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TITLE

Study Of The Economic Dispatch Applied To The Algerian Electric Network

Submitted by

Mammeri Ousama

Bekri Mohammed

Under the supervision of

Ph D Ben Attous Djilani

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Dedicate

It is impossible to find the right words to thank my mother for her love and encouragement. Without it, this thesis would not be completed. This work is dedicated to my mother, father, grand mothers, grand father, brothers and all the family, uncles, especially my uncle ZEGHIB ghani and all his family.

To all the friends ,especially Amer, Omar, Bachir ,el hafsi…

Mohammed

Dedicate

It is impossible to find the right words to thank my mother for her love and encouragement. Without it, this thesis would not be completed. This work is dedicated to my mother, brothers and all the family, uncles

To all my friends especially Kader soufian,salah ,bachir,hassan…

Oussama

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All praise, glory and gratitude be to Allah who said in the Holy Quran that "He who taught (the use of) the pen. Taught the man that which he knew not". Peace is upon the Prophet Mohammad, his family, his companions, and all those who followed him until the Day of Judgment.

Allah said (9-105): *And say: "Work (righteousness): Soon will Allah observe your work, and his messenger, and the believers."*

First of all we wish to express our deepest gratitude, thanks, and profound gratitude to our thesis advisor Dr. Ben Attous Djilani for his invaluable advice, personal attention, and continuous encouragement throughout our Final Year Project program.

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SUMMARY:

CHAPTER ONE \ GENERAL BACKGROUND

CHAPTER TWO \ POWER FOW STUDIES

CHAPTER THREE \ OPTIMAL POWER FLOW

CHAPTER FOUR \ APPLICATION

CHAPTER ONE \ GENERAL BACKGROUND

1-1 Historical note:

In the early days, there used to be small power stations for each locality as urban area. Since the demand power come in more and more growth the interconnection of different generating stations- to develop a grid (network)-, come an essential subject that electrical engineers think to do. When the complex system consisting the Generation, Transmission and Distribution sub-networks, requires an special operation studies, the necessity of an trusted tool to manage the power as the suitable way, has appeared .The earlier operating system in energy networks in the last century, has taken in consideration the efficient electric power rules and formulas by hand solving , in 1929 a special purpose analog device called network analyzer* -and sometimes AC analyzers- was invented to enter in operation [1]. The analogue-or network calculator**- does not make any formulation, simulation or modelling of the network, but a performing of a representation of currents and voltages of the nodes and the lines, by analog with a scale very reduced. Just the United States and Canada engineers utilized about 50 one in 1950 [2], this limitation was solved by computer availability, since the 50th years; about 1955 and 1957 from IBM and the American Electric Power Service Corporation; here a successful program was developed and preferred then the analyzer and specially by the extend capacity to solve either; short circuit and transient stability calculations. All the programs written were required on nonlinear methods using the base of a matrix variable .The using of a digital computer and a larger algorithm offer a greater flexibility ,economy ,accuracy and quicker operation[3].

* G.E. ** Westinghouse

1-2 Electric Energy Systems:

Initiation:

Electric energy systems engineering (ESEE) is that branch of electrical engineering which concerns itself with the technology of generation, transmission, and distribution of electric energy.

The vast electric energy systems that span every modern nation represent the largest and he expensive of man-made systems. To the electric energy systems engineer whose job it is to ***design*** and ***operate*** them, they offer some of the most challenging problems to be found in any branch of engineering.

The objective of an electric energy system is simply stated:

- ✓ It shall generate electric energy in sufficient quantities at the most suitable generating locality,
- ✓ Transmit it in bulk quantities to the load centers,
- ✓ And then distribute it to the individual customers in proper form and quality and at the lowest possible **ecological** and ***economic*** price. [4]

The Electric Energy system –Operational Considerations:

The basic objective of an electric energy system is to supply electric energy to the various loads throughout a given service area. Properly designed and operated, it should meet the following requirements;

1-it must supply energy practically every where the customer demand.

2-the load demand for real and reactive power vary with time. The system must be able to supply this ever-changing demand.

3-the delivered energy must meet certain minimum requirements in regard to “quality”. These three basic factors determine this quality:

(a) Constant frequency.

(b) Constant voltage.

(c) High reliability.

4-it should deliver energy at minimum economic and ecological costs [4].

1-3 Power System Components :

Power system network is a complex network consisting of the following sub-networks:

1- Generation
2- Transmission
3- Distribution

In general, the different components which constitute the network are; synchronous generators, transmission lines (over high voltage), transformers, distribution networks (in three and one phase) and static, or dynamic loads. The power circulation is on the whole, balanced i.e. symmetric, so we can considered them as a single phase system; in order simplify the analysis and the treatment in calculations [3].

The first major part in subdividing of power system consist of three phase synchronous generators , designed to feed the network by a three phase balanced voltages (scale of some ten KVs),the adaptation system represented in high voltage transmission lines is the second part of the network whose role is to transport the energy after the elementary step consist of voltage elevation using transformer (to super then 220 KV), to minimize the losses and costs of power transmission ,either in balanced characteristics, hence the distribution sub-networks in symmetrically arrangement or unsymmetrical take the object of finest meshes in the overall network by supplying energy at small or medium size ,respecting the customers normalized alimentation between domestic and industrial[4].

The modelling ,design, planning and operation study at the 3 levels of electric energy systems structure is the necessary step that companies should do in first before performing the scientific analysis and computations to ensure the working in reliability and economy strategies .

Electrical engineers are concerned with every step in the process of generation, transmission, distribution and utilization of electrical energy in a safe, clean, and economical manner[14].

1-4. Engineering Problems And Computer:

The development of computer technology, especially in United States offer to engineers, especially electrical engineers; some important advantages for solving electric energy system problems and specially power system problems-represented in networks –like the following ones:

a) More efficient and economic means of performing routine engineering calculations required in the planning, design, and operation of power system.
b) A better utilization of engineering talent by relieving the engineer from tedious hand calculations and permitting him to spend ore time on technical work; because the difference between hand and computer calculation is incomparable and either in physical effort.
c) The ability to perform more effective engineering studies by applying calculating procedures to obtain a number of alternate solutions for a particular problem to provide a board base for engineering decisions.
d) The capability of performing studies which heretofore were not possible because the volume of calculations involved [1].

The major factors those contribute in these benefits realization are;

_ declining cost of computing equipment
_ the development of computational techniques

More of people think and imagine that computer can solve any problem that we give to solve by him, by thinking and giving some formulas of subject …

But any machine is incapable to do anything without including the desired work in form of instructions respecting the programming language …

The principal effort must by do by programmers and engineers, after the formulation of problem, developing of algorithms, organizing the input data file, writing the codes, debugging, checking, and finally interpreting …

1-5. Digital Simulation Of Power Systems:

The process of applying a computer to the solution of engineering problems involves a number of distinct steps. These steps are [1, 3];

1\ **Problem definition** and also description of the main objective to be achieved. This step is important and may be the difficult one because all the considerations, limitations and desired results that will be discussed should be given in this sequence part.

2\ **Mathematical formulation** or problem modelling; here we construct the suitable mathematical model of the network to be solved, to represent the physical system. The characteristics of individual system components as well as the relations -which govern the interconnection of the elements-is the required information to develop the equation or equations those specify the system, to design correctly the physical network.

3\ **Selection of a solution technique** (habitually numerical); after a suitable mathematical model of a given power system has been constructed; solution techniques are needed to solve these mathematical equations (nonlinear, differential, trigonometric…). In most of the cases, the mathematical model (i.e. mathematical equations) of the power system problems, are a set of linear or non linear algebraic equations and or differential equations and since the digital computer can only perform 4 operations (+ - × and ÷) numerical techniques are needed to transform these mathematical equations to set of these four basic operations. We should choose the method which is practical for machine computation and that can give desired results in minimum time.

4\ **Program design** This is the most important stage in the sequence; logical steps by which a particular problem to be solved .The aspects of computer program design are in most of cases allocation of memory, access of data, and assignment of input, output units. The preparing of program design is done in form of a diagram called *flow chart*. So the planning is necessary before any work on the problem that will be solved on the digital computer. This planning is normally aided by the flow chart. After the flow chart is made for solving the problem, it is necessary to translate instructions for solving the problem and also the data into language which can be decoded by the machine and thus the problem is solved. This is known a programming. Most of the programs are written nowadays in the high-performance language for technical computing called MATLAB (its name stands for matrix laboratory).

5\ **Program verification** there is many opportunities to introduce errors in the development of a complete computer program. therefore a systematic series of checks must be performed to ensure the correctness of;-problem formulation, method of solution, and operation of the program.

6\ **Application engineering programs** and they are classified into 2 kinds .The first consist of special purpose codes, which developed in a relatively short period for the solution of simple engineering problems. The second group is those the general purpose that are designed for the analysis of large system's computing and becomes an integral part of power system engineering(commercial or educational) such as; **PSAT,** PST, MATPOWER, and sometimes performed to an independent software such as KNITRO , POWER DESIGNER, POWER WORLD ,CYME…etc.

1-6. Power Flow Problems:

The basic function of an electric power system is to supply electrical energy as economically as possible and with acceptable degree of reliability and quality.

Power flow study is the basic requirement in power system planning, operation, economic scheduling and exchange of power between utilities, so it is very important for planning the future expansion of the power system as well as determining its best operating conditions.

In the planning of power systems, care is taken to predict in advance the system voltage levels , and the loading of lines and equipment .There fore ,such information is necessary for all points in the system both for normal operations as where as various open -line conditions (emergency) .Longhand calculations would most be difficult as this involves a complex network of many generators ,lines, transformers, or loads.

The information usually obtained from the load flow studies are the magnitude and phase angle of voltages at each bus and active and reactive power flow in each line i.e. in each element of the power system networks.

As what is mentioned in § 1-1 until 1956 just 50 network's analyzer where installed at manufactures, but after this year, since the computer was included in scientific problems, it has attracted the industry rapidly because of the description of the first successful computer program for solving power flow problems by Ward and Hale, using Gauss Seidel algorithm for solution of the implemented network equations. 4 years after, the interconnection networks have been increased and come greater and greater in solving, which appeared the instability of the method ; so another algorithm replace the old those called Newton-Raphson in 1961.

1-7. Economic Dispatch:

The prime financial objective planning a power system is to maximize profit.

In the P.F. it will be implicit dealt with one aspect of this problem, that of minimizing capital investment. The many expansion plans that are formulated must be tested by a multiplicity of load flow and short-circuit studies to determine which can provide satisfactory service with minimum investment. A partial list of the considerations that must be addressed in selecting an expansion plan is as follows;

1. A time must be selected for the initiation of a higher-voltage transmission in the expansion program.
2. A site must be selected for the installation of new generating equipment. A mine-mouth machine remote from the load center will require more transmission investment then a station near the load center at a considerable in fuel cost.
3. The selection of the fuel (nuclear or fossil) is extremely difficult. The decision is based largely on management's dedication or aversion, to accepting nuclear generation.

The day of dispatching load by the "seat of the pants" is rapidly coming to a close for the larger power utilities. Too much saving is to be gained in *minimizing* costs through lower line losses, start -up and shunt-down costs, fuel costs, and maintenance costs. This cost reduction is best realized through the determination of three basic factors.

1. A reasonable *short-term* or load prediction. This prediction must consider weather effects such as temperature, humidity, light, wind, and velocity. Some knowledge of industrial and residential lad demand is also essential. A brief coverage of the subject of the forecasting is included in chapter 13 sufficient to indicate the importance of forecasting to the total problem of economics.

2. Economic scheduling of generators (*unit commitment*). The object of this phase of the problem is to guarantee at all times the optimum combination of generators on the line to provide hourly load demand plus system reserve. “Spinning reserve” requirement must be maintained to account for forecast errors and possible forced outages. Some attention must be given to the operating constraints of generators, lines, and transformers with respect to loading capability and system stability. Careful geographic scheduling of reserve is necessary in case of partial isolation of the system during a critical line outage. To commit units economically involves the minimizing of costs which include the effect of start-up and shutdown costs, fuel costs, line losses, and maintenance costs. Obviously, it is essential to a meaningful scheduling program that a good short-term forecast program is also available.

3. *Economic dispatch*. This refers to the most economic loading of the generators, once they are committed or running on the line. In the past this third factor has received more attention than has the commitment problem. Economic dispatch accomplishes the minimizing of generator fuel costs and system line losses. As anew load increment is added to the system, the online computer is able to determine which generator can most economically take on the added load.

1-8. Objective Of Project ((Abstract))

The introduction to any study is very important, that we have done in the first chapter called ***general background***; to the power system, system's simulation, computer programming, power flow and optimal power flow.

In any network the subject of power flow or load flow is to satisfy the loads and obtain the 4 variables of each bus (node) and so the transit powers and losses in each line (branch); starting from knowing 2 variables at every node and with the resolution of the main power flow formula, by one of iterative methods for nonlinear systems of equations; we can obtain the two remain variables. The methods of Gauss Seidel and Newton Raphson are the most chosen ones in problem solution. After finding the generated powers at the swing and control buses, the fuel analysis give us some coefficients to calculate the cost of absorbed power in static aspect. This function point is not optimum; with term of a minimum cost, therefore another study should be done to determine the values of generated powers those assure a total cost respecting the limits in min and max of the generators . The methods used to solve this problem are Lagrange multipliers and Gradient method of optimization.

The power flow problem will be discussed in the Chapter 2, some of titles are indispensables before the treatment such as; the definition end formulation of P.F. called with each method GSLF , NRLF and FDLF of course after the classification of buses in the 3 major types and sometimes more of three.

Chapter 3 is concerned by the optimization of the power flow solving, taking in sequence the methods of optimization ,like the Lagrange's ,Lambda and of Interior Point Method; before these the economic dispatch need the definition of costs in term of polynomial form.

