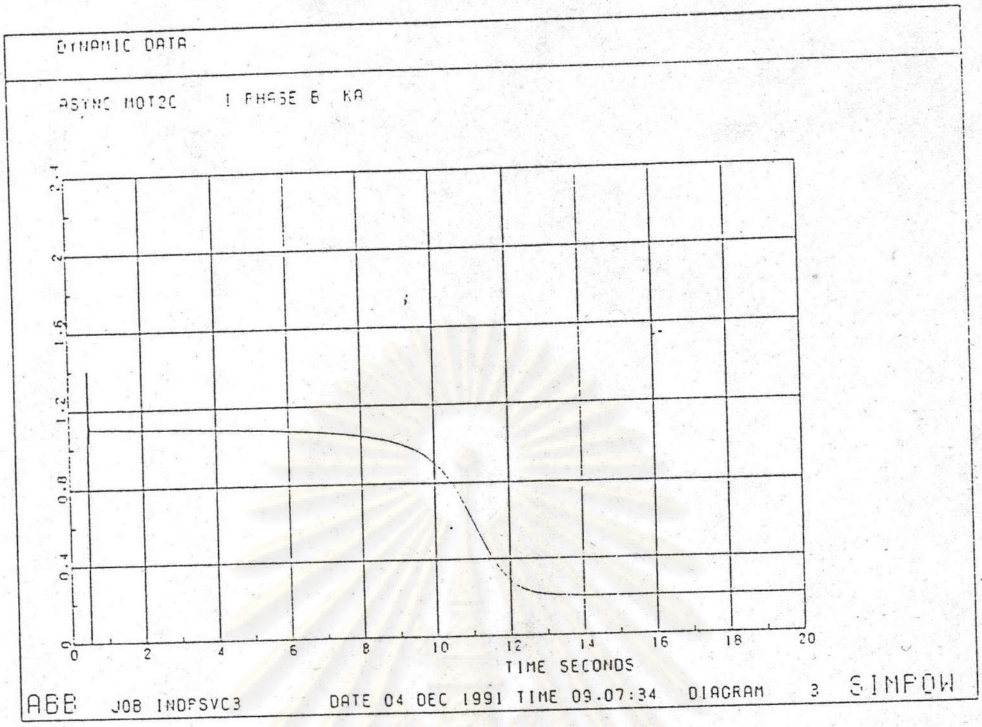


Figure A14.7 ASYNCHRONOUS MOTOR PHASE B CURRENT (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

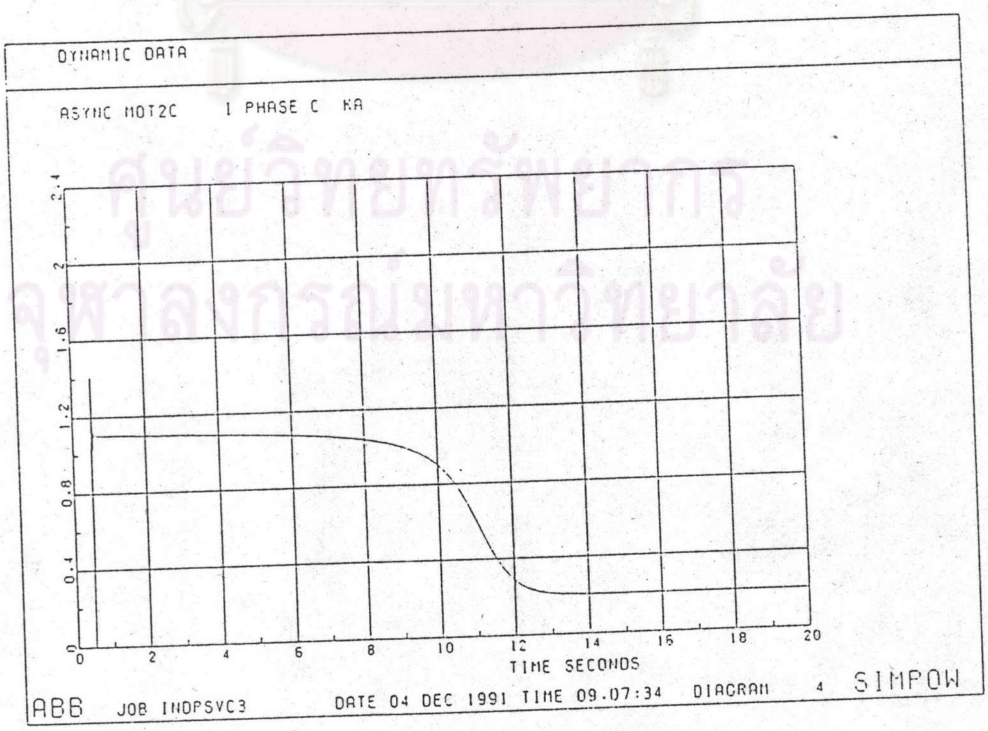


Figure A14.8 ASYNCHRONOUS MOTOR PHASE C CURRENT (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

