ANALYSIS OF REAL POWER ALLOCATION FOR DEREGULATED POWER SYSTEM

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ABSTRACT

The aim of deregulation in the electric power industry is to optimize the system welfare, by introducing competitive environment, mainly among the suppliers. Developing fair and equitable real and reactive power allocation method has been an active topic of research, particularly in the new paradigm, with many transactions taking place at any time. The current tracing method is chosen because this method is simple and more flexible. Based on solve load flow and network parameter, the method converts power injections and line flow into real and imaginary current networks. This current is represented independently as real and imaginary current networks. Since current network are acyclic lossless networks proportional sharing principle and this method is used to trace the relationship between current sources and current sinks. From this relationship of current components of individual generators, it is possible to find real power contribution of each generator. This method also applied for real power allocation with a few modification. The advantages of the proposed methodologies are demonstrated by commonly used test system and TNB systems. The proposed methodologies provide better reliability and minimize the limitation of conventional real power allocation method.

CHAPTER 1

INTRODUCTION

1.1   Background

The electricity supply industry (ESI) through out the world, which has long been regarded as the largest regulated monopoly, is undergoing enormous changes. The ESI is evolving into a distributive and competitive industry, with the aim to improve system efficiency and reduce energy cost, through increased competition among the industry participants.

Technology improvement, market pressure, politics and legislative initiatives are the driving forces that facilitate the modern deregulation and reform in the ESI. The primary steps undertaken in the deregulation process are functional unbundling of generation, transmission and distribution segments. There are, in addition, major developments underway to bring about full competition in many sectors of electricity business, including the implementation of nondiscriminatory transmission open access and unbundling of ancillary services to name a few. The experience gained since last decade and the recent movements unveils the success of the deregulation process. But this success is achieved not without crisis and challenges [2].

Deregulation and unbundling of major entities and services in the ESI worldwide has given rise to new problems. Many new concepts and terminologies in the field of power systems had to be reevaluated. A major criticism of the early models was that it did not address crucial issues such as the use of system charges

and transmission losses on a sound engineering basis. Indeed, at that time of deregulation, the issue was deemed as too complicated to have a viable solution [1].

Since the new regime is still young, many technical and economical issues are yet to be solved. It is the unbundling and transmission open access that provides the introduction for the work of this project.

1.2 Project objective

The objectives of this project are:

i. To compute the contribution of each generator to the each transmission line

ii. To analyse the generator that generates the higher power contribution to the transmission line.

iii. To get allocation factor for transmission line that is contributed by individual generator.

1.3 Project scope

The power transfer and transmission usage allocation are a central issue of the new cosmos of the deregulated electricity markets. The increased requirements for fair and transparent allocation and pricing scheme in the competitive environment , as well as the complexity introduced by unbundling the services, point out why these issues of great importance and require urgent solutions.

The primary objective of the work reported in the thesis is to determine the contribution of each generator that is contributed by each of generator to line flows and loads.

For the purpose of identifying different allocation factors, real power allocation method is used. The current tracing approach is applied. The obtained allocation factors are then employed in knowing how much and to what extent each generator makes use of the system and its service.

The scopes of this project are to study and analyze the conventional real power allocation method. According to this method, we have to trace current through the transmission line. In addition, the other scope is to develop and test the proposed method. Besides, a program is created to calculate real power contribution at the lines and loads by using MATPOWER and IEEE data in MATLAB. The results will be displayed through Graphical User Interface (GUI).

MATPOWER is package of M-files for solving power flow and optimal power flow problems. From that we ignore the optimal power flow because this project not includes the cost of power flow calculation. There is a lot of information in MATPOWER. We can know the power problem solvers like Newton's method, Fast-Decouple method and Gauss-Seidel method. The default power system solver based on Newton's method using on Jacobian, updated at each iteration. From the MATPOWER and IEEE data, we can know real and reactive power at transmission line, generation and load, voltage magnitude and its angle. This analysis will also help to estimate the generator's share to real transmission lines.

1.4   Literature Review

The transmission system is the most crucial element that connects the suppliers and loads. It is an integrated network that is shared by all market participants and a medium that generators compete to supply their customers. In the context of deregulated environments, transmission business is taken as a separate service that provides condition for competition. It is treated separately and funded independently irrespective of the ownership of the wires. Transmission system is

responsible to provide capacity to transmit power, offer adequate standards of security and quality of supply [3].