The application of PF and OPF, and the SONELGAZ Algerian network description is the object of the fourth chapter; validation of the comparison of the results obtained by the programs and software. And finally a conclusion in interpretation form is included on the last project work.

1-9. SONELGAZ Network:

Sonelgaz is the historic operator in the domain of electric energy supply of and gas in Algeria. Its main missions are the production, the transmission and the distribution of electricity as well as the transportation and the distribution of gas by pipelines. Today, it is erected in industry group composed of 29 subsidiaries. But it becomes, from EGA (Electricity and Gas of Algeria) since 1969, and called the national society of electricity and gas, the acronym utilized is in French (***SO***CIETE ***N***ATIONALE DE L'***EL***ECTRICITE ET DU ***GAZ***).

The Company, Sonelgaz Production Electricity (***SPE***) has for mission the production of electricity with a capacity that totals a power installed of 6740MW.

The society, Administrator of the Network of Electricity Transportation (***GRTE***), is society for mission the exploitation, the maintenance and the development of the network of energy transmission in the best conditions of service quality and to the least cost.

The Company, Electric System Operator (***OS***) has for mission of the management and the coordination of the system of production and transmission of electricity in order to assure the permanent balance between the production and the consumption of electricity.

The system operator has a National Center of Management of the interconnected network (National Dispatch) for the management, the safety and the coordination of the system of production and transmission of electricity at the national level.

The society, Sonelgaz Distribution Center (***SDC***) has for mission:

*the exploitation and the maintenance of the distribution network of electricity and gas,

*the development of networks electricity and gas permitting the adjusting of the new customers,

*the merchandising of electricity and gas,

The SDC has for extension the two societies,

(SDE) Sonelgaz Distribution EST.
(SDO) Sonelgaz Distribution OUEST.

1-10. Nomenclature:

S: complex bus power
SD: complex power demand
SG: complex power generation
P: real bus power
PD: real power demand, MW
PG: real power generation
Q: reactive bus power
QD: reactive power demand in MVAR
QG: reactive power generation
V: complex voltage
$|V|$: Bus voltage magnitude
δ : Bus voltage angle
R: series resistance
X: series reactance
B: shunt susceptance
Zse: series impedance
Yse: series admittance
Ysh: shunt admittance
*Y*bus: bus admittance matrix

List of Terms; Acronyms:

CPF: Continuation Power Flow

DISCO: Distribution Company

ELD: Economic Load Dispatch

ESCO: Energy Services Company

FACTS: Flexible AC Transmission Systems

GENCO: Generation Company

IEEE: Institute of Electrical and Electronics Engineers

IPM: Interior Point Method

OPF: Optimal Power Flow

TRANSCO: Transmission Company

TWO \ POWER FLOW STUDIES

2-1.Introduction:

The network in electrical engineering analysis contains nodes and branches with impedances specified in per unit, per phase on a common MVA base.

The system is assumed to be operating under balanced conditions and is represented by a single-phase network. Then one develop form the fundamental electric formula the relations between all network components.

Network equations can be formulated systematically in a variety of forms. However, the most commonly used method is the node-voltage method, which is the most suitable form for many power system analyses. The formulation of the network equations in the nodal *admittance* form results in complex linear simultaneous algebraic equations in terms of node currents. When node currents are specified, the set of linear equations can be solved for the node voltages. However, in a power system, powers are known rather than currents. Thus, the resulting equations in terms of power, known as the *power flow equation*, become nonlinear and must be solved by *iterative techniques*. Power flow studies, commonly referred to as load flow, are the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. In addition, power flow analysis is required for many other analyses such as transient stability and contingency studies.

2-2. Definition And Formulation Of Load Flow Problems:

Load flow problem solution is essential for designing a new power system as well as for planning an extension or operation of the existing one for varying demand.

Load flow or power flow is a steady state or static solution of a power system given the set of conditions. This study gives us the sinusoidal state of the entire system - voltages, real and reactive power generated and absorbed and line losses. Since the load is a static quantity and it is the power that flows through transmission lines, the purists prefer to call this **Power Flow studies** rather than load flow studies.

The load flow solution of the power system mainly requires the following calculations/steps:

1. Formulation of equations for the given network
2. Suitable mathematical technique for the solution of the equations

In the first major step we will construct the power-flow equations in a structured manner using the admittance matrix Y_{bus} representation of the transmission network. The admittance matrix Y_{bus} is assumed to be known for the system under consideration.

The data of system is very required within ending this step; the variables those are given can be classified in three kinds: uncontrollable which are the demand powers symbolized by the vector ***p***, state defined as voltage angle and magnitude, their vector is represented by ***x***, and control variables constituted by generator's output designed by ***u*** in a special vector of course.

The choice of the model that we will take as writing form, is the next step and here many algorithms can be used .The procedure technique in solving is very important to ensure that it is the rapid and efficient method of solution founding.

At the mathematical language and in term of nominal variables $\boldsymbol{x^0}$, $\boldsymbol{u^0}$ and $\boldsymbol{p^0}$ the load flow study is defined by the following expression:

"Assume a certain nominal bus load configuration $\boldsymbol{p}^0$ *.Specify then exactly 2n components of the two vectors* $\boldsymbol{x}^0$ *and* $\boldsymbol{u}^0$ *.Solve the remaining 2n unspecified components by using the 2n SLFE .Finally with all bus voltage known, compute all line flows"*

That means solve the nonlinear set of equations;

$$f\ (x,\ u,\ p) = 0$$

Where **f** is an *n*-dimensional function. [14]

To summarize each node of electric energy networks have 4 variables -at initial state in static case -we known just two, then we shall solve a specified equations those describe the relations between the components, to obtain the remained variables and deduce transit powers and line losses respecting the rules of power engineering analysis, and we call all this work the power flow study. And since that the computer is now an indispensable tool in power system operation and planning, we insist that 'power flow is a computer algorithm that displays the MW and MVAR loading of transmission lines and transformers after an iterative process of solving for node voltages'.

2-3. Types Of Buses:

Preliminaries "STATIC LOAD FLOW EQUATIONS "SLFE:

In an electric network system the analysis of component comportments give us the equations those relate voltages and currents ,these equations can be written on an other method that's relate powers and voltages ,and because of complex power form it comes nonlinear ,briefly the algebraic equations of an *static* model state that the sum of the real/reactive generation power equals the sum of the real/reactive demand power plus the real /reactive losses . These equations are called in electrical engineering analysis the static load flow equations. [4]

Demonstration example "CASE OF TWO BUSES":

The discussion of the following two-bus system introduce to the classification of system variables cited early:

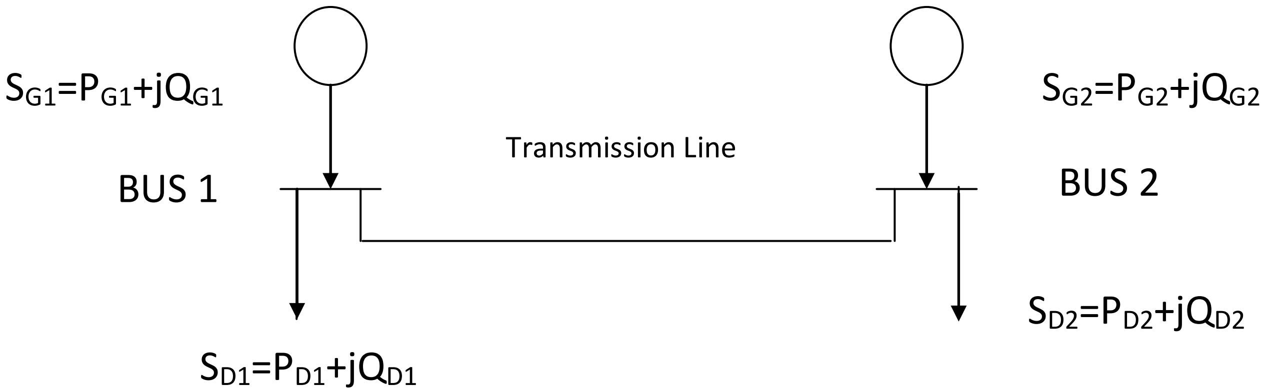


Fig 1 demonstration example 2 buses scheme

Since the transmission line may be represented by series impedance Z_{se} and two half shunt admittances Y_{sh} in ∏ equivalent model;

However;

$Z_{se} = R + jX_L$ and $Y_{sh} = \frac{j}{X_C}$

With $\alpha \triangleq \frac{R}{X_L}$; so we can consider that $\alpha \ll 1 \therefore Z_{se} \approx X_L . e^{j(\pi/2 - \alpha)}$

Then, rapidly we obtain ***four*** equations whose describe the study state operating system for the given example;

$$P_{G1} - P_{D1} - \frac{|V1|^2}{X_L} \sin\alpha + \frac{|V1||V2|}{X_L} \sin[\alpha - (\delta 1 - \delta 2)] = 0$$
$$P_{G2} - P_{D2} - \frac{|V2|^2}{X_L} \sin\alpha + \frac{|V1||V2|}{X_L} \sin[\alpha + (\delta 1 - \delta 2)] = 0$$
$$Q_{G1} - Q_{D1} + \frac{|V1|^2}{X_C} - \frac{|V1|^2}{X_L} \cos\alpha + \frac{|V1||V2|}{X_L} \cos[\alpha - (\delta 1 - \delta 2)] = 0$$
$$Q_{G2} - Q_{D2} + \frac{|V2|^2}{X_C} - \frac{|V2|^2}{X_L} \cos\alpha + \frac{|V1||V2|}{X_L} \cos[\alpha + (\delta 1 - \delta 2)] = 0$$

The state variables are in order those concerned by the voltage in polar form (magnitude, angle) and power in rectangular form (real, imaginary).[4]

The uncontrolled variables are the demands of our customers in power term which are the active and reactive ones.

An detailed study has been done on this system and concluded that one have just 2 methods to solve the 4 equations (SLFE) since we have 12 variables 4 are uncontrolled (P_{D1},Q_{D1},P_{D2}, Q_{D2})arranged into the vector ((***p***)),called disturbance variables, and 8 remains are (|V1|,|V2|, δ1, δ2,P_{G1}, P_{G2}, Q_{G1}, Q_{G2}) clearly the generator outputs are our control variables called of vector ((***u***)) whenever we define as state variables or the vector ((***x***)),the voltage magnitude and angle|V1|,|V2|, δ1, δ2 ,logically we should specify 4 of the last 8 ones ;

a) Set |V1|, δ1,|V2|, and P_{G2}, at a specified values, So solve a system of nonlinear 4 equations with 4 unknowns,

b) Set |V1|, δ1, P_{G2}, and Q_{G2} at a specified values, either the problem come solvable.

The last examination is due to the choice oriented by rules such as

- We cannot priori specify all the 4 generation variables because the losses are not known.
- The SLFE can not authorize solving individual phase's δ1and δ2 but the difference, as shown in the equations in sin and cosine functions. This is evident because of ignoring the direction of flowing power and so the power that the line transit it to provide system balance.
- We cannot specify at the same time Q_G and |V|, or P_G and δ in the same bus it all depends the basic's of control theory.

In the two previous selected cases (a) and (b) at the bus number 'one' we do not specify the generated powers to ensure the supplying of the difference between the sum of the real/reactive powers plus the losses and the demand's ones, and we says that this node is selected to provide the additional real and reactive power to be supply in transmission losses since these are unknown until final solution is defined. During the bus two has token 2 different states.

According to the previous analysis in two-bus system case -which can easily proved in the generalized n-bus case; generalization is done respecting that at each bus, 2 from the 4 variables should be specified-, we deduce that "any bus in any network can and should be one of three kinds of buses ", one like bus '1' and 2 as what the second bus has classified.

Bus number 'one' is always the reference bus, because it takes up ***<u>the slack</u>*** in losses, this rule is applied at all the power problems.

Classification Of Buses:

Based on the type of priori specification it is possible to classify the nodes in the network power flow to be solved in three major kinds [8];

I. ***SWING BUS*** : it is the reference bus, called "slack bus", for this category of buses we know |V| and δ ,usually the angle is set to zero ,the remains control variables will be render from then on solution of the load flow equation is done. This type of buses currently called of balance to indicate that it plays the role of balance as shown previous.

II. ***GENERATION BUS*** : ((control bus)) ,here P and |V| are specified ,this is why it is called voltage control node ,the voltage angle and reactive power will be calculated by solving system's equations.

III. ***LOAD BUS***: in a load point just the demands of real reactive power are specified, so the state variable values will be determined after network power flow problem is resolved. In "normal" power systems PQ-buses or load buses are the far most common, typically comprising more than 80% of all buses.

Remarks

1- If slack bus is not specified, than a generation bus usually with minimum real power is taken as slack bus .There can be more then one slack bus in a given scheme.
2- At all bus type we confirm that there were some limitations in the variable's values, such as |V| with a value between 1.1 and 0.9 p.u.
3- At the generation bus, the reactive power is limited by Q_{min} and Q_{max}, because this power is related to the |V|, whose value is imposed first.
4- Most of the searchers distinguish between the load bus with and without generation and called these new under types; PQ Load and PQ Generator. Some of them don't do any distinction between the load and control buses and treat the two kinds as one type, mostly of load.
5- Nowadays, some of searchers (MATPOWER) introduce a new type of buses called *isolated* bus.

2.4 -Solution Methods Of Non-Linear Algebraic Equations:

The numerical analysis is very essential in many engineering applications when the problem is oriented to solving system of equations under specified conditions. The electrical engineering is the domain that treats very large systems and so developing equations with many variables, these last can not be resolved with direct methods, for this purpose we shall present the interesting ones.

