# Chapter 4

# Embeded Diakoptics in Modified Fast Decoupled Load-Flow

## 4.1. Introduction

Diakoptics was applied to power-flow problem initially to overcome the size limitation of the Bus Impedance Matrix power-flow (6,31,33,39,40-42). The tearing method in the NRLF was applied in order to reduce the size of the Jacobian matrix (33,43,44). However, in the piecewise NRLF, the nonlinear conditions are considered for the Jacobian matrix as in the standard NRLF. This means that, the convergence of the piecewise NRLF is expected to be close to the untorn NRLF, but not as good as the NRLF. If low-impedance tie-lines are selected, the convergence is considered to be poor. In the FDLF, the Jacobian matrices are linear, so that the linear Diakoptics can be directly applied. Reference 45 presented a technique to calculate an exact solution from the piecewise FDLF. The temporary reference buses were used to overcome singularities (32), but the calculation process is very complicated. Normally, Diakoptics is not included in Load-Flow application software available on the market, because it is hard to understand and too complicated (46,61).

4.2. Happ's Piecewise Algorithms for NRLF (33,40)

The NRLF as described previously is based upon a Jacobian matrix that is a function of admittances, voltage magnitudes, and electrical angles. By means of the Jacobian matrix, corrections in bus voltages and angles are calculated from a vector of residual bus powers that usually diminishes in magnitude from one iteration to the next. The Jacobian matrix represents a linearization.

The Jacobian matrices of the subsystems represent submatrices that lie along the diagonal of the Jacobian matrix of the original system and form a block-diagonal.

In the piecewise NRLF, the nonlinear conditions will be considered by means of the Jacobian matrices, as in standard NRLF, but the interconnection of the subsystems will be considered by the six-step piecewise procedure in Chapter 3. The effect of the missing off-diagonal terms of the Jacobian matrix that provide contributions to the correction vectors, $\Delta\delta$ and $\Delta V$, in a subsystem due to residuals in other subsystems, are considered by the piecewise method based on impedance elements.

The approach is briefly as follows: each subsystem is solved by the standard NRLF approach. The tie-line's current flows into the subsystems are determined from the adjacent tie bus voltages, and contributed power residuals which go to zero as convergence is attained. The tie representation is consistent with the voltages contained in the Jacobian matrix, and with the linearization it represent.