Another strategy the real power pricing problem is to approach it from the power engineering perspective. Indeed, there are at least two research directions published in literature using this strategy. The most important method is power tracing method.

This method compute power flowing for a given generator to each load or calculates each generator's contribution to a particular load. If such 'usage allocation' questions are answer clearly and unequivocally, it will be very useful to ensure the competitive market to be fair and efficient.

Two of most popular types of power tracing method were developed by D.Kirshen and J.Bialek, respectively. They proposed generation distribution factors to determine the share of a particular generator in line the flow. Kirshen based his method on generator domains and started with tracing active power flows from generators to loads. This method was extended to reactive power in.

Based on a solved power flow solution, all power injection are translated into real and imaginary currents to avoid the problems arising from a non-linear coupling between active and reactive power flows caused by losses. The method then trace these currents to determine how much current each source supplies to each sink. This current contribution can then be translated into contributions to the active and reactive power output of the generators. Bialek introduced a topological method to allocate the supplementary transmission charge to active and reactive loads. Another method for determine the share of the generator in a customer load has been developed based on the nodal generation distribution factors. It is stated that this method can be used for both active and reactive power flows since the transmission losses are taken into account [4].

Although the power tracing method emphasizes the technical aspect of reactive power procurement and brings up a potential research direction, the

published methods all have some disadvantages. For example references use active and reactive current. The methodology seems to be interesting and mathematically correct. However, it has no physical meaning and can be difficult to implement in practice. In general, these methods are more appropriate for active power than for reactive power. Furthermore, some of them lack technical foundation and sometimes are based on untenable assumptions.

1.5 Thesis Outline

In Chapter 1, the literature review, objective and scope of the project is discussed in details. The literature review is about the history of deregulation for power system such as about the application and the aim of deregulation in the electric power system.

In Chapter 2, the deregulated power system and real power allocation method are explained characteristics of real power allocation methods and current flow network is discussed more details.

In chapter 3, the methodology is discussed. Current tracing method is applied. This method is explained more details in this chapter. In addition, the flow chart about the main process in real power allocation methodology and flowchart for work progress is discussed.

In Chapter 4, the proposed real power allocation methods have been tested and analyzed for Test System I, Test System II and Test System III bus systems. The results of the project are discussed and analyzed in this chapter.

The conclusions of this project can be found in Chapter 5. Moreover, some suggestions on the extensions to potential topics for future research are presented.

CHAPTER 2

REAL POWER ALLOCATION FOR DEREGULATED POWER SYSTEM

2.1   Introduction

Deregulation and unbundling of major entities and services in the electricity supply industry (ESI) worldwide has given arise to new problems. Many new concepts and terminologies in the field of power systems had to be reevaluated. The main objective in the electric industry restructuring is to bring fairness and open access to the transmission network. Fairness can only be achieved by adopting a fair and transparent usage allocation methodology acceptable for all parties. It is become an important thing to know the role of individual generators to loads to transmission wires and power transfer between individual generators to loads. A basic requirement in the supply of electricity is to ensure that the voltage magnitude is within a specified range at each bus. This chapter will discuss a lot of about real power in power system. Then, a new method based on the current tracing method is developed.

2.2   Real Power Allocation Method

The principal difficulty in allocating transmission usage to loads, generators or to bilateral contracts is that, regardless of the approach, the final allocation always contains some degree of arbitrariness.

This is due to the fact that the system transmission quantities are a non-separable, nonlinear function of the bus power injections, which makes it impossible to divide the system usage and/or losses into the sum of terms, each one uniquely attributable to a generation or load. Thus, the issue of fairness will probably never be fully resolved by any allocation .Nevertheless, it is possible to identify a number of characteristics in an allocation scheme that are, arguably reasonable and necessary for the scheme to be equitable, or at least, acknowledged as equitable.

In general, the allocated methods should reflect the magnitude of the power or current injections at each bus, reflect the relative position of the bus in the network, reflect both the network topology and the voltage-current relationships, and are simple to understand and implement, and be consistent with a solved load flow.

2.3   Deregulation Power System

The aim of deregulation in the electric power industry is to optimize the system welfare, by introducing competitive environment, mainly among the suppliers.