Consider that n linear equations in n unknowns (x_1; . . . ; x_n) are given. The" a_{ij} "and "y_i "coefficients and the "x" dependent variables are known: where $a_{ij} \neq 0$ if i=j;

$$\left.\begin{aligned} a_{11}x_n + a_{12}x_2 + \cdots + a_{1n}x_n &= y_1 = f_1(x_1, x_2, \ldots, x_n) \\ a_{21}x_n + a_{22}x_2 + \cdots + a_{2n}x_n &= y_2 = f_2(x_1, x_2, \ldots, x_n) \\ &\text{--------------------} \\ &\text{--------------------} \\ a_{n1}x_n + a_{n2}x_2 + \cdots + a_{nn}x_n &= y_n = f_n(x_1, x_2, \ldots, x_n) \end{aligned}\right\} \quad (2\text{-}1)$$

To solve this equation system and while the functions *f* is nonlinear we need an iterative technique such as Gauss, Gauss Jordan, determinant's methods…etc

The Gauss Seidel method is one of the famous iterative procedures of linear and nonlinear equations based on successive operations to the principal system:

These equations can be written as

$$\left.\begin{aligned} x_1 &= {}^1/_{a_{11}}(y_1 - a_{12}x_2 - a_{13}x_3 - \cdots - a_{1n}x_n) = g_1(x_2, x_3, .., x_n) \\ x_2 &= {}^1/_{a_{22}}(y_2 - a_{21}x_1 - a_{23}x_3 - \cdots - a_{2n}x_n) = g_2(x_1, x_3, .., x_n) \\ x_3 &= {}^1/_{a_{33}}(y_3 - a_{31}x_1 - a_{32}x_2 - \cdots - a_{3n}x_n) = g_3(x_1, x_2, .., x_n) \\ &\text{--------------------} \\ &\text{--------------------} \\ x_n &= {}^1/_{a_{nn}}(y_n - a_{n1}x_1 - a_{n2}x_2 - \cdots - a_{nn-1}x_{n-1}) = g_n(x_1, x_2, .., x_{n-1}) \end{aligned}\right\} \quad (2\text{-}2)$$

In the general form $x_p = {}^1/_{a_{pp}}(y_p - \sum_{\substack{q=1 \\ q \neq p}}^{n} a_{pq}\, x_q)$ for p=1, 2, 3… n

In the solving by Gauss- Seidel method which it is an iterative method we make successive approximations to each x of the system, beginning from initial values

$x_1^{(0)} = y_1/a_{11}, x_2^{(0)} = y_2/a_{22}, \ldots\ldots x_n^{(0)} = y_n/a_{nn}$

Based on the Gauss method, but with profit on each calculated X value on the next step, was done the Gauss- Seidel method, so the general form of any iteration can be written as; with k≥1,

$$x_1^{(k)} = {}^1/_{a_{11}}(y_1 - a_{12}x_2^{(k-1)} - a_{13}x_3^{(k-1)} - \cdots - a_{1n}x_n^{(k-1)})$$

$$x_2^{(k)} = {}^1/_{a_{22}}(y_2 - a_{21}\boldsymbol{x_1^{(k)}} - a_{23}x_3^{(k-1)} - \cdots - a_{2n}x_n^{(k-1)})$$

$$x_3^{(k)} = {}^1/_{a_{33}}(y_3 - a_{31}\boldsymbol{x_1^{(k)}} - a_{32}\boldsymbol{x_2^{(k)}} - \cdots - a_{3n}x_n^{(k-1)}) \qquad (2\text{-}3)$$

$$x_n^{(k)} = {}^1/_{a_{nn}}(y_n - a_{n1}\boldsymbol{x_1^{(k)}} - a_{n2}\boldsymbol{x_2^{(k)}} - \cdots - a_{n\,n-1}\boldsymbol{x_{n-1}^{(k)}})$$

All the values $\boldsymbol{x_i^{(k)}}$ are calculated used from the previous calculations −except $\boldsymbol{x_1^{(1)}}$ −, this is the characteristic that differentiate Gauss Seidel to Gauss, the process is continued till the convergence condition is verified which represented by; the difference between the *k*th and the (k+1) iteration is equal or less then a very small number value depends upon the accuracy desired called ε or the tolerance and the condition can be take the following mathematical form;

$$\left|x_i^{(k+1)} - x_i^{(k)}\right| \leq \varepsilon \text{ For i=1, 2, 3....n.}$$

After every step, we should do this test, and we exit the procedure when the test is verified.

We can not assure that the method will converge to the desired solution or with slowly convergence, so it appears the application of “acceleration factor” α, its role is to be multiplied by the difference between the two X founded after iteration called Δx or ‘correction vector’ and so add the result to the old iteration solution and replace the new value, as what indicate the formula;

$$\boldsymbol{x_i^{(k+1)}} = \boldsymbol{x_i^{(k)}} + \boldsymbol{\alpha} * (\boldsymbol{x_i^{(k+1)}} - \boldsymbol{x_i^{(k)}}) \qquad \text{For} \quad i=1, 2, 3\ldots n$$

If α=1 the procedure is the same preceding one; so always we take α>1such as 1.4

Another iteration method and may be by far the most sophisticated, is Newton Raphson by the equations expanding using Taylor’s theorem like following :

Recall that any function of x can be written as the summation of a power series, Taylor has developed as,

$$f(x) = f(a) + f'(a)\frac{x-a}{1!} + f''(a)\frac{(x-a)^2}{2!} + \cdots + f^n\,(x)\frac{(x-a)^n}{n!}$$

For x near a, if we replace a by x and x by (x+Δx) and assume the second and amore then derivations to zero, the series become

$$y = f(x+\Delta x) = f(x) + \Delta x\,.\,f'(x)$$

By doing iterations to the previous equation by considering that;

$x^{(1)} = x^{(0)} + \Delta x$ We find,

$$f\left(x^{(1)}\right) = f\left(x^{(0)}\right) + f'\left(x^{(0)}\right)(x^{(1)} - x^{(0)})$$

While $x^{(1)}$ is closer approximate to $x^{(0)}$ the last equation is equal to 0, then we obtain by generalizing;

$$x^{(k+1)} = x^{(k)} - \frac{f\left(x^{(k)}\right)}{f'(x^{(k)})}$$

This equation is for one unknown x

The procedure can be applied to n nonlinear equations in n unknown variables as

$$y_1 = f_1(x_1, x_2, \ldots, x_n) + \Delta x_1 \frac{\partial f_1}{\partial x_1} + \Delta x_2 \frac{\partial f_1}{\partial x_2} + \ldots + \Delta x_n \frac{\partial f_1}{\partial x_n}$$

$$y_2 = f_2(x_1, x_2, \ldots, x_n) + \Delta x_1 \frac{\partial f_2}{\partial x_1} + \Delta x_2 \frac{\partial f_2}{\partial x_2} + \ldots + \Delta x_n \frac{\partial f_2}{\partial x_n}$$

$$y_n = f_n(x_1, x_2, \ldots, x_n) + \Delta x_1 \frac{\partial f_n}{\partial x_1} + \Delta x_2 \frac{\partial f_n}{\partial x_2} + \ldots + \Delta x_n \frac{\partial f_n}{\partial x_n}$$

Now it is clearly that the first approximations give us the values of

$f_i^{(0)}(x_1, x_2, \ldots, x_n)$ and i=1, 2, 3…., n

The values of y are known either the functions coefficients, the partial can be calculated as numerical quantities and the unknowns are the $\Delta x^{(0)}$, so we should rewrite the last equations on the form

$$y_1 - f_1^{(0)} = \Delta x_1^{(0)} \left(\frac{\partial f_1}{\partial x_1}\right)^{(0)} + \Delta x_2^{(0)} \left(\frac{\partial f_1}{\partial x_2}\right)^{(0)} + \ldots\ldots + \Delta x_n^{(0)} \left(\frac{\partial f_1}{\partial x_n}\right)^{(0)}$$

$$y_2 - f_2^{(0)} = \Delta x_1^{(0)} \left(\frac{\partial f_2}{\partial x_1}\right)^{(0)} + \Delta x_2^{(0)} \left(\frac{\partial f_2}{\partial x_2}\right)^{(0)} + \ldots\ldots + \Delta x_n^{(0)} \left(\frac{\partial f_2}{\partial x_n}\right)^{(0)}$$

$$y_n - f_n^{(0)} = \Delta x_1^{(0)} \left(\frac{\partial f_n}{\partial x_1}\right)^{(0)} + \Delta x_2^{(0)} \left(\frac{\partial f_n}{\partial x_2}\right)^{(0)} + \ldots\ldots + \Delta x_n^{(0)} \left(\frac{\partial f_n}{\partial x_n}\right)^{(0)}$$

$f_n^{(0)}$: designed $f_n\left(x_1^{(0)}, x_2^{(0)}, \ldots, x_n^{(0)}\right)$

So the original nonlinear equations have reduced to linear equations which constitute the trick of the method.

Habitually the use of matrix form clarify more the written expressions as well as;

$$\begin{bmatrix} y_1 - f_1^{(0)} \\ y_2 - f_2^{(0)} \\ \cdot \\ \cdot \\ \cdot \\ y_n - f_n^{(0)} \end{bmatrix} = \begin{bmatrix} \left(\frac{\partial f_1}{\partial x_1}\right)^{(0)} & \left(\frac{\partial f_1}{\partial x_2}\right)^{(0)} & \cdot & \cdot & \cdot & \left(\frac{\partial f_1}{\partial x_n}\right)^{(0)} \\ \left(\frac{\partial f_2}{\partial x_1}\right)^{(0)} & \left(\frac{\partial f_2}{\partial x_2}\right)^{(0)} & \cdot & \cdot & \cdot & \left(\frac{\partial f_2}{\partial x_n}\right)^{(0)} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \left(\frac{\partial f_n}{\partial x_1}\right)^{(0)} & \left(\frac{\partial f_n}{\partial x_2}\right)^{(0)} & \cdot & \cdot & \cdot & \left(\frac{\partial f_n}{\partial x_n}\right)^{(0)} \end{bmatrix} * \begin{bmatrix} \Delta x_1^{(0)} \\ \Delta x_2^{(0)} \\ \cdot \\ \cdot \\ \cdot \\ \Delta x_n^{(0)} \end{bmatrix}$$

And finally the extract of the x values is by adding the old to the Δx then we get

$x_i^{(1)} = x_i^{(0)} + \Delta x_i^{(0)}$ For i=1, 2, 3…., n

Comparing the $\Delta x_i^{(0)}$ by ε and decide if the solutions are commode or we need to repeat the step for the next iteration.

The matrix of partial derivative is sometimes referred as the Jacobian matrix or D=JC.

The process starts by assuming initial estimate for the elements of vector D, then calculate the Jacobian elements J(i,j), using one of iterative methods to solve the system like determinant's method to obtain the correction vector C .The values of $x_i^{(1)}$ are again used to compute the D and J elements, this last one is built with the latest values of unknowns.

2.5- Solution Techniques:

Power system equations

The equation describing the performance of network of a power system using the bus frame of reference in impedance form is

$$E_{bus} = Z_{bus}\, I_{bus} \quad \text{Eq.1}$$

or in admittance form

$$I_{bus} = Y_{bus}\, E_{bus} \quad \text{where}$$

Z_{bus} , Y_{bus} are successively the impedance and admittance matrixes

E_{bus} , I_{bus} are the voltage at the nodes and currents of branches on the network.

If power at any bus k is known, then it can be expressed by the following basic equations via:

$$P_p - jQ_p = E_p^*\, I_p \quad \text{Eq.2}$$

Where P_p , Q_p are real and reactive power at the k bus , we deduce that

$$I_p = \frac{P_p - jQ_p}{E_p^*} \qquad \text{Eq. 3}$$

These equations are the projection of Kirchhoff and Ohm laws from the classic system's analysis, and until this change they will be the basic and fundamentals formulas of network's problem and what we concern here the load or power flow problem.

The formation of the matrix admittance Y is similarly to the ordinary one in direct methods of circuit analysis.

The constructing of admittance matrix Ybus respect the steps;

Y_{bus} is symmetric unless the circuit has phase shifters or active devices;

Since the nodal solution is based upon Kirchhoff's current law, impedances are converted to admittance, i.e.

$$y_{ij} = \frac{1}{z_{ij}} = \frac{1}{r_{ij} + jx_{ij}}$$

Diagonal term Y_{ii} is the sum of all admittances connected to bus I, obtained by the inversing of impedances at each line so all impedances are converted to admittances, i.e.

So, $Y_{ii} = \sum_{j=1}^{n} y_{ij}$ and i=1,2,3,…,n

Off-diagonal term Y_{ij} is the negative of the sum of all admittances directly connecting bus i to bus j

$Y_{ij} = Y_{ji} = -y_{ij} \quad \forall\, i \neq j$ and I, j=1,2,3,…,n

In setting up the load-flow problem, the system equations will be linear or non linear, depending upon our choice of methods. Three possibilities are suggested here.

1-*Current equations* can be written at the *p*th node in terms of the unknown voltages. These equations are of the form

$$I_p = Y_{p1}V_1 + Y_{p2}V_2 + \dots\dots + Y_{pn}V_n \qquad \text{Eq. (4)}$$

This is a very popular approach, yielding a set of linear equations. The known current source I_p can be written in terms of P_p, Q_p and Vp if necessary. The linear equations may be written in matrix form utilizing the bus admittance matrix. Furthermore the set of equations are often solved by an iterative process in preference to a direct approach (method).

2-*Voltage equations* can be written for the *k*th loop in terms of unknown currents and of the general form

$$V_p = Z_{p1} I_1 + Z_{p2} I_2 + \dots\dots\dots + Z_{pn} I_n \qquad \text{Eq. (5)}$$

Again this yields a set of linear algebraic equations. The *p*th loop can be identified with the *p*th bus if the loop current I_p is also the actual current flowing into (or from) bus *p* from (or into) the load or generator branch In question.