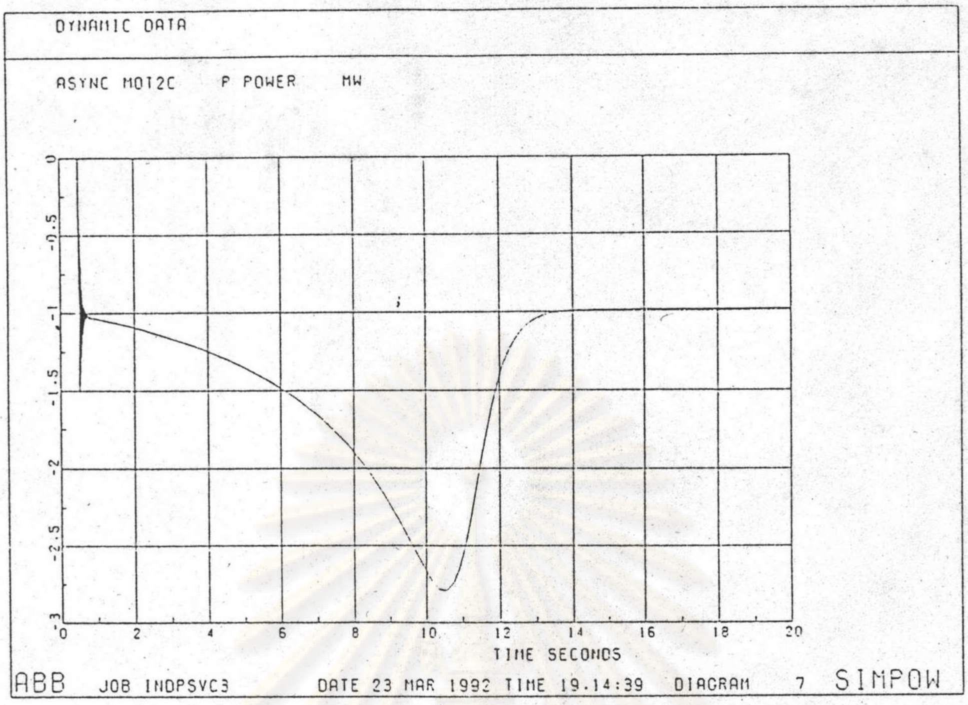


Figure A14.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

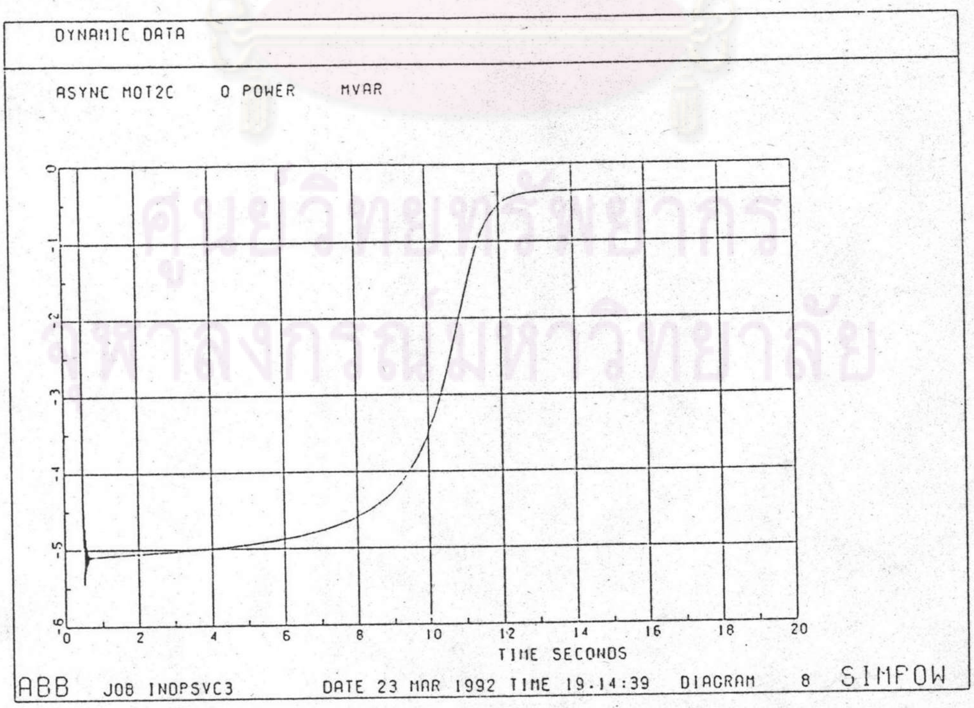


Figure A14.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 3 )