In a deregulated power system structure, the transmission system is used by multiple generation and load entities under the bilateral or multilateral transactions. Some methodology should be developed to allocate various transmission system quantities such as line MW and MVAR flows and MW losses. If these quantities are allocated accurately to an individual line, these can be summed for each area or zone to determine its allocation to each transaction.

2.4 AC Load Flow Techniques

Starting from AC power flow solution one can convert the complex power injections and line flows into complex current equivalents. Injected currents, line currents and currents due to shunt elements can be represented respectively as:

$$I_{inj} = (S_i / V_i)^*$$
(2.1)

$$I_{inj} = y_{ij} (V_i - V_j)$$
(2.2)

$$I_{i\_sh} = y_{i\_sh} (V_i)$$
(2.3)

Where;

I_{inj} = injected current of bus i

S_i = injected power of bus i

V_i = voltage at bus i

V_j = voltage at bus j

y_{i_sh} = equivalent shunt admittance at bus i

I_{i_sh} = current flow through y_{i_sh}

I_{ij} = line current from bus i to bus j

y_{ij} = series admittance of the line, I_{ij} between buses i and j.

The complex current flow network obtained can be further decoupled into real and imaginary current networks since the real and imaginary component of the current are orthogonal and Kirchoff's current law (KCL) can be applied to each of them independently.

2.5   Acyclic Properties of Current Flow Networks

The most power flow tracing methods are suitable only to systems without circulating flows. But it is true that generally, there are several loops in real power flow networks. The reason is that many types of elements behave as real power sources and things are no more complex than tracing only reactive power. In this section, acyclic property of real and imaginary current networks is proved based on some reasonable assumptions. It is mainly drawn from reference [2].
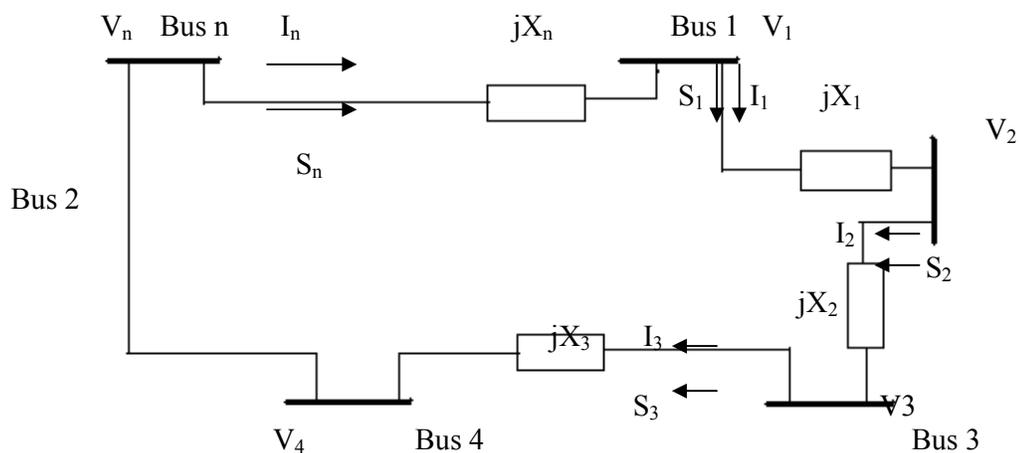
Figure 2.1: Acyclic nature of current flow networks.

Figure 2.1 shows the acyclic nature of current flow networks. V_1 to V_n indicates the complex voltages, I_1 to I_n and S_1 to S_n are the complex current and power transferred through the branches respectively. For transformers and high voltage transmission lines, it is reasonable to neglect their resistances since they are very small compare to the reactance. This simplification will not affect the calculation precision notably, and therefore, the branch impedances are represented as jX_1 to jX_n.

2.6   Summary

The proposed real power allocation method can be utilized, suitable and very efficient in deregulated power systems. In addition, the complex current flow network obtained can be further decoupled into real and imaginary current networks since the real and imaginary component of the current are orthogonal and Kirchoff's current law (KCL) can be applied to each of them independently.

CHAPTER 3

CURRENT TRACING METHOD

3.1   Introduction

This chapter will explain about the methodology to identify generator contribution of real power to loads and flow by using current tracing method. According to current tracing method, we have to calculate the real power contribution at the transmission line and to determine generator's contribution of real power to loads and flows. In this project, we have to make a programming and do analysis. The flow chart in the next subchapter shows about the operation for executing this engineering project.