However it does not yield as radical a simplification to the load-flow problem as was achieved for short-circuit applications.

3-one might also choose to write the node equations in terms of *real and reactive power*-moving into or out of the individual nodes. In this case, the equation for power flowing to or from bus p takes the general nonlinear form of

$$P_p + jQ_p = |Y_{p1}|\ |V_1|\ |V_p| \angle(\delta_p - \delta_1 - \theta_{p1})$$

$$+ |Y_{p2}|\ |V_2|\ |V_p| \angle(\delta_p - \delta_2 - \theta_{p2}) + \dots\dots\dots$$

$$+ |Y_{pn}|\ |V_n|\ |V_p| \angle(\delta_p - \delta_n - \theta_{pn}) \qquad \text{Eq. (6)}$$

Equation (6) is easily derived by a substitution of Eq. (4) into a general form of equation (((($P + jQ = VI^*$)))). Of the four 4 variables at the kth node (P_p, Q_p, $|V_p|$, and δ_p) two of the variables are known and two unknown. The Newton Raphson method has been proven to be an effective method for solving the setoff equations represented by Eq. (6)

After giving the three forms that power system can be take, we give free to choose any suggestion under condition of technique availability and procedure convergence.

2.5-1 GAUSS SEIDEL Method:

The gauss seidel method of solution developed rapidly of the ease of writing a program to implement the algorithm. Furthermore, the computer memory requirement of the method is minimal. This factor was an important consideration when power flow programs were being written for systems of just 99 buses using computers with 2000 words of memory –nowadays the computation are with lines and pages!

As what shown early ,each node of a network has 4 variable quantities ;2 known(specified) and 2 to calculate ,begin from the Slack bus symbolized by “S” where both |V |and δ are specified so we let its equation until the final solution is found and replace by the calculated variables value’s to obtain the real and the reactive powers.

Since P and Q are given for all the buses _accept temporally this information, later it shall be reformed_, the equation 5 is written for any bus

$I_p = \frac{P_p - jQ_p}{V_p^*}$ For p=2,3,4,….,n taking the consideration that the swing bus is the reference so it takes the number one “1” ;you can take it another ,but it may be the good assumption.

The performance equation in the bus frame of reference using $\boldsymbol{Y_{bus}}$ by selecting the reference node as ground will be obtained from the equation 4 as follows;

$I_{bus} = Y_{bus} E_{bus}$

The expanding of the last formula will be done in n-1 independent equations, and then we get: the equation (4)

$I_p = Y_{p1}V_1 + Y_{p2}V_2 + ... + Y_{pn}V_n$,p=1,2,3,…..,n ;p $\neq s$ since ’ s ‘ is the symbol of the slack bus,

The separation of terms in the sum gives the expression

$$\mathrm{I_p} = \mathrm{Y_{pp}V_p} + \sum_{\substack{q=1 \\ q\neq p}}^{n} \mathrm{Y_{pq}}\,\mathrm{V_q} \quad \text{so} \quad V_p = \frac{1}{Y_{pp}}\left(\mathrm{I_p} - \sum_{\substack{q=1 \\ q\neq p}}^{n} \mathrm{Y_{pq}}\,\mathrm{V_q}\right)$$

Thus $V_p = \frac{1}{Y_{pp}}\left(\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1 \\ q\neq p}}^{n} \mathrm{Y_{pq}}\,\mathrm{V_q}\right)$ for p=1, 2, 3… n; p $\neq s$

In this equation only bus voltages are involved as variables, the detailed equations from this equation give us the set of nonlinear equations to be solved by the iterative techniques $V_p^{(0)}$

Interpretation:

Doing a small comparison of the last general set of voltage equation and the general system of Gauss Seidel we mark that the form of

$x_p = {}^{1}/_{a_{pp}}(y_p - \sum_{\substack{q=1 \\ q\neq p}}^{n} a_{pq}\, x_q)$ is similar to the voltage form.

By similarity ,in the method of Gauss Seidel the value of bus voltages calculated for any bus immediately replace the previous values in the next step while in the case of Gauss as stated earlier ,the calculated bus voltages replace the earlier value at the end of iteration. Due to this Gauss Seidel method converges much faster and very popular than that of Gauss, in term of iteration number. The process is continued till the difference between

$\left|V_i^{(k+1)} - V_i^{(k)}\right| \leq \varepsilon$; ε is very small and depends upon the system accuracy, normally equal to 0.0001 etc and k is iteration number

$$\Delta V_p^{(k)} = V_p^{(k+1)} - V_p^{(k)}$$

Generation Bus

A modification of, or derivation from the normal computational procedures for the solution of the power flow problem is required to take into account voltage controlled buses .Here P is specified ,because it is a voltage controlled bus. However, usually limit of reactive power i.e. Qmin and Qmax to hold the generation voltage within limits are also given. Then the reactive power at the generation bus must be calculated before proceeding with the calculation of voltage at that bus.

Eq. (3) can be written in the form

$$\mathrm{P_p} - \mathrm{jQ_p} = V_p^* \sum_{q=1}^{n} \mathrm{Y_{pq}} \mathrm{V_q}$$

Thus $\mathrm{Q_p}$ = - imaginary $(V_p^* \sum_{q=1}^{n} \mathrm{Y_{pq}} \mathrm{V_q})$

As the exact expression

$$Q_p^{(k)} = -IM\left[\left\{V_p^{(k)}(new)\right\}^* \left\{Y_{pp} V_p^{(k)}(new) + \sum_{\substack{q=1 \\ q\neq p}}^{n} \mathrm{Y_{pq}} \mathrm{V_q^{(k)}}\right\}\right]$$

Selecting the algebraic form of voltages, real and imaginary parts we have

$$e_p = |\mathrm{V_p}| \cos \delta_\mathrm{p}$$

$$f_p = |\mathrm{V_p}| \sin \delta_\mathrm{p}$$

Since the voltage magnitude of controlled bus is specified, therefore the values of e and f must satisfy the relation

$$e_p^2 + f_p^2 = \{|\mathrm{V_p}|\}\mathrm{scheduled}^2$$

Then substituting these assumed values in the formula of reactive power. In actual practice the limits of Q must be taken in account before continuing to the next step;

If the calculated Q exceeds the Qmin or Qmax, then we do the following

If $Q \geq$ Qmax

Put $Q =$ Qmax

If $Q \leq$ Qmin

Put $Q =$ Qmin

And treat this bus as a load bus to find the voltage solution.

If the last rules are not true use the phase angle of the assumed bus voltages to recalculate the real and imaginary parts of voltages;

We know that the phase angle of estimated bus voltage is

$\delta_p^k = \tan^{-1}(f_p^k / e_p^k)$ Assuming this phase angle also to be that of the scheduled bus voltage, then adjusted estimates for e and f are

$e_p^k(new) = |\mathrm{V_p}|\mathrm{scheduled}\ \cos\delta_\mathrm{p}^\mathrm{k}$

$f_p^k(new) = |\mathrm{V_p}|\mathrm{scheduled}\ \sin\delta_\mathrm{p}^\mathrm{k}$

To obtain Q just substitute in its expression and the new e and f are to be used $\mathrm{V_p}$(new) to calculate that one of next iteration, continue the process until convergence is ensured.

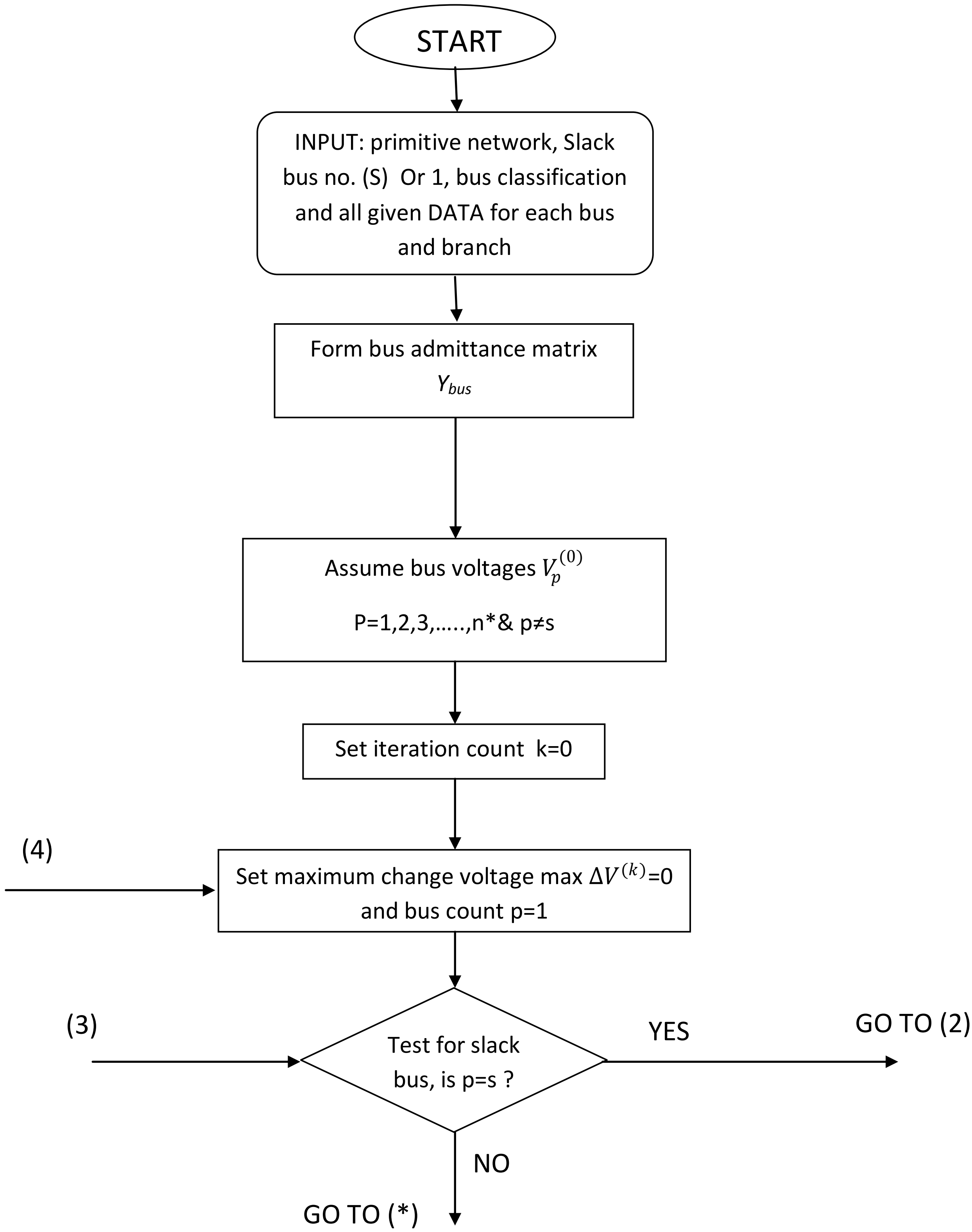
Nota the acceleration factor cited early with a values between 1.4and 1.6 may be used to increase the rate of convergence and possible with different values to each voltage part.

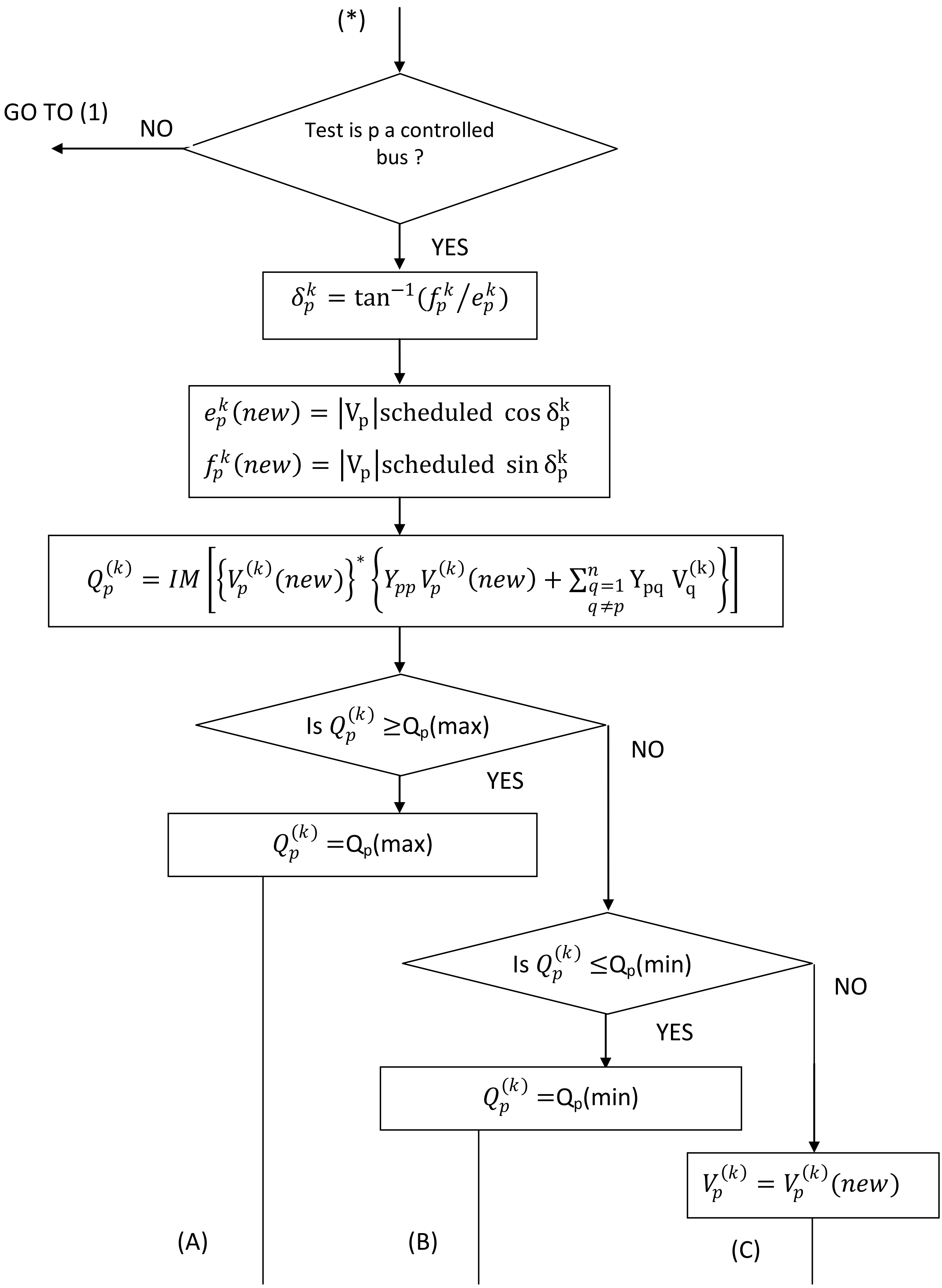
Finally to be sure of the general formula in GS method, and by separating or expanding the immediately used variables the developed formula of voltage is