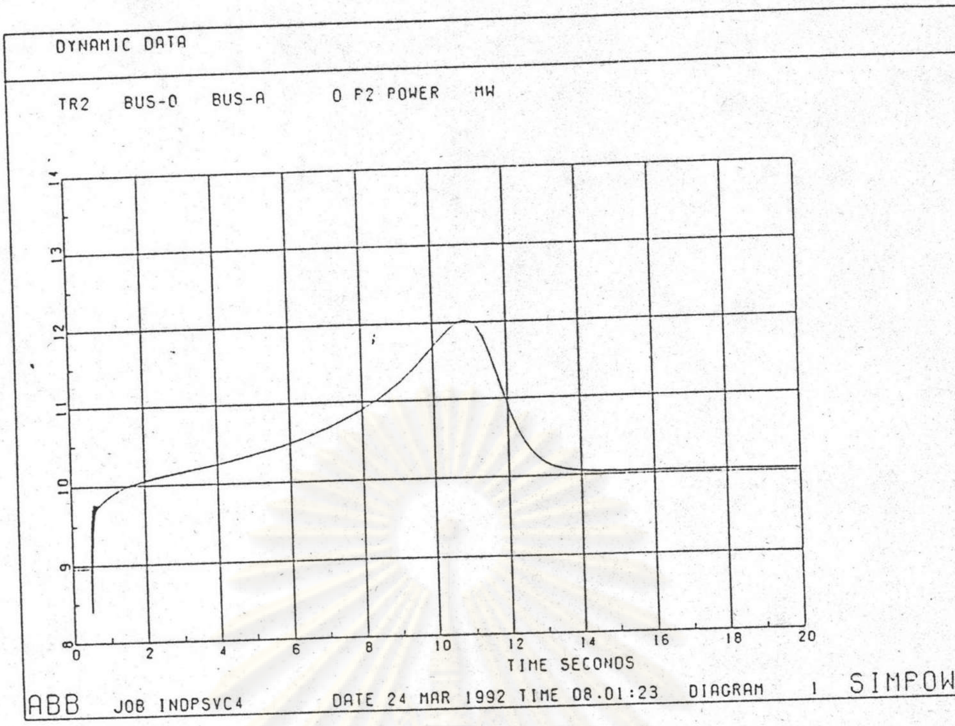


Figure A15.1 POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

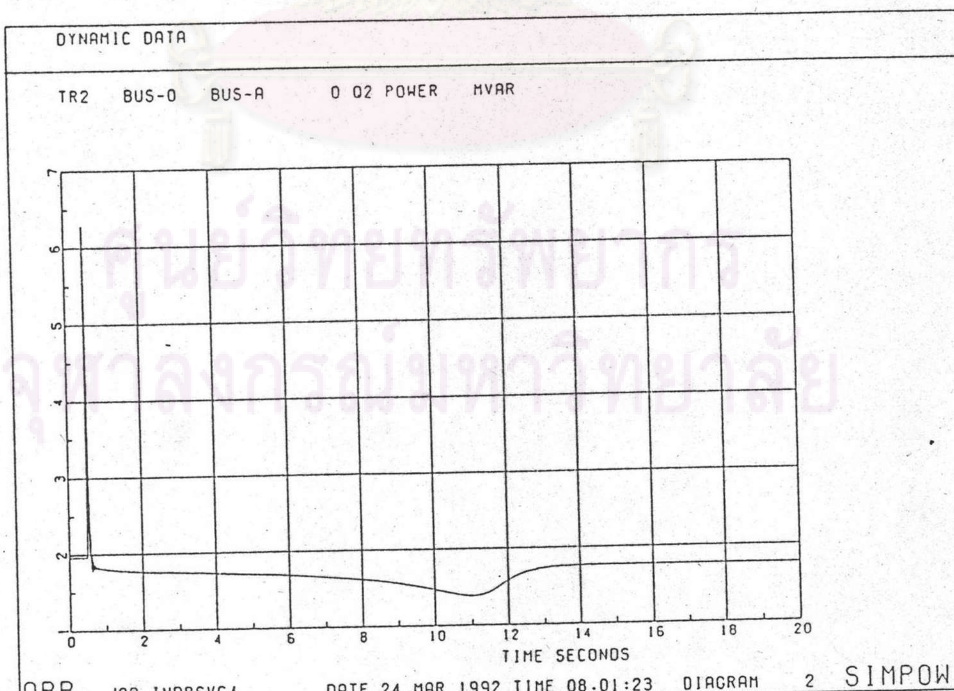


Figure A15.2 REACTIVE POWER INJECTION CURVE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