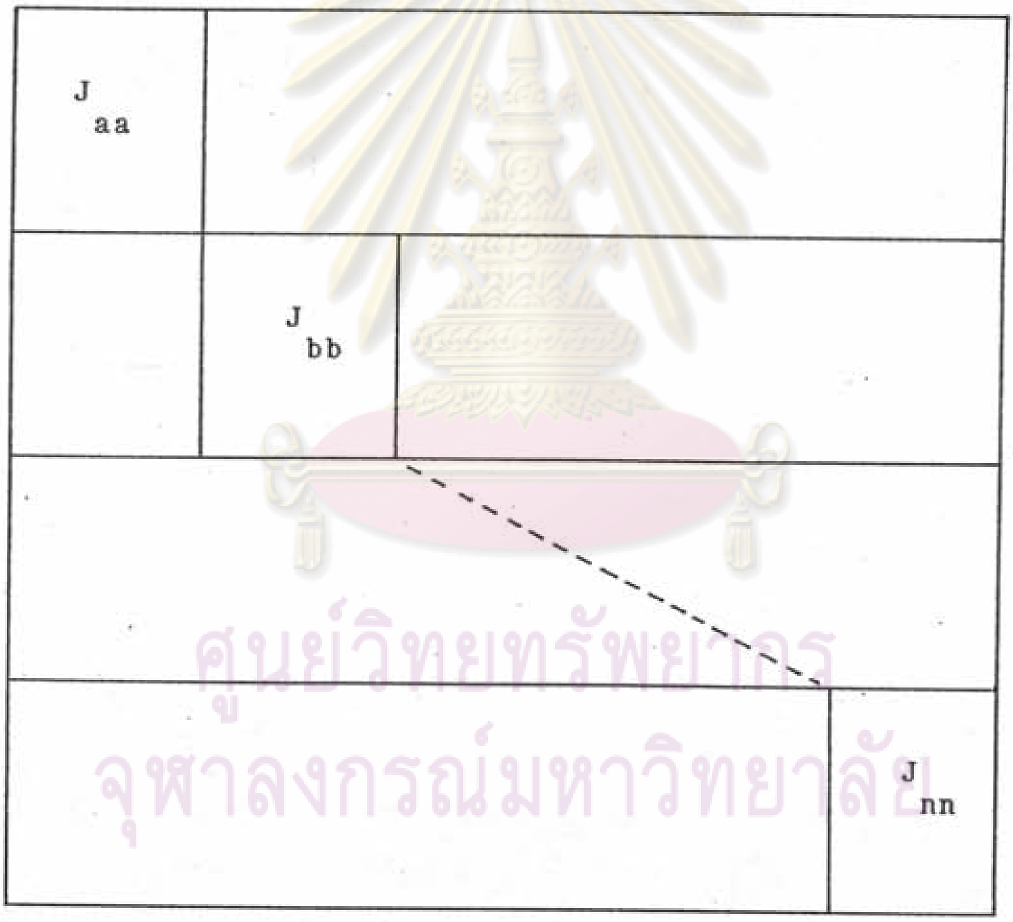



Fig. 4.1 Jacobian Matrix in Block-Diagonal Matrix Form.

The tie-line flows and their associated residuals do not take into account the effect of:

1. residuals within the subsystems within the iteration and

2. the residuals external to the subsystems, both of which contribute to changes in tie-line powers as represented in the NRLF process.

The six-step piecewise method recognizes the interconnections of the subsystems and takes the latter effects into consideration in each iteration, and produces additional corrections in voltages and angles, which are added on to those produced by the NRLF procedure.

### 4.3. Model of [ B' ] and [ B" ]-Networks

Hereafter, this chapter describes a simple and reliable different approach of Diakoptics in the FDLF. The steps of calculation have been simplified, however the performance is still good in the case of low-impedance tie-line and the convergence (40,47,48) of the FDLF is still linear.

The FDLF equations, eq. (2.4) and (2.5), are the Power System models. If the mismatch vectors, [ $\Delta$P ] and [ $\Delta$Q ] are represented by the injected current sources, [ I ] in eq. (3.4). The Jacobian matrices, [ B' ] and [ B" ], are represented by the Bus Admittance Matrix (see Appendix B), and they are called B'-network and B"-network respectively. At last, [$\Delta\delta$ ] and [ $\Delta$ V ] are respresented by bus voltage vectors [ E ] in eq. (3.4).

Since the electrical angle of swing bus does not change, let S be swing bus, so in B'-network:

$$\Delta\delta_s = 0 \qquad (4.1).$$

From eq. (2.4), S is treated as shorted-circuit to ground equivalently. Furthermore, in B"-network, the voltage of PV-bus and swing bus do not change, let Q be PV-bus, so:

$$\Delta V_s = 0 \qquad (4.2),$$

and

$$\Delta V_q = 0 \qquad (4.3).$$

From eq. (2.5), S and Q are treated as shorted-circuit to ground equivalently. The equivalent networks, original, B' and B"-networks, are shown in Fig. 4.2, 4.3 and 4.4 respectively.

## 4.4. Implementation of Diakoptics in The Modified FDLF

If Diakoptics is used in the FDLF, the [ B' ] and [ B" ] have submatrices which lie along their diagonals. They are form block-diagonal as shown:

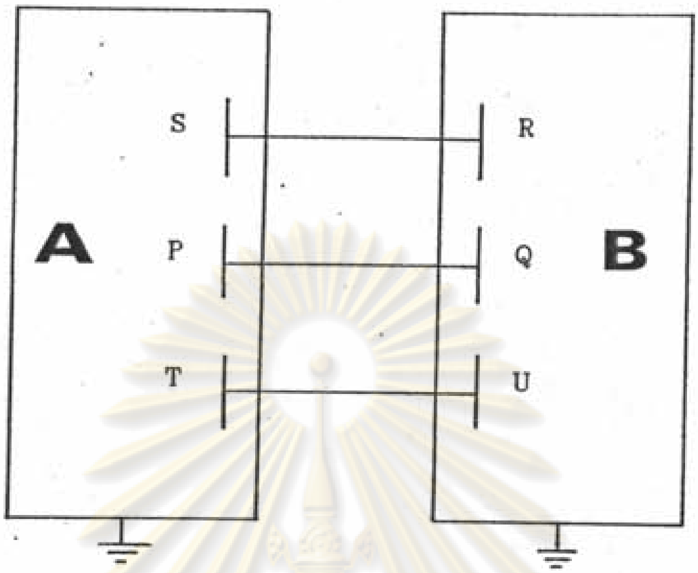



Fig. 4.2 Original-Network.

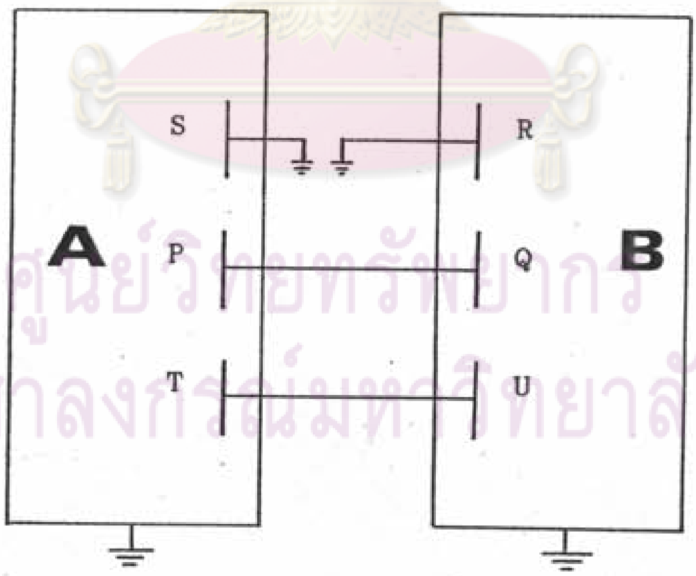



Fig. 4.3 B'-Network.

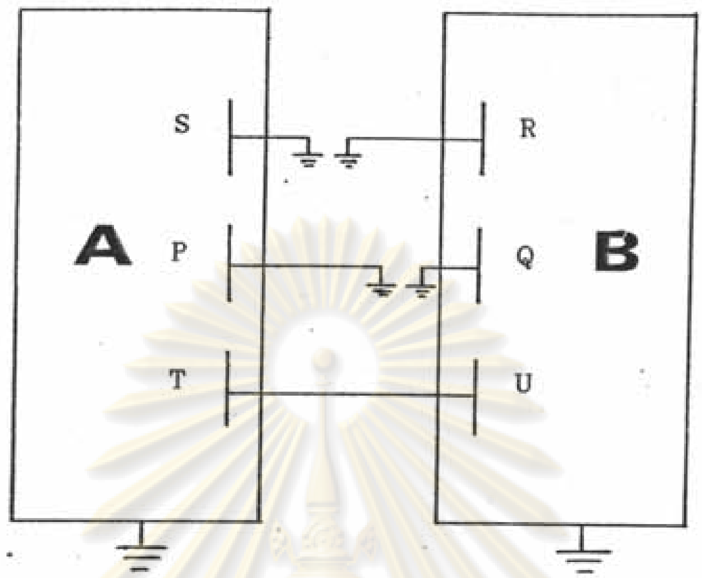



Fig. 4.4 B"-Network.

$$[B'] = \begin{bmatrix} B'_{aa} & & & \\ & B'_{bb} & & \\ & & \ddots & \\ & & & B'_{nn} \end{bmatrix} \quad (4.5),$$



and

$$[\,B''\,] = \begin{bmatrix} B''_{aa} & & & \\ & B''_{bb} & & \\ & & \ddots & \\ & & & B''_{nn} \end{bmatrix} \quad (4.6).$$



Considering Fig. 4.3, the B'- network, tie-line R-S is shorted-circuit to ground at bus S, such that the impedance of R-S can be included in [ B' ] of area B on the diagonal position of R. The dimension of [ $Z_4$ ] of original-network is 3 X 3 or the dimension of tie-line. But in B'-network, tie-line R-S shall not be used again, so the dimension of [ $Z_4$ ] of B'-network ( called [ $Z'_4$ ]) is 2 X 2. Fig. 4.5 shows the manner of described procedure above.