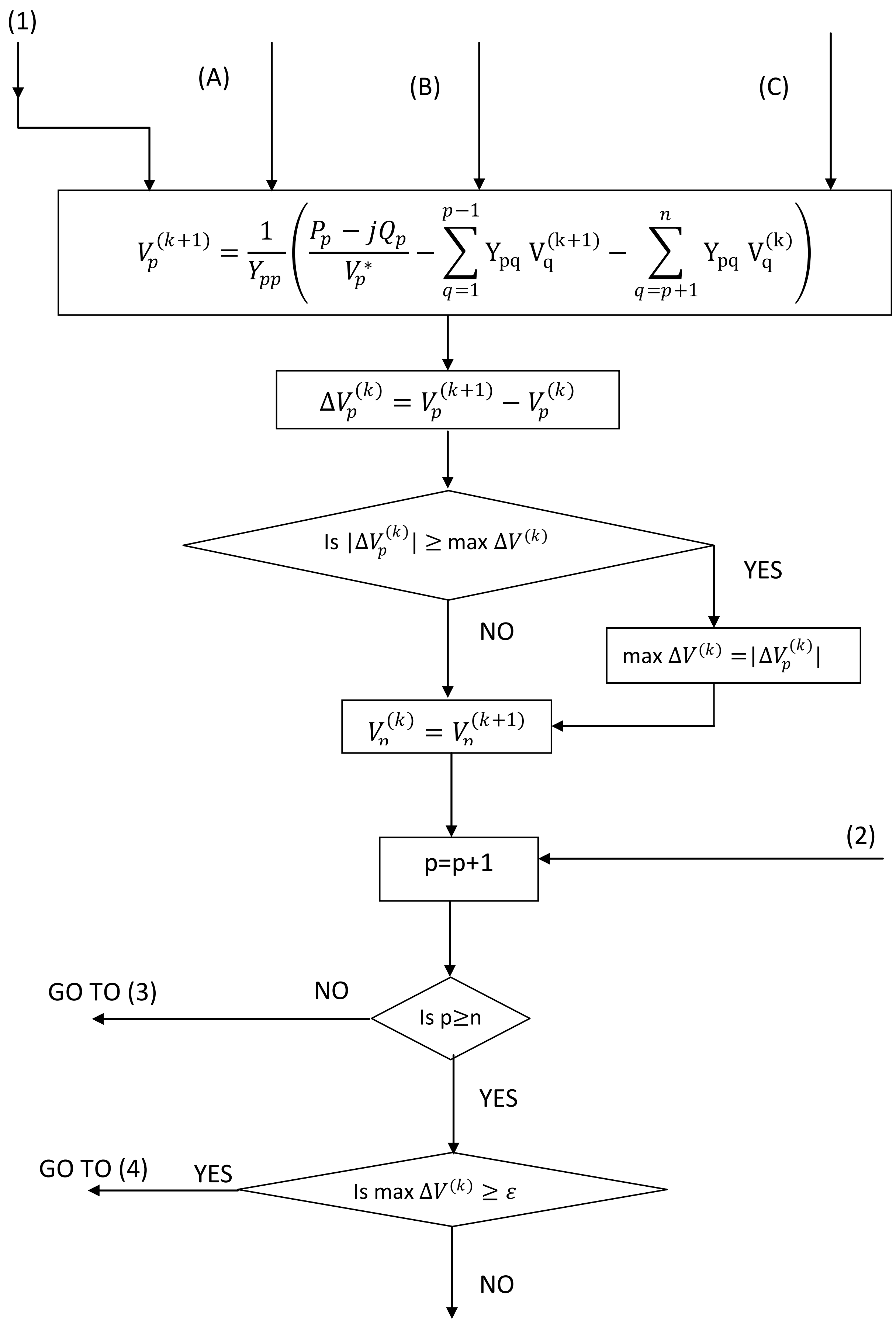
$$V_p^{(k+1)} = \frac{1}{Y_{pp}}\left(\frac{P_p^{(k)} - j\,Q_p^{(k)}}{\left(V_p^{(k)}\right)^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} \mathrm{Y_{pq}}\ \mathrm{V_p^{(k)}}\right) \quad \text{In Gauss method}$$

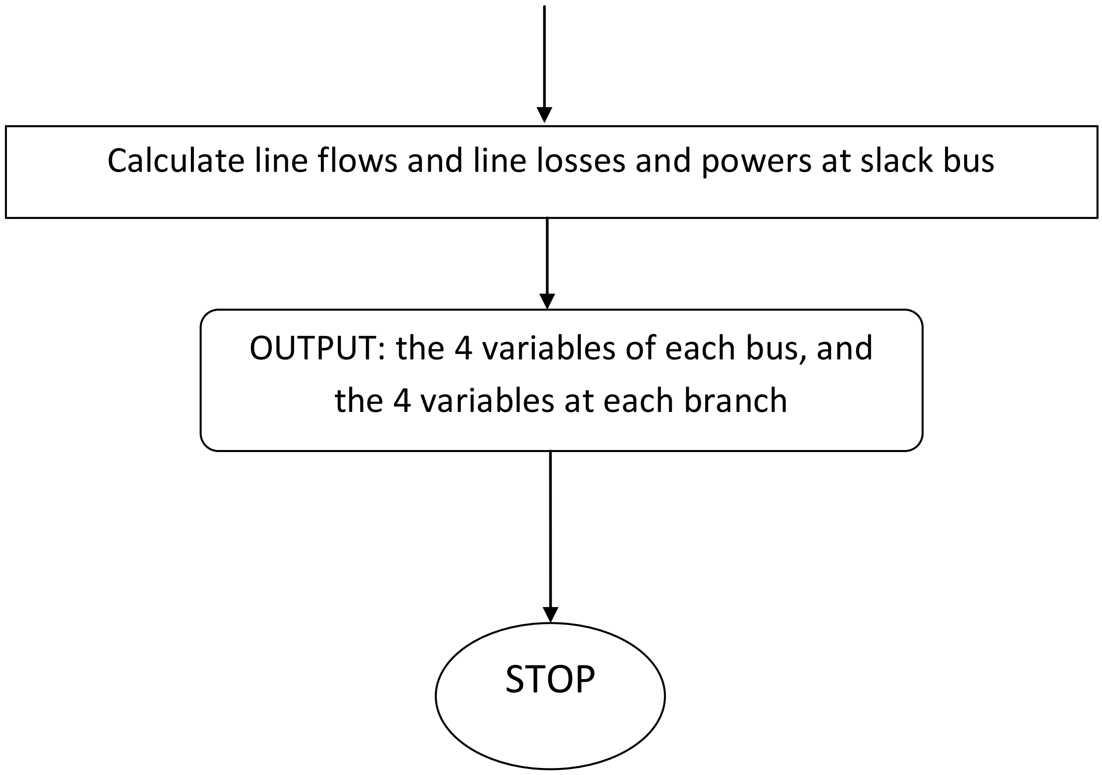
$$V_p^{(k+1)} = \frac{1}{Y_{pp}}\left(\frac{P_p^{(k)} - j\,Q_p^{(k)}}{\left(V_p^{(k)}\right)^*} - \sum_{q=1}^{p-1} \mathrm{Y_{pq}}\ \mathrm{V_q^{(k+1)}} - \sum_{q=p+1}^{n} \mathrm{Y_{pq}}\ \mathrm{V_q^{(k)}}\right)$$

Gauss Seidel Flow Chart




(*)
Test is p a controlled bus ?
NO
GO TO (1)
YES
$\delta_p^k = \tan^{-1}(f_p^k / e_p^k)$
$e_p^k(new) = |V_p|$scheduled $\cos\delta_p^k$
$f_p^k(new) = |V_p|$scheduled $\sin\delta_p^k$
$Q_p^{(k)} = IM\left[\left\{V_p^{(k)}(new)\right\}^* \left\{Y_{pp} V_p^{(k)}(new) + \sum_{\substack{q=1 \\ q\neq p}}^{n} Y_{pq} V_q^{(k)}\right\}\right]$
Is $Q_p^{(k)} \geq Q_p(max)$
YES
NO
$Q_p^{(k)} = Q_p(max)$
Is $Q_p^{(k)} \leq Q_p(min)$
YES
NO
$Q_p^{(k)} = Q_p(min)$
$V_p^{(k)} = V_p^{(k)}(new)$
(A)
(B)
(C)


(1)
(A)
(B)
(C)
$V_p^{(k+1)} = \frac{1}{Y_{pp}}\left(\frac{P_p - jQ_p}{V_p^*} - \sum_{q=1}^{p-1} Y_{pq} V_q^{(k+1)} - \sum_{q=p+1}^{n} Y_{pq} V_q^{(k)}\right)$
$\Delta V_p^{(k)} = V_p^{(k+1)} - V_p^{(k)}$
Is $|\Delta V_p^{(k)}| \geq$ max $\Delta V^{(k)}$
YES
max $\Delta V^{(k)} = |\Delta V_p^{(k)}|$
NO
$V_n^{(k)} = V_n^{(k+1)}$
p=p+1
(2)
GO TO (3)
NO
Is p≥n
YES
GO TO (4)
YES
Is max $\Delta V^{(k)} \geq \varepsilon$
NO



This is the universal Gauss Seidel flow chart that takes the most consideration in account, it may remain that the limits of voltage currently between 0.9 and 1.1 p.u. to enter in consideration.

We design by the 4 variables at each branch the 2 transit power and the 2 losses powers (real and reactive)

Line Flow And Losses;

After the sufficient solution of voltages are obtained at the end of process, the accomplishment of procedure should be done by calculation of control variable's values which are the real and reactive powers transmitted and dissipated.

The line flows between any buses p and q, taking the ∏ line representation can be calculated by;

Since $i_{pq} = [V_p - V_q]y_{pq} + V_p \left({y'_{pq}}/{2} \right)$ when y'_{pq} represent the line charging

The power flow in the line (p---q) is gotten by

$$P_{pq} - Q_{pq} = V_p^* \; i_{pq}$$

Substitute i_{pq} by the last expression,

$$P_{pq} - Q_{pq} = V_p^* \{[V_p - V_q]y_{pq} + V_p \left({y'_{pq}}/{2}\right)\}$$ This is the PF at the bus p

More ever the line flow in the line (p---q) at the bus q will,

$$P_{pq} - Q_{pq} = V_q^* \{[V_q - V_p]y_{pq} + V_q \left({y'_{pq}}/{2}\right)\}$$

Easily, by the algebraic sum of the two powers we can got the (p---q) line losses.

2.5-2 NEWTON RAPHSON Method:

In 1961 Van Ness and Griffin have used Newton Raphson method by the exploitation of the formula that relates real /reactive power to bus voltages (2) which expression is;

$P_p - jQ_p = V_p^* I_p$

But $I_{bus} = Y_{bus} E_{bus}$ that can be written in the large structure

$I_p = Y_{p1}V_1 + Y_{p2}V_2 + \dots\dots\dots + Y_{pn}V_n$ or $I_p = \sum_{q=1}^{n} Y_{pq} V_q$

Then $P_p - jQ_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q$

Since

$V_p = e_p + jf_p$ and $Y_{pq} = G_{pq} - jB_{pq}$ the last equation becomes ,after real _imaginary part's separation ;

$$P_p = \sum_{q=1}^{n} [e_p\{e_q G_{pq} + f_q B_{pq}\} + f_p\{f_q G_{pq} - e_q B_{pq}\}]$$

$$Q_p = \sum_{q=1}^{n} [f_p\{e_q G_{pq} + f_q B_{pq}\} - e_p\{f_q G_{pq} - e_q B_{pq}\}]$$

Now let distribute the sum in heading for determining he derivates of this nonlinear set of (2n-2) equations –except the slack -,we found (distinction of the case where p=q)

$$P_p = [e_p\{e_p G_{pp} + f_p B_{pp}\} + f_p\{f_p G_{pp} - e_p B_{pp}\}] + \sum_{\substack{q=1 \\ q\neq p}}^{n} [e_p\{e_q G_{pq} + f_q B_{pq}\} + f_p\{f_q G_{pq} - e_q B_{pq}\}]$$

$$Q_p = [f_p\{e_p G_{pp} + f_p B_{pp}\} - e_p\{f_p G_{pp} - e_p B_{pp}\}] + \sum_{\substack{q=1 \\ q\neq p}}^{n} [f_p\{e_q G_{pq} + f_q B_{pq}\} - e_p\{f_q G_{pq} - e_q B_{pq}\}]$$

These complicated equations are similar to the functions f in the set of equations treated early by Newton Raphson since P and Q are known for all the buses except the slack ? the reactive power at generation is unknown and limited! so we should treat it in a different manner ,will be discussed further .the use of rectangular form or polar is due to methodology considerations in the approximations those give the searchers to this projection yields the unknown vector of voltage must be consider in polar or algebraic form ?!!