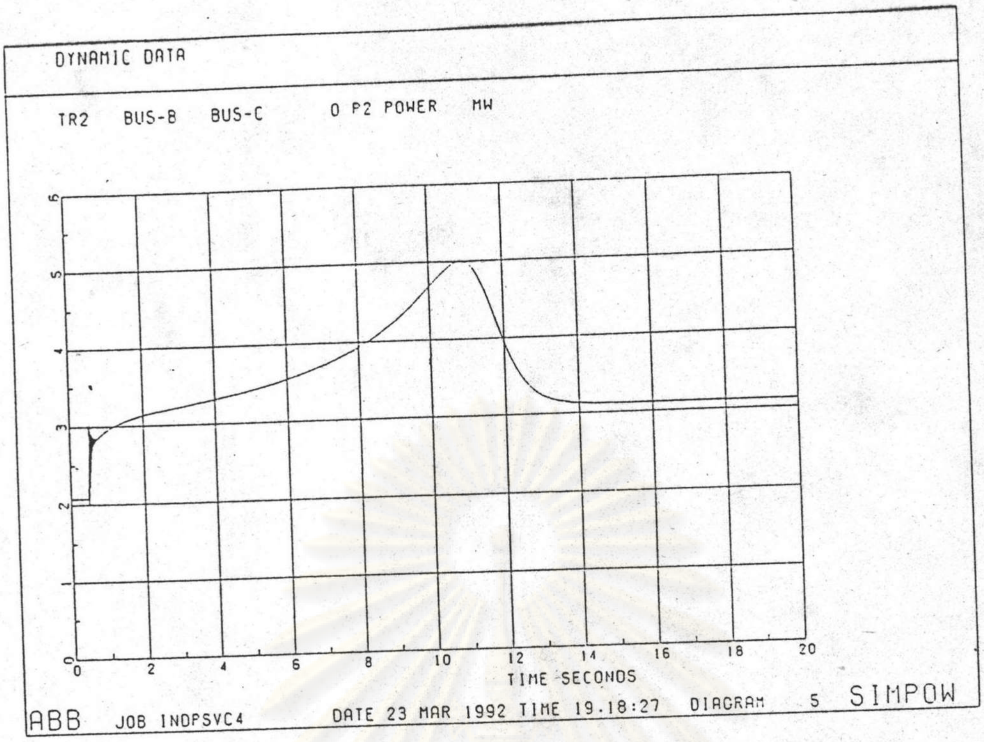


Figure A15.3 POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

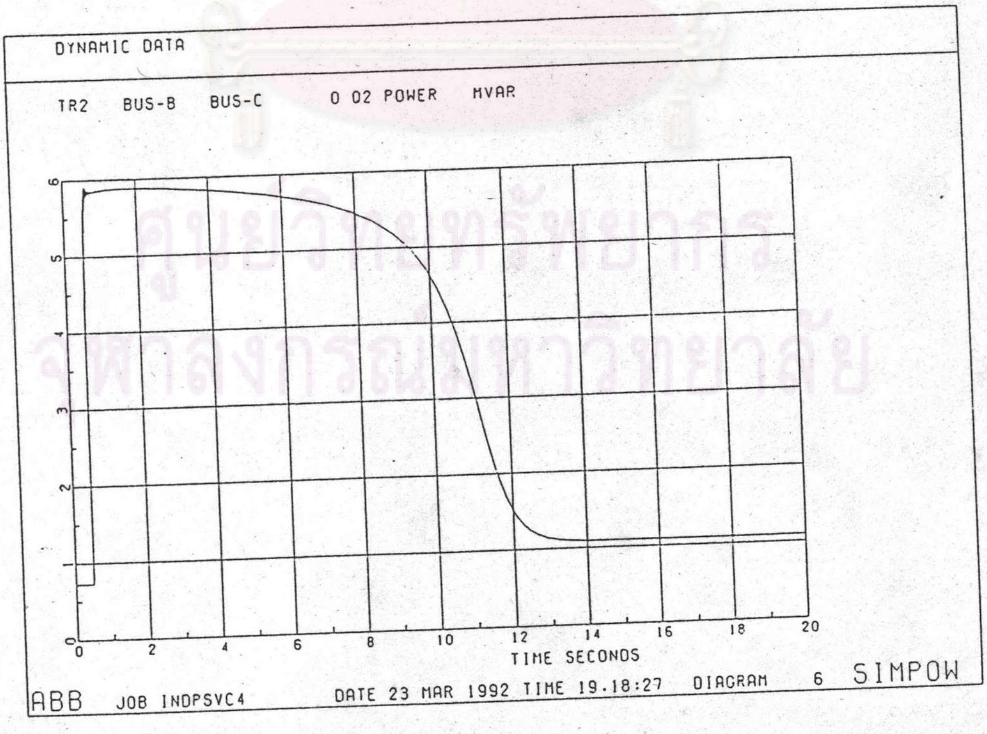


Figure A15.4 REACTIVE POWER INJECTION CURVE AT BUS-C
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