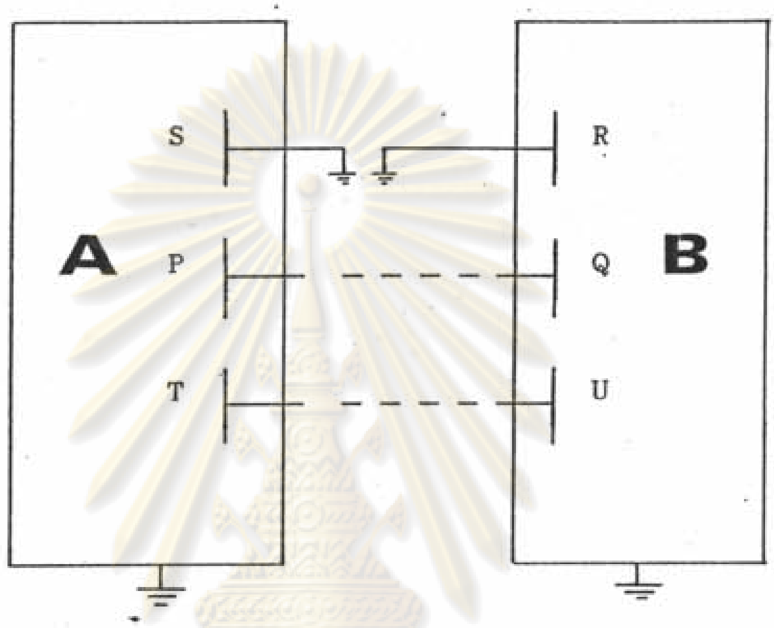



Fig. 4.5 Diakoptics in B'-Network.

In B"-network, tie-lines R-S and P-Q are shorted-circuit to ground at buses S and Q. The impedance of R-S can be included in [ B" ] of area B on the diagonal position of R, the impedance of P-Q can be included in [ B" ] of area A on the diagonal position of P. The dimension of $[ Z_4 ]$ of B"-network ( called $[ Z"_4 ]$) is 1 X 1. Fig. 4.6 shows the manner of the above described procedure.

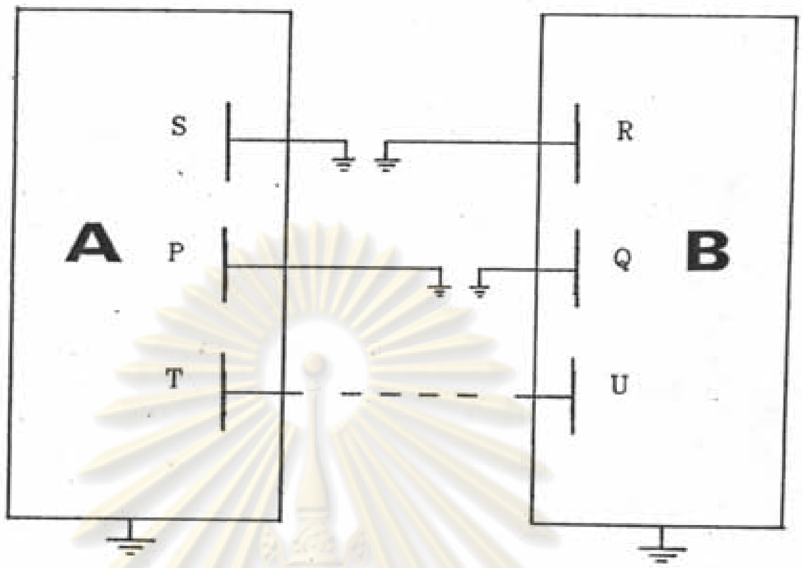



Fig. 4.6 Diakoptics in B"-Network.

However, in case of many areas, [ B' ] and [ B" ] may be singular in some areas. This problem is overcome by including shunt admittance in [ B' ] and [ B" ] or by the technique of the modified FDLF.