The first analysis has done an analogy in the form to the known and unknown to obtain the system symmetry, as follows;

Remember that we have classified the variables into a ;disturbance , control and state ; the state vector x is constituted by the voltage angle an magnitude ,so it is the vector of unknowns and may take the rectangular form with e and f parts ;the variables of control –load demands for the moment –are the known values of the real/reactive power and they compose the D vector in the matrix form of NR ,then

Since there are 2n-2 equations we shall separate them into 2 kinds, real and imaginary. Firstly we are to determine the elements of Jacobian by deriving the bus power equations.

The matrix form is like

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta e \\ \Delta f \end{bmatrix}$$

Where ΔP and ΔQ represent the changes in power sometimes called the mismatch vector, Δe and Δf are the correction in real and imaginary parts of bus voltages; the J1, J2, J3, and J4 are the 2*2 types of Jacobian matrix and each one is veritably an dependent matrix has an special structure according to the derivates those are different from diagonal to off diagonal elements. [12]

These elements are calculated from the power's expressions as following:

J1

Off Diagonal Elements;

$$J_1 = {\partial P_p}/{\partial e_q} = e_p G_{pq} - f_p B_{pq} \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_1 = {\partial P_p}/{\partial e_p} = 2e_p G_{pp} + f_p B_{pp} - f_p B_{pp} + \sum_{\substack{q=1 \\ q \neq p}}^{n} \left(e_q G_{pq} + f_q B_{pq} \right)$$

J2

Off Diagonal Elements;

$$J_2 = {\partial P_p}/{\partial f_q} = e_p B_{pq} + f_p G_{pq} \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_2 = {\partial P_p}/{\partial f_p} = e_p B_{pp} + 2f_p G_{pp} - e_p B_{pp} + \sum_{\substack{q=1 \\ q \neq p}}^{n} \left(f_q G_{pq} - e_q B_{pq} \right)$$

J3

Off Diagonal Elements;

$$J_3 = {\partial Q_p}/{\partial e_q} = f_p G_{pq} + e_p B_{pq} \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_3 = {\partial Q_p}/{\partial e_p} = f_p G_{pp} - f_p B_{pp} + 2e_p B_{pp} + \sum_{\substack{q=1 \\ q \neq p}}^{n} \left(f_q G_{pq} - e_q B_{pq} \right)$$

J4

Off Diagonal Elements;

$$J_4 = {\partial Q_p}/{\partial f_q} = f_p B_{pq} - e_p G_{pq} \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_4 = {\partial Q_p}/{\partial f_p} = e_p G_{pp} + 2 f_p B_{pp} - e_p G_{pp} + \sum_{\substack{q=1 \\ q \neq p}}^{n} \left(e_q G_{pq} + f_q B_{pq} \right)$$

The arrangement of the 8 elements in J and the global matrix form is shown in the next equation:

$$\begin{bmatrix} \Delta P_2 \\ \cdot \\ \cdot \\ \Delta P_n \\ \hline \Delta Q_2 \\ \cdot \\ \cdot \\ \Delta Q_n \end{bmatrix} = \left[\begin{array}{cccc|cccc} \frac{\partial P_2}{\partial e_2} & \cdot & \cdot & \frac{\partial P_2}{\partial e_n} & \frac{\partial P_2}{\partial f_2} & \cdot & \cdot & \frac{\partial P_2}{\partial f_n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \frac{\partial P_n}{\partial e_2} & \cdot & \cdot & \frac{\partial P_n}{\partial e_n} & \frac{\partial P_n}{\partial f_2} & \cdot & \cdot & \frac{\partial P_n}{\partial f_n} \\ \hline \frac{\partial Q_2}{\partial e_2} & \cdot & \cdot & \frac{\partial Q_2}{\partial e_n} & \frac{\partial Q_2}{\partial f_2} & \cdot & \cdot & \frac{\partial Q_2}{\partial f_n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \frac{\partial Q_n}{\partial e_2} & \cdot & \cdot & \frac{\partial Q_n}{\partial e_n} & \frac{\partial Q_n}{\partial f_2} & \cdot & \cdot & \frac{\partial Q_n}{\partial f_n} \end{array}\right] * \begin{bmatrix} \Delta e_2 \\ \cdot \\ \cdot \\ \Delta e_n \\ \hline \Delta f_2 \\ \cdot \\ \cdot \\ \Delta f_n \end{bmatrix}$$

This form is probably the famous from some arrangements as the put of the two variables of the same bus in order to complete all the buses in the same vector since this vector may be on the rectangular or polar form, and either the partial derivates, so we obtain many different forms for the application of NRLF (Newton Raphson load flow) matrix equation.

Algorithm:

1-At the load buses, P and Q are specified, so we assume the bus voltage magnitude and angle for these buses,-except slack-. Normally we have the flat voltage start i.e. we set the assumed voltages equal to the slack bus one in angle and magnitude, or real and imaginary parts.

2-Use the given initial set of bus voltages in the calculation of the real and reactive powers are calculated (computed) from the developed equations.

3-The change in P and Q powers is respectively the difference between the scheduled and calculated values of real and reactive power, indicated by ΔP, ΔQ, as follows

$$\Delta P_p^{(k)} = P_p(scheduled) - P_p^{(k)}(computed)$$

$\Delta Q_p^{(k)} = Q_p(scheduled) - Q_p^{(k)}(computed)$ p=1, 2, 3… n k; is the iteration number.

Always the calculated powers are with the latest bus voltage parts.

4-Then the Jacobian elements are calculated with the latest bus voltages, the evaluation is done at any iteration.

5- The linear set of equations is prepared now to solve ,evidently by one of direct methods and we choose the determinant ones ,to determine the voltage correction vector and obtain the Δe_p and Δf_p for each bus.

6- These values should added to the old e and f values to get the new estimated for any bus voltage by the logical expression

$$e_p^{(k+1)} = e_p^{(k)} + \Delta e_p^{(k)}$$

$$f_p^{(k+1)} = f_p^{(k)} + \Delta f_p^{(k)}$$

7-As what said early, these new estimate voltages are used to recalculate the error in power and thus the process is repeated from the step 3 as an entire algorithm.

And since any iteration is complete, the test of convergence must be verified which made as the condition of achieving a very small power error.

Interpretation:

This method converges faster than the Gauss and Gauss Seidel method because of quadratic convergence. When the system has a great number of buses NR come only the most chosen one because of iteration number increasing according to problem size increasing in GS procedure, on the other hand Newton Raphson give the solution in almost constant number of iterations, for example a system of 50 buses treated by GS in 30 iterations, since NR finite it just in 5 iterations but any iteration need more than some of iterations by GS in memory space, operations..

Formulation of Newton Raphson in polar coordinates:

Because the data form in voltage specially, the last study is not sufficiently desire, since it has a good symmetry –the data interest by voltage angle and magnitude to relate the control of Q to |V| and P to δ -, that's guide to use polar coordinates in the correction vector (of voltage).

Let V the bus voltage;

$V_p = |V_p|\angle\delta_p = |V_p|e^{j\delta_p}$

And $Y_{pq} = |Y_{pq}|e^{-j\theta_{pq}}$

And since the power at any bus is given by the equation: [8]

$$P_p - jQ_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q$$

We get that;-by substituting

$$P_p - jQ_p = \sum_{q=1}^{n} |V_p||V_q||Y_{pq}|e^{-j(\theta_{pq}+\delta_p-\delta_q)}$$

This expression should be separated into real and imaginary parts to obtain real and reactive powers as next;

$P_p = \sum_{q=1}^{n} |V_p||V_q|\,|Y_{pq}| \cos(\theta_{pq} + \delta_p - \delta_q)$

$Q_p = \sum_{q=1}^{n} |V_p||V_q|\,|Y_{pq}| \sin(\theta_{pq} + \delta_p - \delta_q)$ for p=1, 2, 3….n

The case of p=q can be extracted to do the good approach in the formula like;

$$P_p = |V_p||V_p||Y_{pp}| \cos(\theta_{pp}) + \sum_{\substack{q=1 \\ q\neq p}}^{n} |V_p||V_q|\,|Y_{pq}| \cos(\theta_{pq} + \delta_p - \delta_q)$$

$$Q_p = |V_p||V_p||Y_{pp}| \sin(\theta_{pp}) + \sum_{\substack{q=1 \\ q\neq p}}^{n} |V_p||V_q|\,|Y_{pq}| \sin(\theta_{pq} + \delta_p - \delta_q)$$

Since p=2, 3…n except slack bus which number is mostly 1, the matrix form come

$$\begin{bmatrix} \Delta \boldsymbol{P} \\ \Delta \boldsymbol{Q} \end{bmatrix} = \begin{bmatrix} \boldsymbol{J}_{11} & \boldsymbol{J}_{12} \\ \boldsymbol{J}_{21} & \boldsymbol{J}_{22} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{\delta} \\ \Delta |\boldsymbol{V}| \end{bmatrix}$$

Here is Jacobian elements take another numeration to distinct from the previous case, similarly each element kind is properly an complete matrix that's we give two calculation expressions of diagonal and off diagonal variables as follows;[11]

J11

Off Diagonal Elements;

$$J_{11} = \partial P_p / \partial \delta_q = |V_p||V_q||Y_{pq}| \sin(\theta_{pq} + \delta_p - \delta_q) \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_{11} = \partial P_p / \partial \delta_p = -\sum_{\substack{q=1 \\ q\neq p}}^{n} |V_p||V_q|\,|Y_{pq}| \sin(\theta_{pq} + \delta_p - \delta_q)$$

J12

Off Diagonal Elements;

$$J_{12} = {\partial P_p}/{\partial |V_q|} = |V_p||Y_{pq}|\cos(\theta_{pq} + \delta_p - \delta_q) \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_{12} = {\partial P_p}/{\partial |V_p|} = 2|V_p||Y_{pp}|\cos(\theta_{pp}) + -\sum_{\substack{q=1 \\ q\neq p}}^{n} |V_q||Y_{pq}|\cos(\theta_{pq} + \delta_p - \delta_q)$$

J21

Off Diagonal Elements;

$$J_{21} = {\partial Q_p}/{\partial \delta_q} = -|V_p||V_q||Y_{pq}|\cos(\theta_{pq} + \delta_p - \delta_q) \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_{21} = {\partial Q_p}/{\partial \delta_p} = \sum_{\substack{q=1 \\ q\neq p}}^{n} |V_p||V_q||Y_{pq}|\cos(\theta_{pq} + \delta_p - \delta_q)$$

J22

Off Diagonal Elements;

$$J_{22} = {\partial Q_p}/{\partial |V_q|} = |V_p||Y_{pq}|\sin(\theta_{pq} + \delta_p - \delta_q) \quad \text{For } q \neq p$$

Diagonal Elements;

$$J_{22} = {\partial Q_p}/{\partial |V_p|} = 2|V_p||Y_{pp}|\sin(\theta_{pp}) + -\sum_{\substack{q=1 \\ q\neq p}}^{n} |V_q||Y_{pq}|\sin(\theta_{pq} + \delta_p - \delta_q)$$

This form of Jacobin takes less computational efforts and also requires less memory space than the rectangular form; however the procedure is the same. So it is preferable than the first and the sub matrixes can easily formed in nearly steps …

Always the same steps of algorithm should be done with the same treatment manner, just include a small change when the bus is of controlled voltage.

Generation Bus

The treatment of controlled voltage buses has a special change to the load, since Q is unknown it will be sorted of the vector of ΔP, ΔQ, either |V|is known then it should sorted from the x vector –in the case of polar form ;

The real power P is given by

$$P_p = \sum_{q=1}^{n} [e_p\{e_q G_{pq} + f_q B_{pq}\} + f_p\{f_q G_{pq} - e_q B_{pq}\}]$$

Also for the voltage magnitude in square expression is written;

$$\{|V_p|\}^2 = e_p^2 + f_p^2$$

This last equation will replace the change in reactive power in the ΔP, ΔQ column Where $\Delta\,|V_p|^2$ take the same form in NR method by the difference between the scheduled-specified- and computed (evident in the square calculation) like $\Delta|V|^2$

$$\Delta\left|V_p^{(k)}\right|^2 = \{|V_p|\text{scheduled}\}^2 - \left|V_p^{(k)}\right|^2$$

So the rectangular form in matrix notation is

$$\begin{bmatrix} \Delta \boldsymbol{P} \\ \Delta \boldsymbol{Q} \\ \Delta|\mathbf{V}|^2 \end{bmatrix} = \begin{bmatrix} \boldsymbol{J}_1 & \boldsymbol{J}_2 \\ \boldsymbol{J}_3 & \boldsymbol{J}_4 \\ \boldsymbol{J}_5 & \boldsymbol{J}_6 \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{e} \\ \Delta \boldsymbol{f} \end{bmatrix}$$

The two new added Jacobian elements J5 and J6 are the partial derivates of the changes in square of the bus voltage magnitude in relation of real and imaginary voltage parts as the following 4 expressions:

J5

Diagonal Elements

$$J_5 = {\partial |\mathrm{V_p}|^2}/{\partial e_p} = 2e_p$$

Off Diagonal Elements

$$J_5 = {\partial |\mathrm{V_p}|^2}/{\partial e_q} = 0 \quad \text{For } q \neq p$$

J6

Diagonal Elements

$$J_6 = {\partial |\mathrm{V_p}|^2}/{\partial f_p} = 2f_p$$

Off Diagonal Elements

$$J_6 = {\partial |\mathrm{V_p}|^2}/{\partial f_q} = 0 \quad \text{For } q \neq p$$

Since the calculations of elements of J1, J2, J3, and J4 were discussed earlier [3].