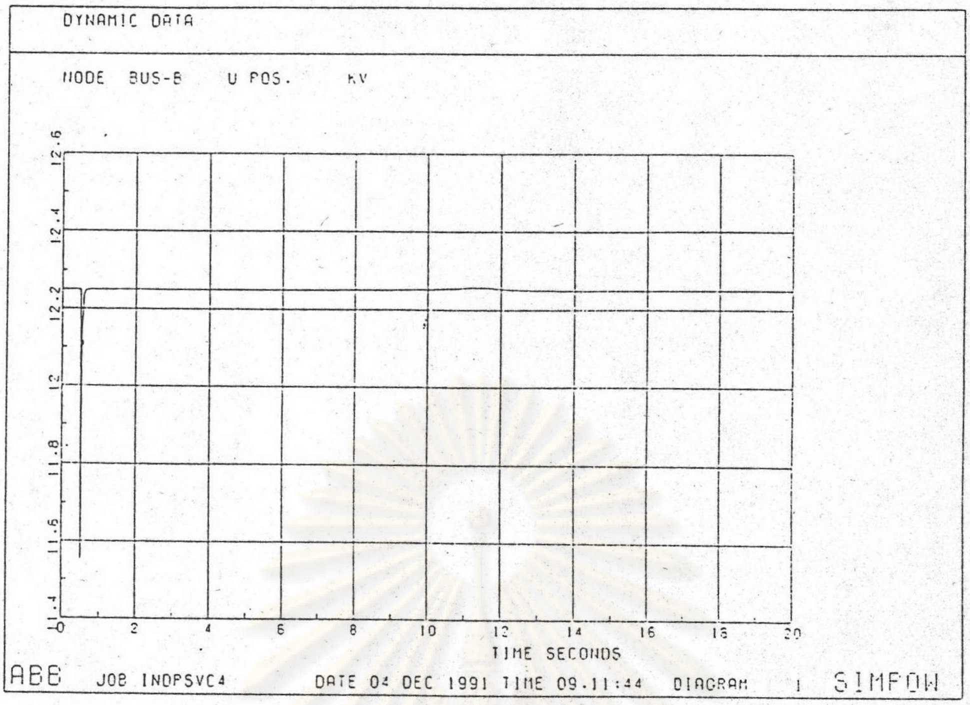


Figure A15.5 VOLTAGE AT BUS-B
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

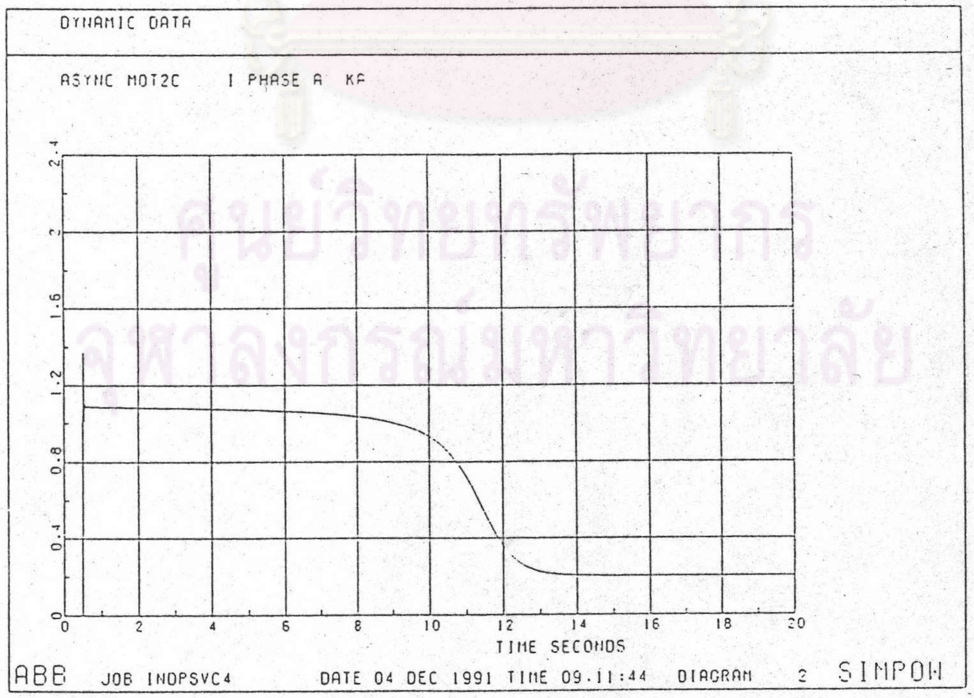


Figure A15.6 ASYNCHRONOUS MOTOR PHASE A CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