3.2   MATLAB

MATLAB is a high-performance language for technical computing. The name MATLAB stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

3.2.1   MATLAB Application

Many applications can use with the MATLAB. The typical uses include:

a) Math and computation.

b) Algorithm development.

c) Data acquisition.

d) Modeling, simulation, and prototyping.

e) Data analysis, exploration, and visualization.

f) Scientific and engineering graphics.

3.2.2   IEEE and MATPOWER

MATPOWER is a package of MATLAB M-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators that are easy to use and modify. MATPOWER is designed to give the best performance possible while keeping the code simple to understand and modify.

IEEE is an association dedicated to the fostering of technological innovation and excellence for the benefit of humanity, is the world's largest technical professional society. The IEEE publishes nearly a third of the world's technical literature in electrical engineering, computer science and electronics. This includes about 130 journals, transactions and magazines and over 400 conference proceedings published annually. IEEE also produces technical books, monographs, guides and textbooks. Furthermore, I get and refer data from this association.

3.3   Current Tracing Method

Current Tracing Method is used to calculate the contribution of individual generators and loads to line flows and the real power transfer between individual generators and loads that are significant to transmission open access. Based on ac

load flow solution, a novel method is used which can decide downstream and upstream power flow tracing paths very fast and calculate contribution factors and generations and loads to line flow efficiently. The power transfer between generators and loads can be determined. In according to this thesis, current tracing is used to trace the current flow networks.

3.3.1   Introduction

Current tracing is quite mature and especially suitable to tackle such network topology related issue. In our case directed graph is used. The vertices of the graph are system buses and the edges of the graph are lines and transformers. The direction of each edge is the direction of power flow inside. The directed graph of active power flow may be different from that of reactive power flow in edge directions.

Related lemmas are presented and proved first which presents the necessary conditions to guarantee the feasibility of the suggested method in power flow tracing. Then based on the widely used bus-line incident matrix, downstream and upstream tracing sequences are determined at ease. A novel approach is suggested to calculate the contribution factors of individual generations and loads to the line flows respectively [6].

The method assumes that a generator has the priority to provide power to the load on the same bus and is based on the following lemmas of current tracing method.

Lemma 1: A lossless, finite-nodes power system without loop flow has at least one pure source, i.e. a generator bus with all incident lines carrying outflows.

Lemma 2: A lossless, finite-nodes power system without loop flow has at least one pure sink, i.e. a load bus with all incident lines carrying inflows.

3.3.2 Contribution and Extraction Factors

The downstream tracing (DSTR) is used for calculating the contribution factors of individual generators to line flows and loads. The tracing path is determined by the method and starting from a pure source. For our example, the DSTR sequence is bus 1, bus 2, bus 3 and bus 4. The state variable in DSTR is the net generator power to solve the problem we first build up two matrices. One is extraction factor matrix of lines and loads from bus total passing current. The other is contribution factor matrix of generators to bus total passing current. The product of these two matrices constitutes the contribution factors of generators to line flows and loads.

(ii)   <u>Extraction factors of lines and loads from bus total passing current</u>

We first build up an extraction factor matrix (A_l) of lines from total passing current of their upstream buses, i.e. $I_l = A_l.I$. Here I_l is the vector of line current. I is the vector of bus total passing current in the bus sequence of downstream tracing and calculated from ac load flow solution. The nonzero element in A_l is calculated as follows [1]:

$$(A_l)_{line\ j,bus\ i} = \frac{line\ j's\ current\ flow}{bus\ i's\ total\ pass\ current\ I_i} \qquad (3.1)$$

Where bus i is the upstream bus of line j. I_i includes both line inflow current and net generator injection current to bus i calculated from load flow solution. Similarly we can form an extraction factor matrix (A_L) of loads from total passing current of their located buses, i.e. $I_L = A_L.I$. The vector of load current I_L takes the same sequence as vector I, therefore matrix will be a diagonal matrix where

$$(A_L)_{ii} = \begin{cases} 0 & i \notin net\ load\ buses \\ \dfrac{net\ load\ current\ on\ bus\ i}{I_i} & i \in net\ load\ buses \end{cases} \qquad (3.2)$$