This modification may be sometimes few difficult because of multiplicity of voltage consideration in the 2 forms, in part real and imaginary and on the other angle and magnitude merely generation buses voltages.

SIMPLIFICATIONS OF NEWTON-RAPHSON METHOD

Like what was mentioned in the method interpretation, the NR method has quadratic convergence characteristics; therefore, the convergence is fast and solution to high accuracy is obtained in the first few iterations. The number of iterations does not increase appreciably with the size of the system. This is in contrast to the Gauss–Seidel method of load flow which has slower convergence even with appropriately applied acceleration factors. The larger the system, the larger are the number of iterations; 50–150 iterations are common.

The NR method, however, requires more memory storage and necessitates solving a large number of equations in each iteration step. The Jacobian changes at each iteration and must be evaluated afresh. The time required for any iteration in the NR method may be 5–10 times that of the Gauss–Seidel method. [12]

The simplifications that can be applied are as follows:

Whenever if the state vector is included in polar form, and eliminate the magnitudes of voltage of the generation buses since they are specified, and automatically the changes in reactive powers of the controlled voltage buses from the D vector ;the equation in matrix form ,come more; logic ,clear ,precise , solvable, and either simple ,without introducing the square of voltage evidently. Now the arrangement method of quantities is very indispensable to construct the correct Jacobian by bus or by type; that means, for example the vector of Δf one introduce $\Delta P2$ $\Delta Q2$, $\Delta P3$ $\Delta Q3$,…, ΔPn ΔQn –except the ΔQ of generation buses – likewise for the δ and $|V|$- so by bus number order.

Or by the quantity kind, so for the correction vector, one put $\Delta\ \delta 2$, $\Delta\ \delta 3$, … $\Delta\ \delta n$ $\Delta|V2|$, and $\Delta|V3|$ … $\Delta|Vn|$ -except the correction in the specified voltage magnitudes.

The partial derivations follow the arrangement method and can not be like the previous ones according to the manner that the variables are ordered.

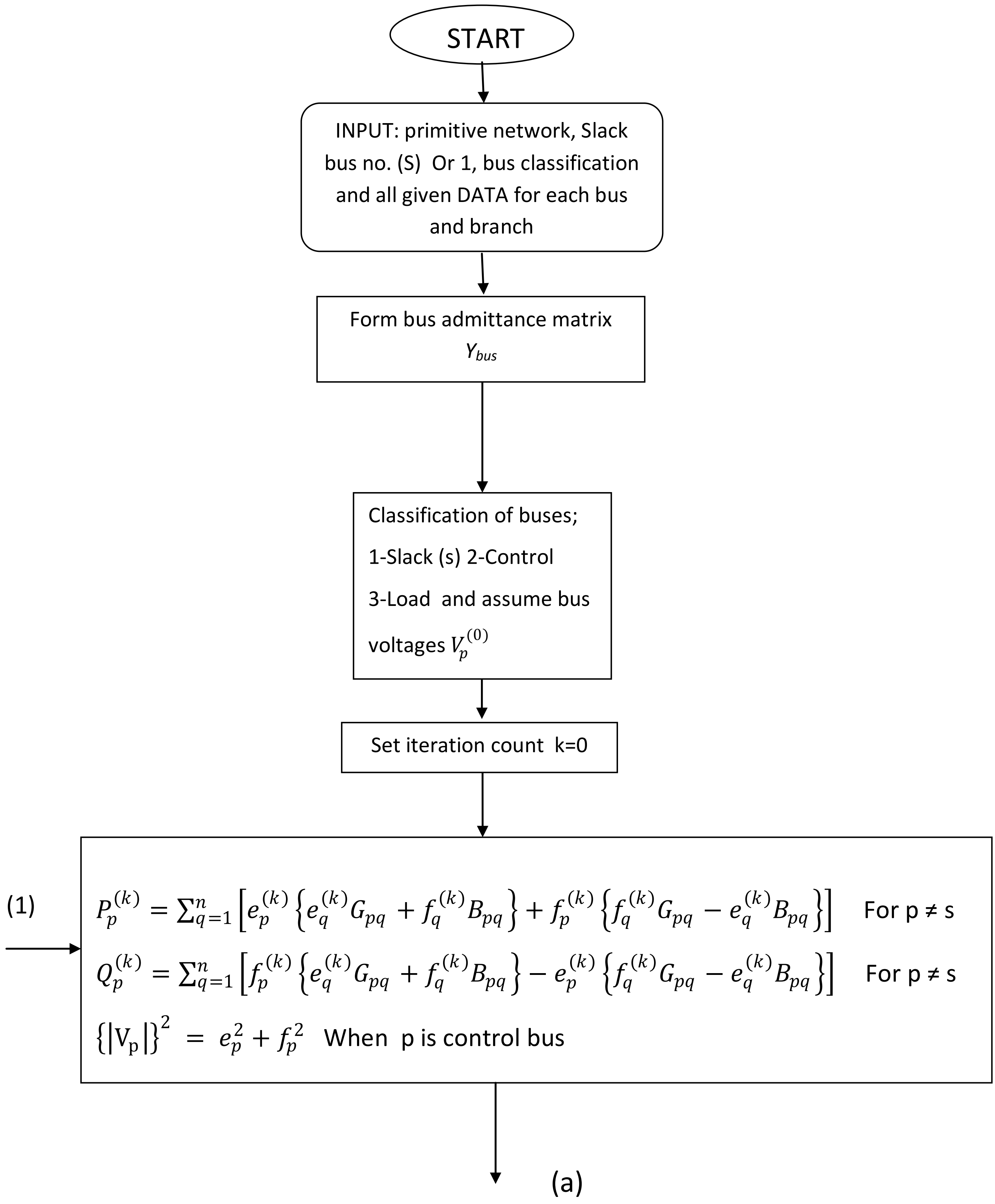
By exploiting the conjugate of Eq.(2) we can found another Jacobian form –using the Δ δ and Δ|V|/V-that gives the linearized relationship between small change in voltage angle and voltage magnitude with the small changes in the real and reactive powers, which elements are called H,M,N and L those defined as the respected reciprocal derivations

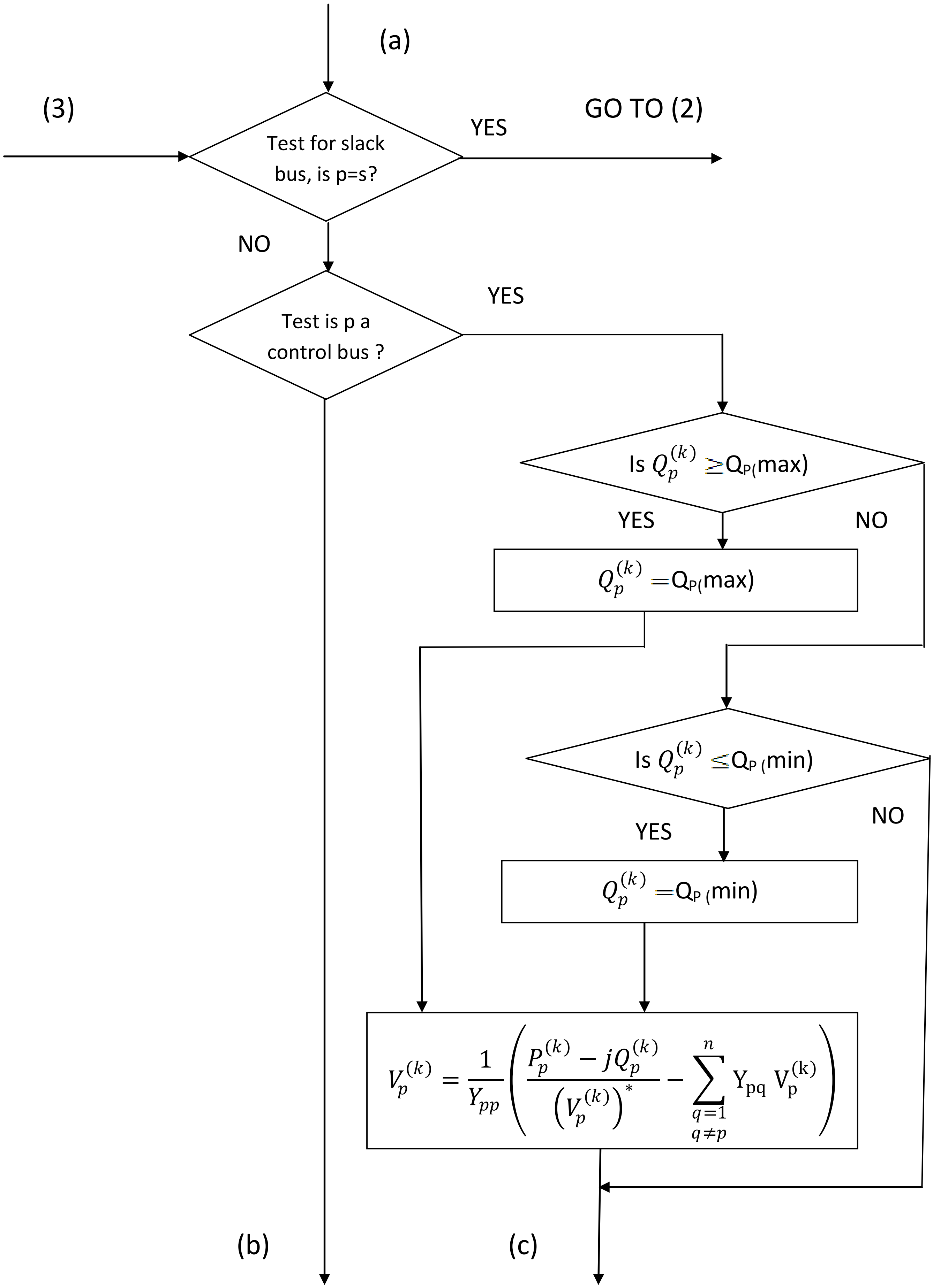
The computed values of real/reactive power to be used in the D vector are:

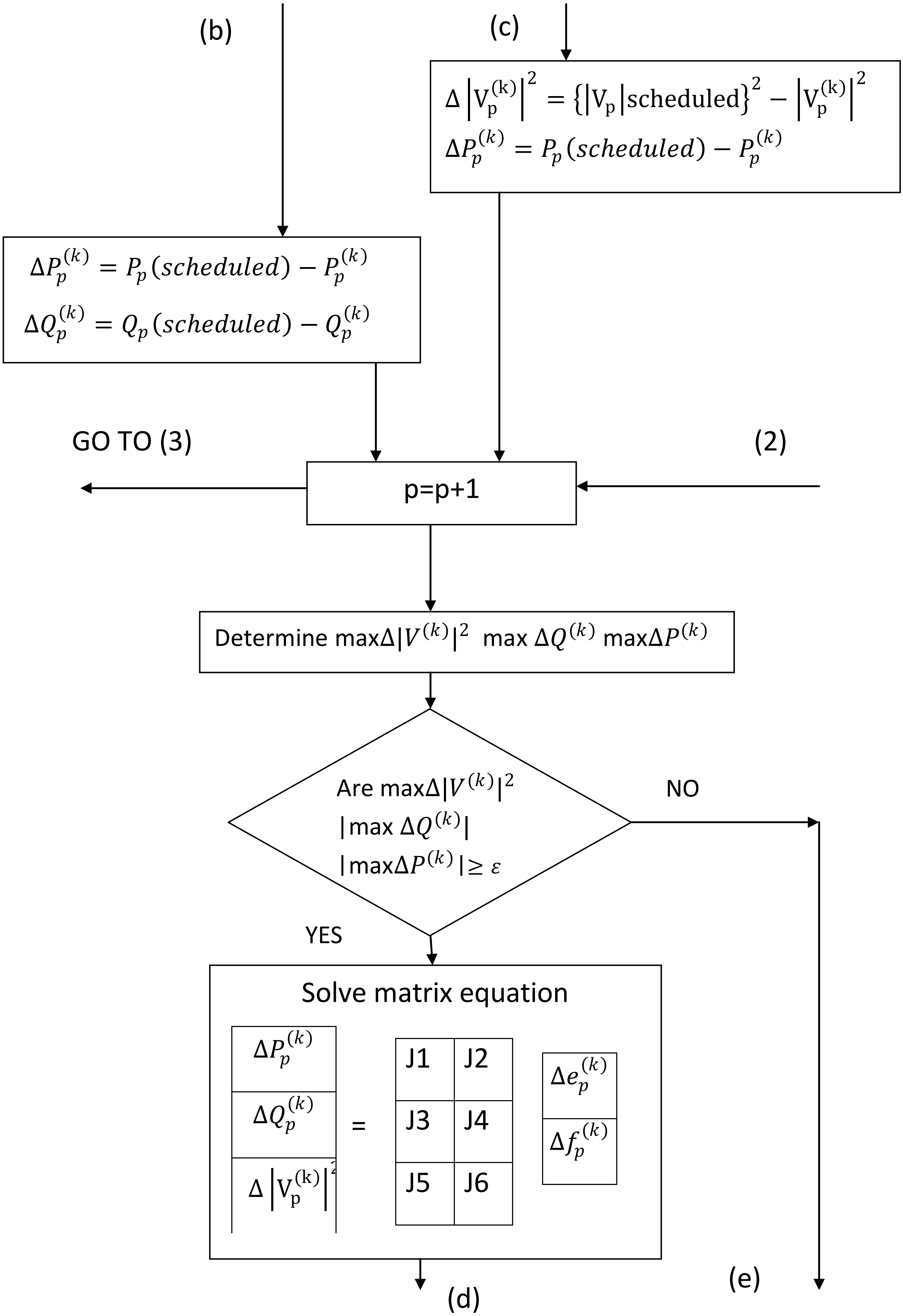
$$P_p^{(k)} = \sum_{q=1}^{n} \left[e_p^{(k)} \left\{ e_q^{(k)} G_{pq} + f_q^{(k)} B_{pq} \right\} + f_p^{(k)} \left\{ f_q^{(k)} G_{pq} - e_q^{(k)} B_{pq} \right\} \right]$$