To calculate real and reactive power mismatch, all tie-lines's current must be calculated from the original-network:

$$I_{ij} = ( V_i - V_j ) Y_{ij} \qquad (4.4),$$

where; $I_{ij}$ is tie-line's current.

$V_i$ is sending end of tie-line.

$V_j$ is receiving end of tie-line.

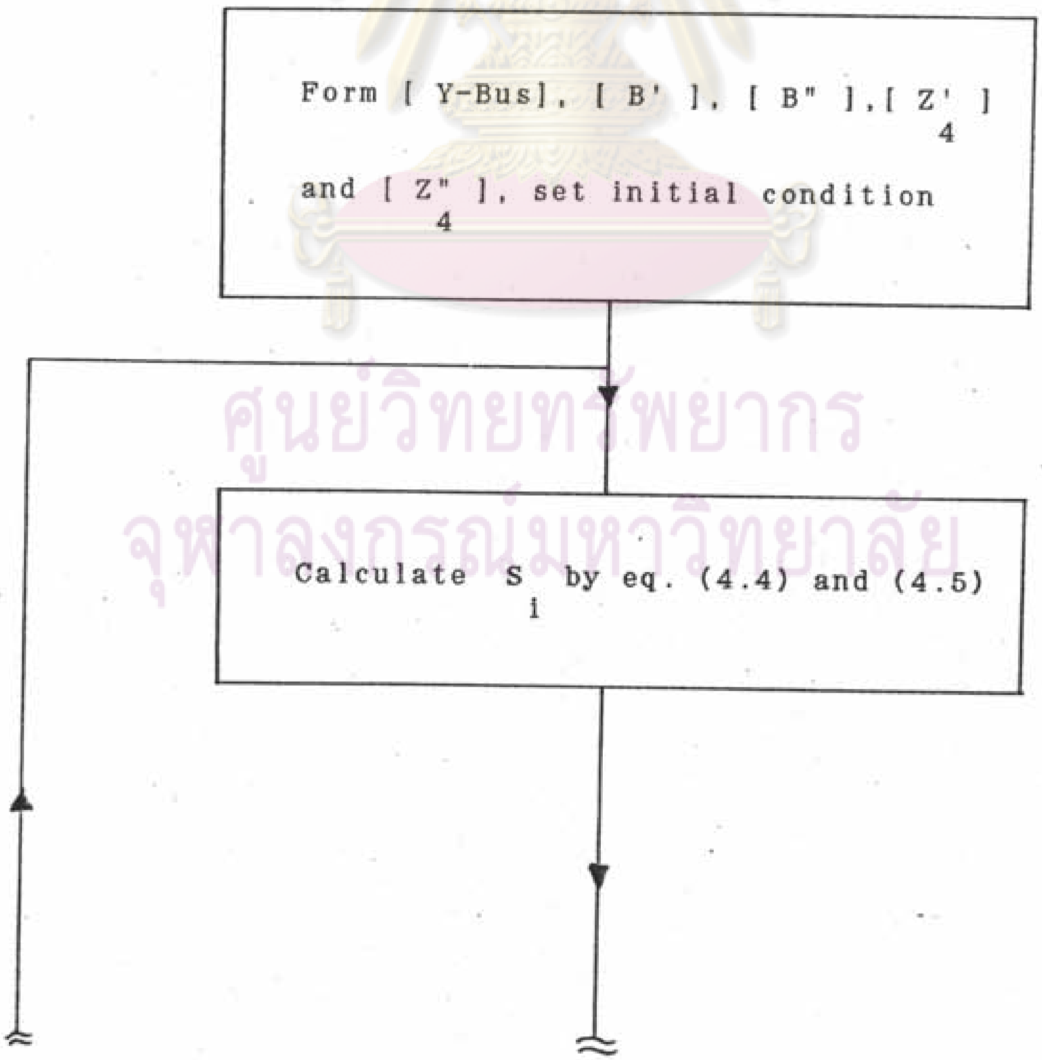
$Y_{ij}$ is series admittance of line i-j.