(ii)   <u>Contribution factors of generators to bus total passing current</u>

The next step involves the calculation of contribution factor matrix, B of generators to bus total passing current. Mathematically this can be expressed as $I = B.I_G$. The elements of B are calculated using the equation given below:

$$
B_{bus-i,bus-k}
=
\begin{cases}
1 & (k = i, k \in net\,gen.buses) \\
0 & (k = i, k \notin net\,gen.buses) \\
0 & (k > i) \\
0 & (k < i, k \notin net\,gen.buses) \\
\displaystyle\sum_{I_j \in i} \left(A_{l_j} - m \right. \\
\left. .B_{m-k} \right) & (k < i, k \in net\,gen.buses)
\end{cases}
\tag{3.3}
$$

Where $k < i$ means k is an upstream bus of bus i, and $k > I$ means k is a downstream bus of bus i . The last expression is for the lower triangular nonzero elements. The term $I_{j \in I}$ means line j is an inflow line of bus i. $A_{lj\_}$ is the unique nonzero element corresponding to line j in matrix A_l with bus m as its upstream terminal. B_{m_k} is the element in matrix B already calculated which represents the contribution of generator k to the total injection current of bus. By substituting $I = B.I_G$ in $I_I = A_1.I$ and $I_L = A_L.I$ contribution of each generator to line flows and loads can be calculated.

3.3.3   Establishing Current Flow Networks

It is important to note that the converted currents satisfy the conditions of KCL independently for both real and imaginary current components for any node under consideration. Besides equation (3.1) and (3.2) implies that the may not necessary be equal to even if the real power at the sending and receiving terminal of the line are the same (lossless line).

$$I_{inj} = \left(\frac{P_i}{V_i} \right)^* \tag{3.4}$$

$$I_{ij} = \left(\frac{P_{ij}}{V_i} \right)^* \tag{3.5}$$

3.3.4   Current Contribution of Generators to Line Flows

The complex current contributed by each generator g to each equivalent line section is simply:

$$I_g^{ik} = \left(I_g^{ik\_r} + j I_g^{ik\_im} \right) \tag{3.6}$$

3.3.5   Translating Currents to Real Power

The current contribution is translated into real power contribution by using:

$$P_g^{ik} = \mathrm{Re}\left\{ V_i \left(I_g^{ik} \right)^* \right\} \tag{3.7}$$

3.4   Flow Chart

In this project, there are two important aspects to be implemented in order to make sure this project success, programming aspects and analysis aspect. The programming part gives student a skill in MATLAB. In addition, this software gives a lot of knowledge and information to the student. The analysis part allows the student to get more understanding of programming that is done.

Figure 3.1 shows current tracing approach for real power allocation. Firstly, power flow program is run and the load flow solution is obtained by using MATPOWER and IEEE data. Then, real power flows and injections are translated into currents. This can be done by using the equation (3.3) and (3.4) as mentioned before.

Then, the actual network is converted into two equivalent real and imaginary current networks. A next, real and imaginary current component is combined that is attributed to each generator as shown in equation (3.5). Then, the real and imaginary current is converted into real power. The equation (3.6) is applied. At this condition, current tracing method is applied. The contribution of each generator to lines and loads is computed. The generator that generates higher to transmission lines is determined.