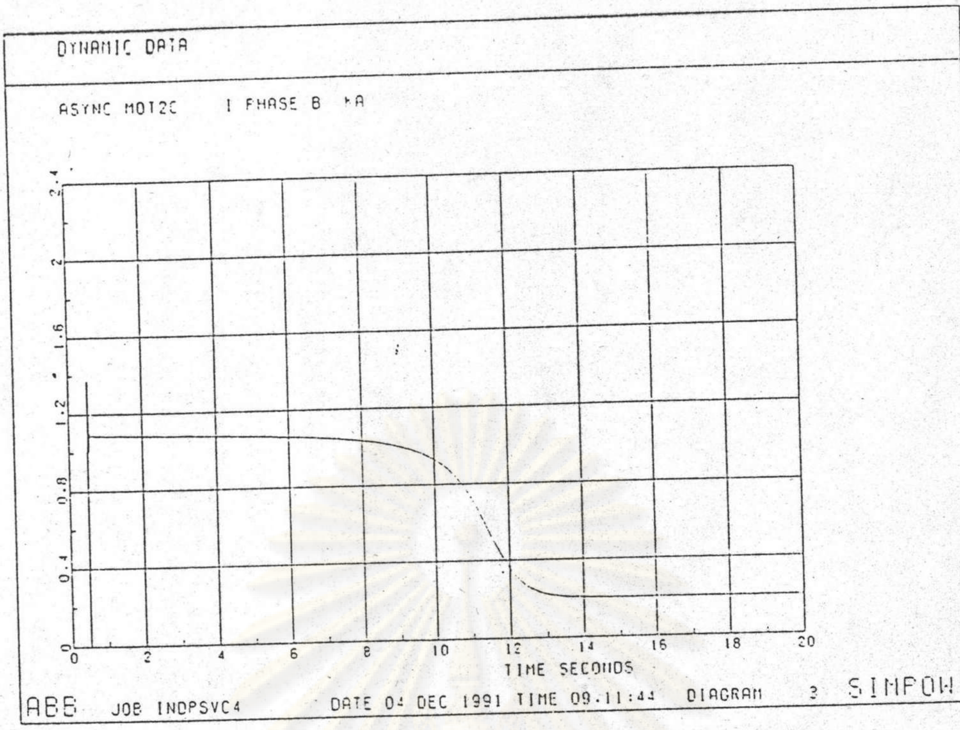


Figure A15.7 ASYNCHRONOUS MOTOR PHASE B CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