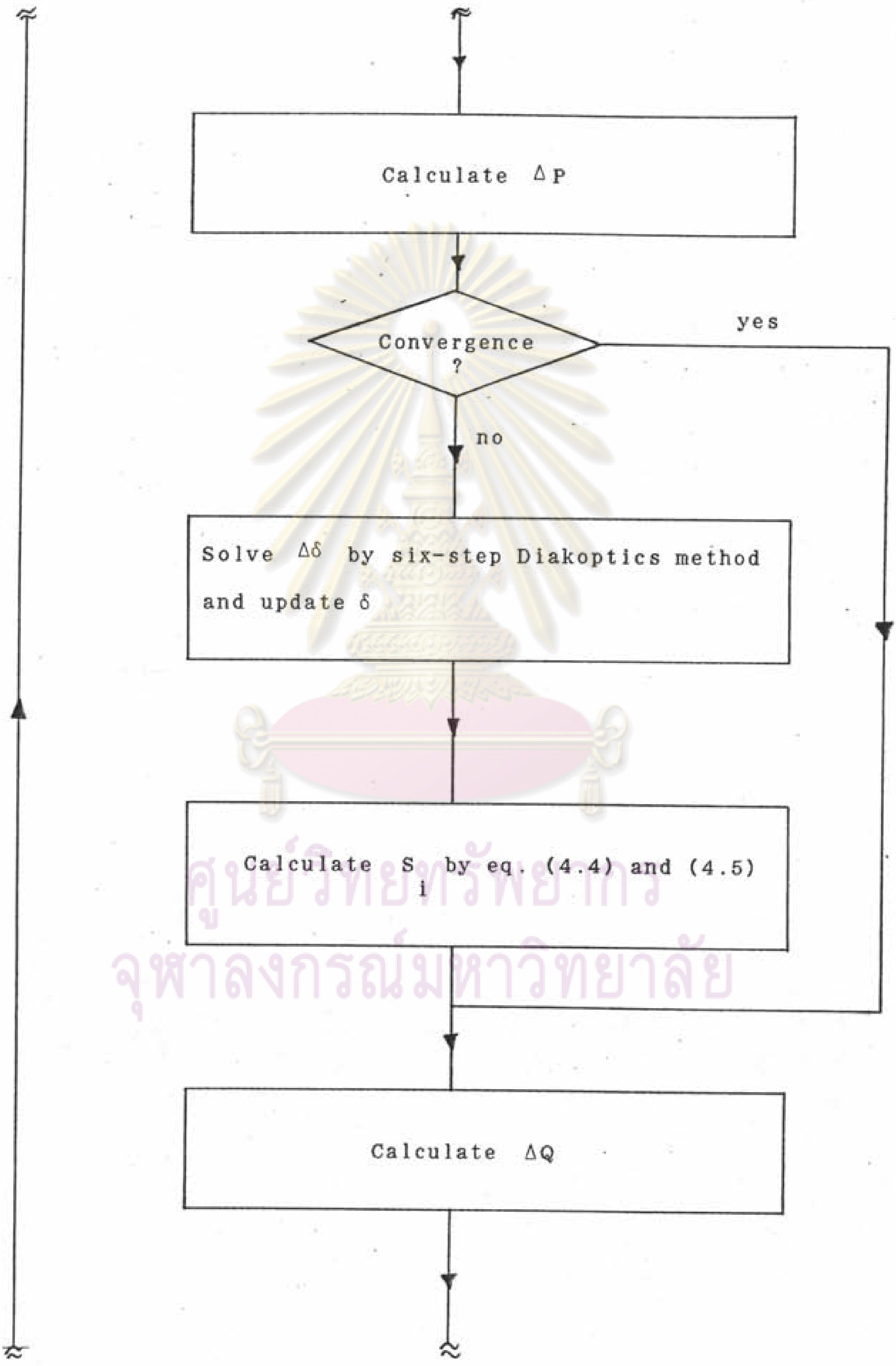
Then, power from tie-line to bus i is:

$$S_i = V_i I^{*}_{ij} \qquad (4.5),$$

where $*$ is conjugate of complex number.

This tie-line power is treated as equivalent load or generator. The flow-chart of Diakoptics in the modified FDLF is shown below, as examples of the tested systems are in Appendix F.