Figure 3.2 shows the flowchart of work progress. The first step is select test system. MATPOWER or IEEE data is applied to obtained load flow solution. Then, the data taken is run in MATLAB. The programming is created in M-file. Real power data taken from load flow solution is used as a basic tool on making the program. Next, the program is run by using the proposed method, current tracing method. Test system for 4, 9 and 14 bus is applied. Then, the data obtained are collected and analyzed shown in the tables on Chapter 4.

```
                          ┌──────────┐
                          │  Start   │
                          └────┬─────┘
                               │
              ╱────────────────────────────────╱        ┌────────┐
             ╱  Input system data under study  ╱         │ Step 1 │
            ╱────────────────────────────────╱           └────────┘
                               │
                   ┌───────────────────────┐             ┌────────┐
                   │  Run power flow program│             │ Step 2 │
                   │  and obtain the load   │             └────────┘
                   │  flow solution         │
                   └───────────┬───────────┘
                   ┌───────────────────────┐             ┌────────┐
                   │ Translate complex power│             │ Step 3 │
                   │ flows and injections   │             └────────┘
                   │ into currents          │
                   └───────────┬───────────┘
                   ┌───────────────────────┐             ┌────────┐
                   │ Convert the actual     │             │ Step 4 │
                   │ network into two       │             └────────┘
                   │ equivalent real and    │
                   │ imaginary current      │
                   │ networks               │
                   └───────────┬───────────┘