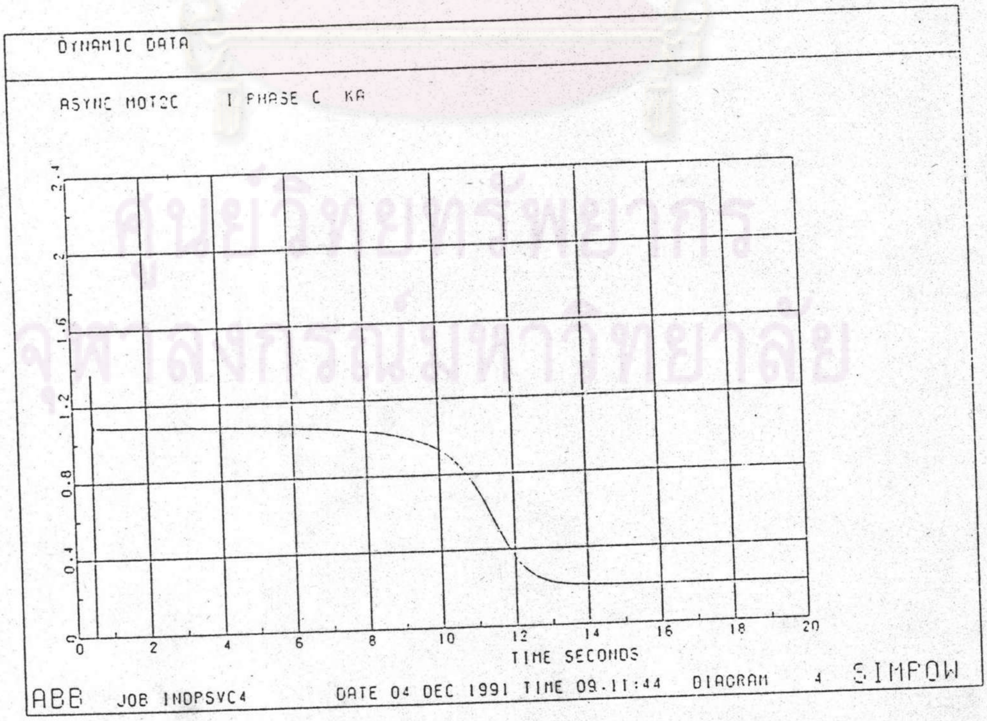


Figure A15.8 ASYNCHRONOUS MOTOR PHASE C CURRENT
(DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

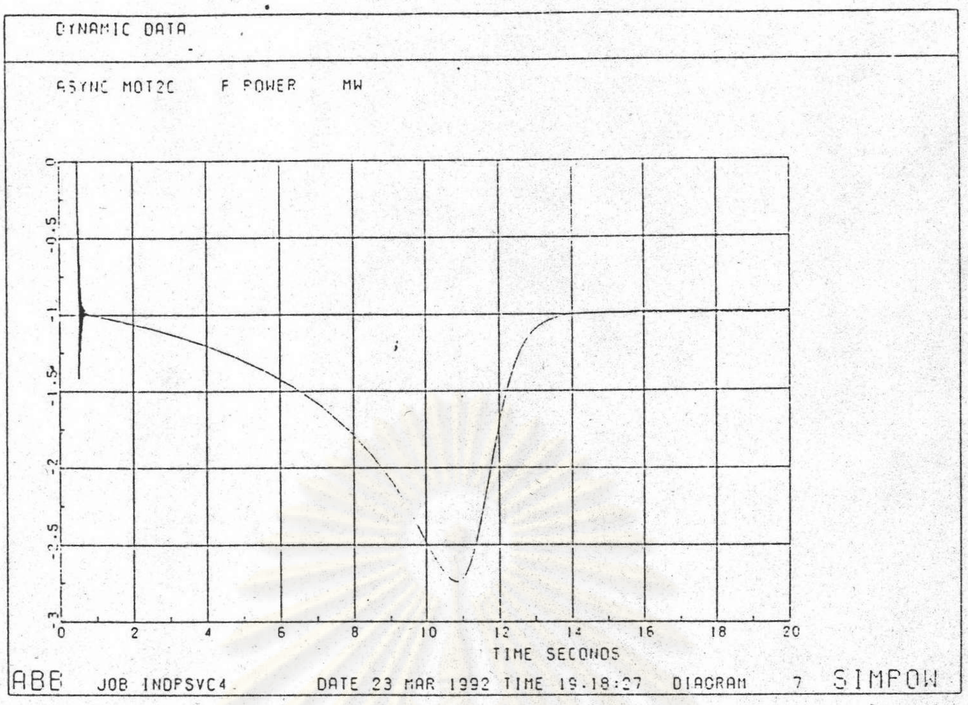


Figure A15.9 ASYNCHRONOUS MOTOR POWER REQUIREMENT (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