Calculate ΔP
Convergence ?
yes
no
Solve Δδ by six-step Diakoptics method and update δ
Calculate $S_i$ by eq. (4.4) and (4.5)
Calculate ΔQ

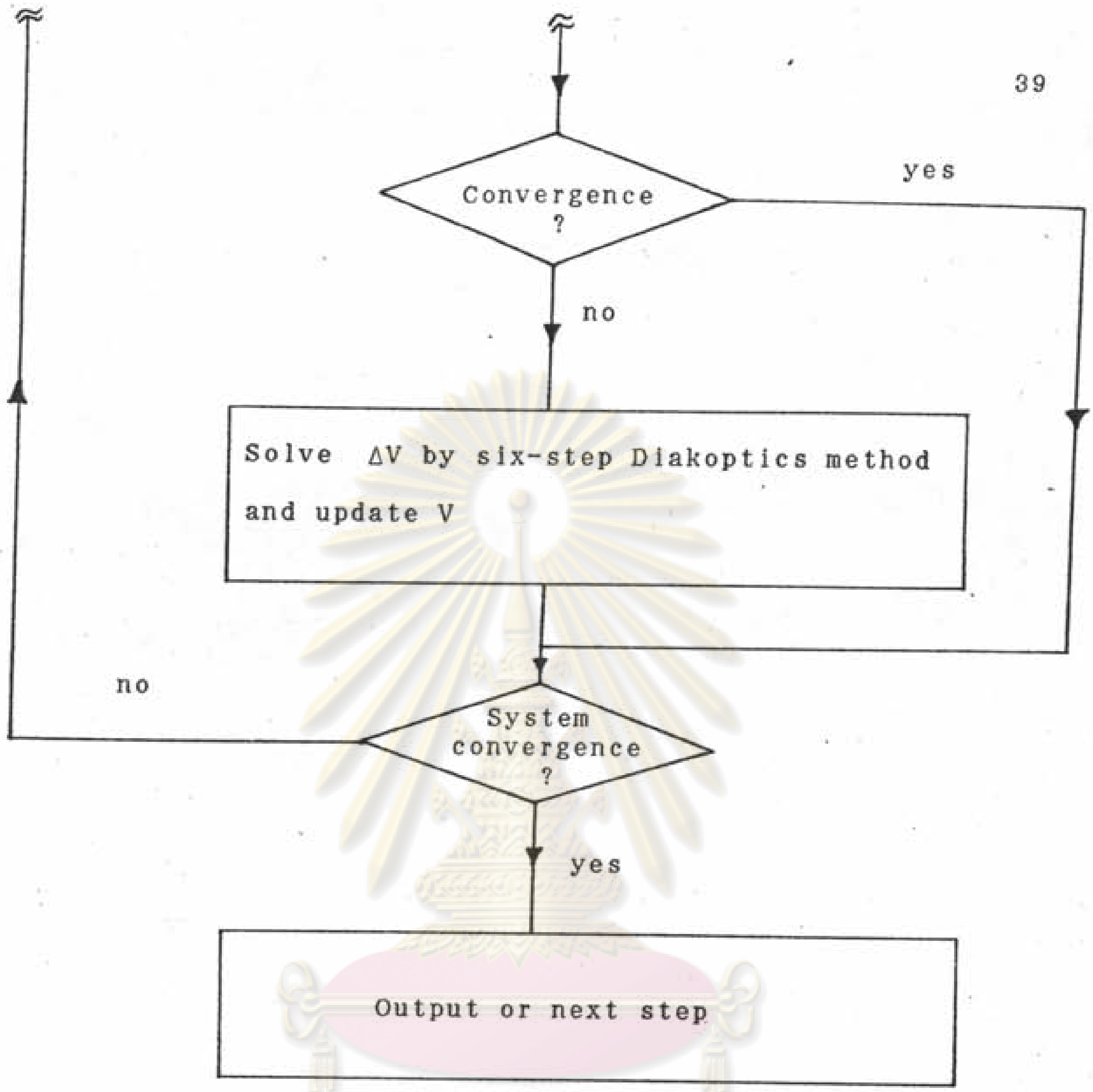



Fig. 4.7 Flow-chart of Diakoptics in Modified FDLF.