                   ┌───────────────────────┐             ┌────────┐
                   │ Combine real and       │             │ Step 5 │
                   │ imaginary current      │             └────────┘
                   │ components attributed  │
                   │ to each generator.     │
                   └───────────────────────┘
                       ┌──────────────┐                  ┌────────┐
                       │ Current      │                  │ Step 6 │
                       │ Tracing      │                  └────────┘
                       │ Method       │
                       └──────────────┘
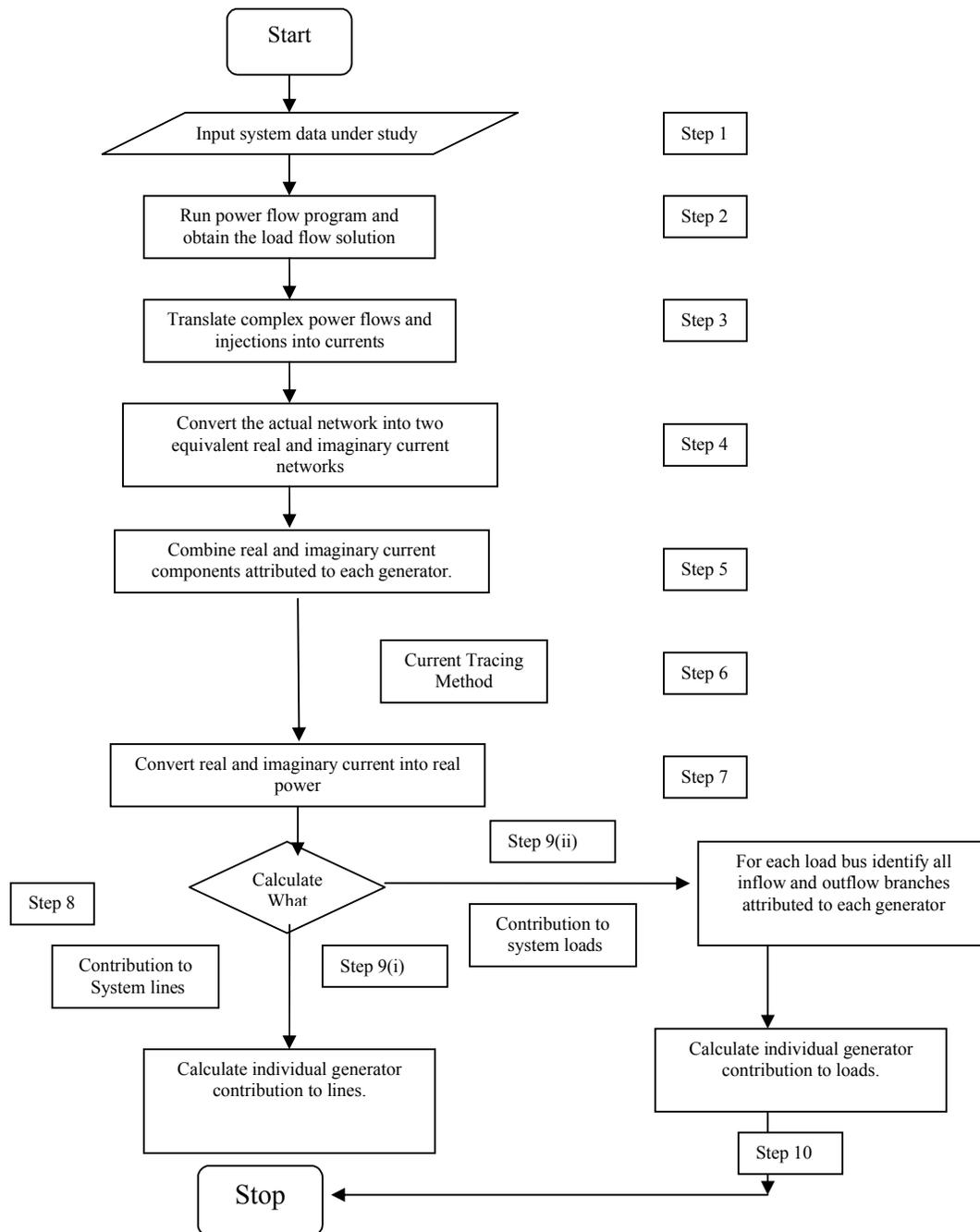```

Figure 3.1 Development current tracing approach for real power allocation

Where;

i.    For Step 3;

        * using equation (3.4) and (3.5)

ii.    For Step 5;

        * using equation (3.6)

iii.    For Step 6;
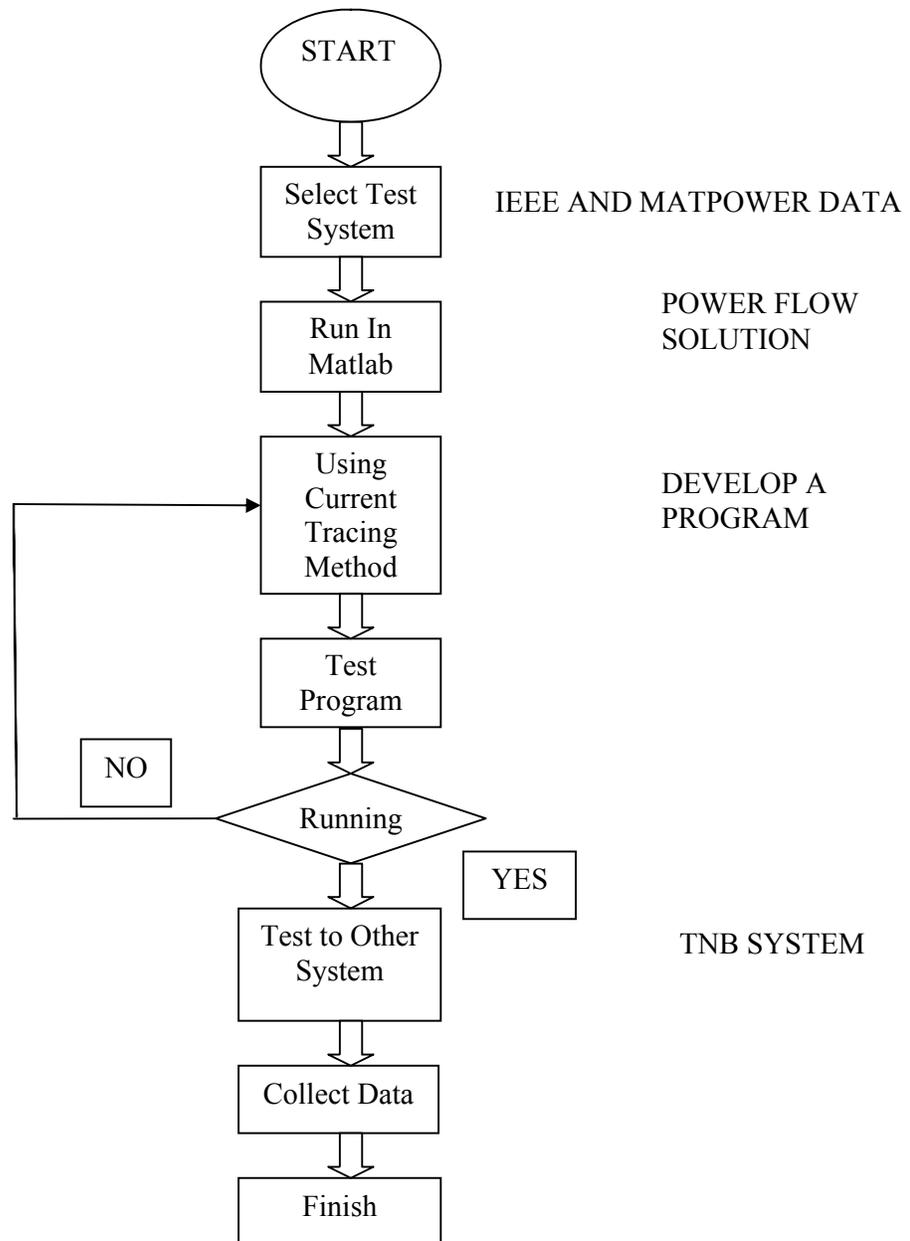
        * using equation (3.7)

START

Select Test System → IEEE AND MATPOWER DATA

Run In Matlab → POWER FLOW SOLUTION

Using Current Tracing Method → DEVELOP A PROGRAM

Test Program

NO

Running

YES

Test to Other System → TNB SYSTEM

Collect Data

Finish

Figure 3.2: Flow chart of work progress

## 3.5    Summary

In this thesis current tracing method is applied to calculate the contribution factors of individual generators to line flows and loads and the extraction factors of individual loads from line flows and generators. The power transfer allocation between individual generators and loads are significant to transmission open access. Related lemmas have been proved to guarantee the feasibility of the method. Bus-inflow-line and bus-outflow-line incident matrices are built up to fast determine the downstream and up-stream power flow tracing sequences.

The DSTR is performed to determine the contribution factors of generations to the line flows and loads, whereas USTR is performed to determine the extraction factors of individual loads from line flows and generators. The suggested method is very efficient and suitable for use in real power systems.