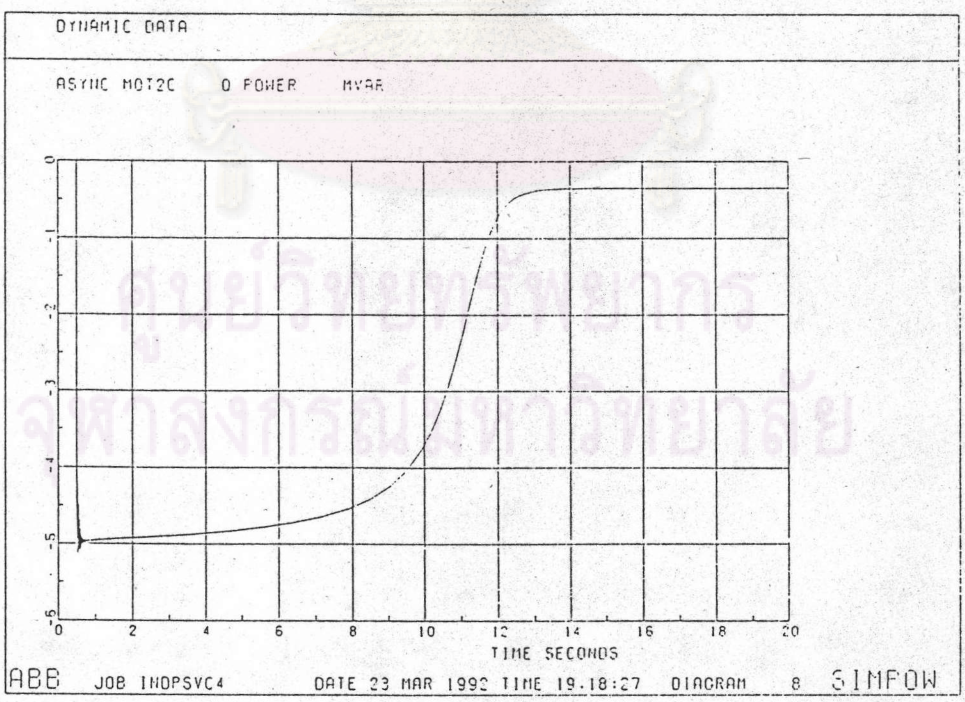


Figure A15.10 ASYNCHRONOUS MOTOR REACTIVE POWER REQUIREMENT (DOUBLE DISTRIBUTION LINE WITH SVC TYPE 4 )

# APPENDIX C

## TARIFF POLICY

### 1. Cost Concepts

Althrough the main principles for pricing may sound simple, the pricing of electricity is complicated in practise, especially when it comes to defining the utility's costs for supplying electricity . They may be defined in accordance with three different principles:

(i) Average Total Costs (ATC). This cost concept is defined by what would be called budgetary restrictions of the utility. This means that the income from total sales of electricity must be sufficient to cover the total costs over a period of years-the average total costs. These costs include all operating, maintainance and administration costs. This cost concept dominate cost calculations for tariff design in the beginning of the power supply era. It is easy to understand that the total costs has to be covered by the incomes from sales. It is still the basis for price regulation of electricity. The ATC has, however, no relation to efficient use of society's resources.

(ii) Short-Run Maginal Costs (SRMC). This cost concept is defined as total costs to increase the supply of electricity to customers within existing capacity of both production, transmission and distribution systems. SRMC equal the changes in incremental costs due to small increases of demand. In the production system SRMC include: a possible increase in fuel costs, decrease of sales of interruptable deliveries,increased costs due to the risks for future power shortages and so on. In the distribution systems the SRMC include mainly increased costs of losses and of the risks for future power shortages. This cost concept corresponds to the total economic costs of delivering an extra kWh to the customers. Since consumers use as much electricity as is economic for them at the existing price level, the SRMC level creates a short-term balance between supply and demand. Due to variation of SRMC both over the year and from one year to the other, tariff can never exactly correspond to the real SRMC. They are based on forecast SRMC.

(iii) Long-Run Marginal Costs (LRMC). This cost concept is defined as the total costs in longer term of meeting a considerable amount of new demand from customers. It includes total costs for new power plants and new transmission and distribution capacity-including capital costs. It is generally considered that existing demand has to pay for the existing capacity, so that the new demand only should pay for the incremental or marginal costs for the increased capacity.

Althrough SRMC from a theoretical point of view is the best cost concept, and tariffs are determined to correspond as closely as possible to SRMC, power utilities in the long run must have sufficient income to cover their total costs. The ATC concept therefore always also has to be considered when determining price levels in electricity tariffs.

2. Practical Tariff Design

There are several criteria for pricing of electricity, not all of which are mutually consistent. The main objective is that economic resources shall be allocated efficiently not only between the electricity sector and other sectors of the economy, but also within the power supply sector itself. This implies that cost reflecting prices must be used to indicate to the electricity consumers the true economic costs of supplying their specific needs, so that supply and demand can be matched efficiently.

Certain principles of fairness and equity have to be satisfied which may imply some limitations to the efficient use of resources:

- A fair allocation of costs among the electricity consumers, according to the costs they impose on the supply system;
- A reasonable degree of price stability from year to year for normal consumers;
- A tariff structure which is simple enough to be understood by the many small consumers;and
- The important restraint that electricity prices must raise sufficient revenues to meet the financial requirements of the power utilities.

Since normal tariffs cannot for practical reasons be individual for each consumer, they have to be structured to vary with the marginal costs of supply:

- in different geographical region,
- by different voltage level and
- by different consumer categories.

# VITA

The author of this thesis, Supakit Saringkarnpoonperm, was born in Bangkok, Thailand, on October 12, 1968. He received a Bachelor's Degree of Engineering (Electrical) from Chulalongkorn University in 1990.

At present, he works for IBM Thailand CO.,LTD. in Software & Services Department as a System Engineer.