# CHAPTER 4

# RESULTS AND ANALYSIS

## 4.1 Introduction

Case studies on different test systems and is used to illustrate the design, qualities and some limitations of proposed methods described in Chapter 3, real power allocation. The systems used for illustrating the power allocation methods are the following.

- Test System I - 4-bus test system

- Test System II – 9-bus test system

- Test System III – 14-bus test system

Each of the above system has their unique features, which may be required demonstrate the performance of the methods. The following sections describe the case studies for the allocation of real power output of generators each of the above systems respectively.

**4.2      Real Power  Results**

The current tracing method is discussed in Chapter 3 for calculating generators' real power shares to system lines and loads was extensively tested. Results are presented for the test systems are shown below.

**4.2.1    TEST SYSTEM I – 4-BUS TEST SYSTEM**

The 4-bus system consists of two generators supplying the system lines and loads. The generators supplied the real power to 2 loads and 4 line flows. The data collected is shown in the tables below. The contribution of generator 1 and generator 2 to system lines and loads is analyzed respectively by using current tracing approach.
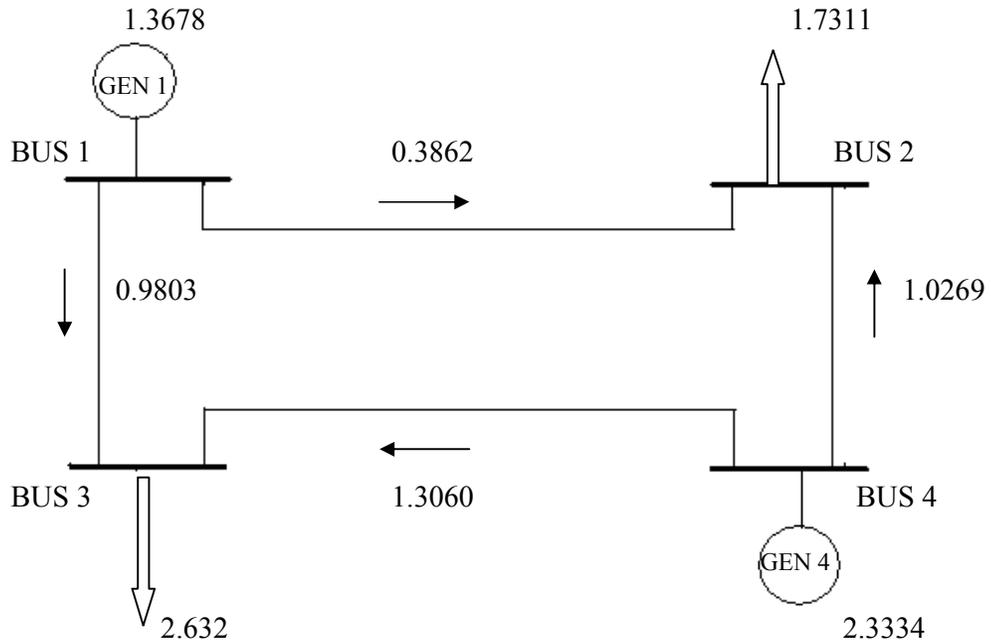
**4.2.1.1 Current Flow Network**



Figure 4.1: Real Current flow network in real power allocation for the 4-bus test system.

Figure 4.1 shows the real current flow for 4 bus test system. By using equations (3.4) and (3.5) in Chapter 3, the power injections and flows can be converted into real current equivalents. From the figure above, the converted bus current injections and its corresponding line current flows are shown.