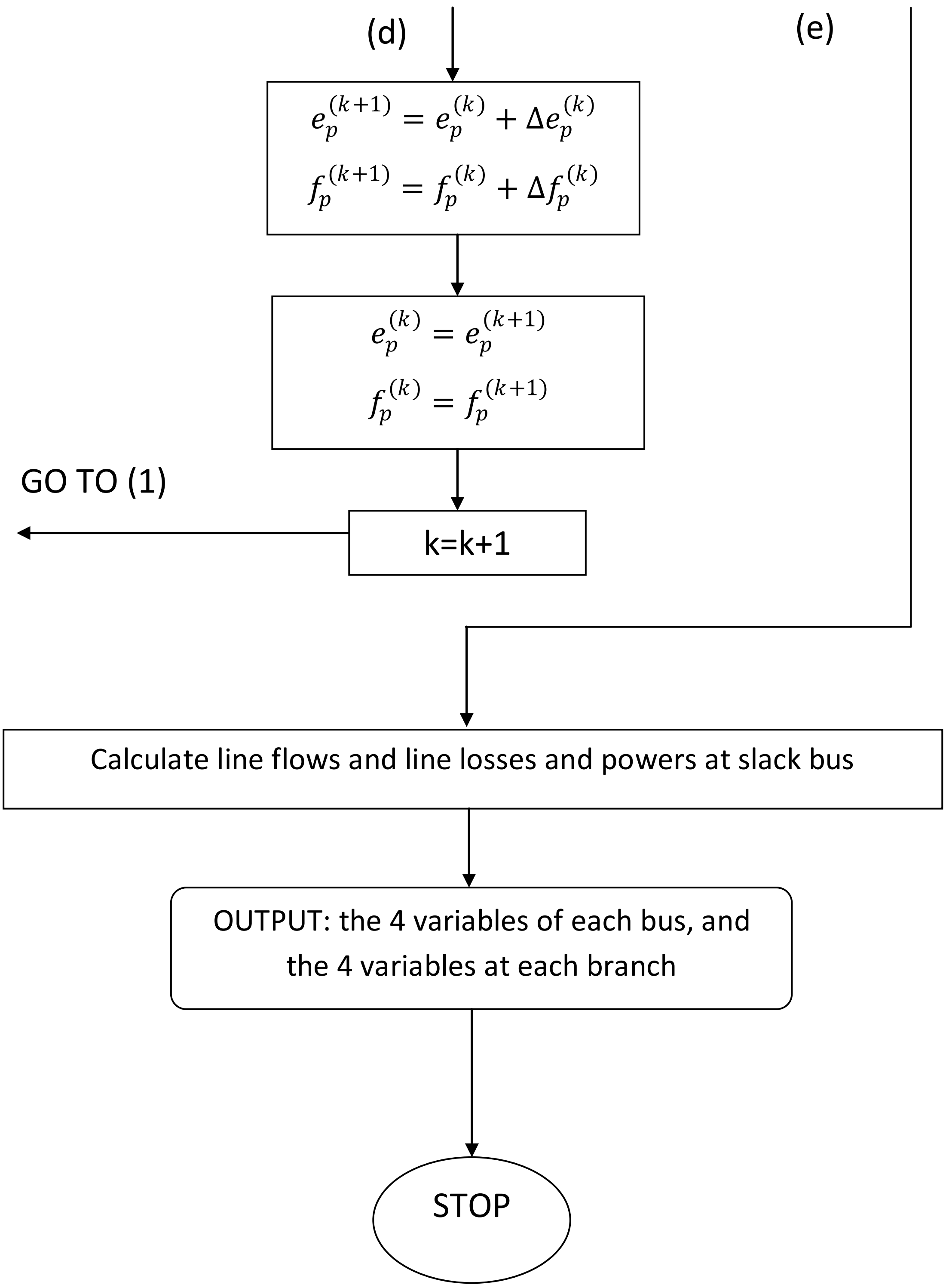
$$Q_p^{(k)} = \sum_{q=1}^{n} \left[f_p^{(k)} \left\{ e_q^{(k)} G_{pq} + f_q^{(k)} B_{pq} \right\} - e_p^{(k)} \left\{ f_q^{(k)} G_{pq} - e_q^{(k)} B_{pq} \right\} \right]$$

The flow chart in the rectangular form with generation buses consideration




(a)
(3)
GO TO (2)
YES
Test for slack bus, is p=s?
NO
YES
Test is p a control bus ?
Is $Q_p^{(k)} \geq Q_{P(}max)$
YES
NO
$Q_p^{(k)} = Q_{P(}max)$
Is $Q_p^{(k)} \leq Q_{P(}min)$
YES
NO
$Q_p^{(k)} = Q_{P(}min)$
$V_p^{(k)} = \frac{1}{Y_{pp}}\left(\frac{P_p^{(k)} - jQ_p^{(k)}}{\left(V_p^{(k)}\right)^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} V_p^{(k)}\right)$
(b)
(c)


(b)
(c)
$\Delta \left|V_p^{(k)}\right|^2 = \{|V_p| scheduled\}^2 - \left|V_p^{(k)}\right|^2$
$\Delta P_p^{(k)} = P_p(scheduled) - P_p^{(k)}$
$\Delta P_p^{(k)} = P_p(scheduled) - P_p^{(k)}$
$\Delta Q_p^{(k)} = Q_p(scheduled) - Q_p^{(k)}$
GO TO (3)
(2)
p=p+1
Determine max$\Delta|V^{(k)}|^2$ max $\Delta Q^{(k)}$ max$\Delta P^{(k)}$
Are max$\Delta|V^{(k)}|^2$
|max $\Delta Q^{(k)}$|
|max$\Delta P^{(k)}$|$\geq \varepsilon$
NO
YES
Solve matrix equation
$\Delta P_p^{(k)}$
$\Delta Q_p^{(k)}$
$\Delta \left|V_p^{(k)}\right|^2$
=
J1 J2
J3 J4
J5 J6
$\Delta e_p^{(k)}$
$\Delta f_p^{(k)}$
(d)
(e)



This flow chart may appear very difficult, but in reality it is simple, when we follow the steps of algorithm one by one.

2.5-3 FAST DECOUPLED Method:

It has been observed in the NR method when doing the calculation of Jacobian in the polar form, that Jacobian elements evaluation is as following;

- Elements of J12 are relatively small
- Elements of J21 are relatively small
- Elements of J11 and J22 are relatively large

Then some of modifications come be necessary to profit and optimize the procedure. The modified Newton method is based on the algorithm developed by W. F. Tinney, extracted from the using of

$$\begin{bmatrix} \Delta \boldsymbol{P} \\ \Delta \boldsymbol{Q} \end{bmatrix} = \begin{bmatrix} \boldsymbol{H} & \boldsymbol{N} \\ \boldsymbol{M} & \boldsymbol{L} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{\delta} \\ \Delta |\boldsymbol{V}| / \boldsymbol{V} \end{bmatrix}$$

This is arrived from one of the previous modifications, of course when controlled voltage buses are included in treating –this is why it is used in polar form-; but with elimination of elements when the concerned value of Y is zero, according to the bus number order of D and C vectors.

Probably the most interesting developed modifications is that bases on Tinney's modification and takes the neglecting of the small changes, in other words; since the changes in real power is less sensitive to the changes in voltage magnitude and the changes in reactive power is less sensitive to the changes in voltage angle, we consider these elements as zeros, that's called FAST DECOUPLED method. This decouple is either due to control manipulation, which affect the variation of real power to the angle variation and of reactive power to the variation of voltage magnitude. So the matrix form is written as

$$\begin{bmatrix} \Delta \boldsymbol{P} \\ \Delta \boldsymbol{Q} \end{bmatrix} = \begin{bmatrix} \boldsymbol{H} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{L} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{\delta} \\ \Delta |\boldsymbol{V}| / \boldsymbol{V} \end{bmatrix}$$

The decoupling of the equations can be expanded like the to equations

$$[\Delta \boldsymbol{P}] = [\boldsymbol{H}][\Delta \boldsymbol{\delta}]$$

$$[\Delta \boldsymbol{Q}] = [\boldsymbol{L}][\Delta |\boldsymbol{V}|/\boldsymbol{V}]$$

The elements of Jacobian H and L are those used in the modified Newton's method.

H

Off Diagonal Elements;

$H_{pq} = {}^{\partial P_p}/_{\partial \delta_q} = |V_p||V_q||Y_{pq}|\sin(\theta_{pq} + \delta_p - \delta_q)$ For q ≠ p after the trigonometric simplification ,we obtain

$$H_{pq} = |V_p||V_q|[-B_{pq}\cos(\delta_p - \delta_q) + G_{pq}\sin(\delta_p - \delta_q)]$$

Diagonal Elements;

$$H_{pp} = {}^{\partial P_p}/_{\partial \delta_p} = -\sum_{\substack{q=1 \\ q \neq p}}^{n} |V_p||V_q||Y_{pq}|\sin(\theta_{pq} + \delta_p - \delta_q) \Rightarrow$$

$$H_{pp} = -V_p^2 B_{pp} - Q_p$$

L

Off Diagonal Elements;

$$L_{pq} = \frac{\partial Q_p |V_q|}{\partial |V_q|} = |V_p||V_q||Y_{pq}| \sin(\theta_{pq} + \delta_p - \delta_q) \quad \text{For } q \neq p \quad \Rightarrow$$

$$L_{pq} = |V_p||V_q|[G_{pq} \sin(\delta_p - \delta_q) - B_{pq} \cos(\delta_p - \delta_q)] = H_{pq}$$

Diagonal Elements;

$$L_{pp} = \frac{\partial Q_p |V_p|}{\partial |V_p|} = 2|V_p^2||Y_{pp}| \sin(\theta_{pp}) + -\sum_{\substack{q=1 \\ q \neq p}}^{n} |V_p||V_q||Y_{pq}| \sin(\theta_{pq} + \delta_p - \delta_q) \Rightarrow$$

$$L_{pp} = -V_p^2 B_{pp} + Q_p$$

In the case of fast decoupled load flow problem the angles are very small than 1rad, the magnitudes are more near than 1 p.u.

$|Vi| \approx 1$ p.u., $\delta i << 1$ rad, $Gij << |Bij|$, $Q_p << V_p^2 B_{pp}$

So rapidly $H_{pq} = L_{pq}$ and $H_{pp} = L_{pp}$; which establish the calculation more simple.

The Fast Decoupled has more advantages than the classical NR methods such as the speed of convergence according to the quadratic convergence and the neglecting of the elements those have very small quantities.-the iteration number can be more than NR- but always with less computation …

The NR method has a lot of manners to apply it since the problem takes many aspects realization, and when the system come large the development will be essential to escort and go with the size and the necessities.

Finally remember that the PF gives some ideas for the allocation of FACTS device in the network, where and when compensation is needed.

CHAPTER THREE \OPTIMAL POWER FLOW

3.1Introduction

From the previous discussions the information that's searched is the variables at nodes and branches, to just satisfy the loads. Since when we do not ensure that it is the 'best' operating strategy, so we can not be sure that the criterion has been made is optimum. In view that money is an important aspect in all our works; it is attempted from ***power flow*** analysis to give the solution of the network at the economic conditions considerations…

In the beginning the orientation to economic load scheduling was not important because there were a small grid, but since the system come more and larger, the application of methods those regard the continuity of supply to the customers under a minimum total operating cost, come an essential domain in electrical energy systems engineering (EESE).

In general, the study of the comportment of any system, it is a remarkable that it may be of regularly operating in terms of the function accomplishment, but with waste. These situations take the attention of the searchers and especially in finance prime. So it has created a separated domain to be the object of the discipline called optimization branch (nowadays many toolboxes in many language are utilized to optimize different function type's in various domains).

Optimization can be aimed at reducing something undesirable in the power system, e.g., the system losses or cost of operation, or maximizing a certain function, e.g., efficiency or reliability. Such maxima and minima are always subject to certain constraints, i.e., tap settings on transformers, tariff rates, unit availability, fuel costs, etc. The problem of optimization is thus translated into the problem of constructing a reliable mathematical model aimed at maximizing or minimizing a certain function, within the specified constraints.

As all systems the electric energy one may be optimized in cost value with satisfying the customers, then should extract and obtain the evaluations of primer energy (sources) at the markets, and so make the suitable study of their costs with each fuel kind and energy production type, without forgotten the maintenance cost, and doing the economic optimization with the suitable method. The power is generated at stations in different areas, with a non regular dispersing by following technical and priority considerations, and then the losses should be taken in computing even if the system was of urban characteristics.

Let consider a multi-variable function to be optimized, it is evident that in adding to the main function constraints are existed such as equality and inequality of course by the cited variables. The relations can be linear or nonlinear, so the programming that to be used is called linear or nonlinear, according to the formula given by the producing control group about the cost variation.

The mathematical procedures can be utile for the optimization are Lagrange multipliers, gradient or lambda method.

As a most attractive one of these technologies, optimal power flow (OPF) was proposed by Capentier in 1960s based on economic dispatch (ED) problem. Unlike ED that allocates load to the generating units only, the OPF integrates active and reactive power operation perfectly into one mathematical model via the AC load flow constraints around all buses, in which the economic and secure aspects of the concerned system are considered.

2.3 Generated Power And Cost

The generation companies primarily produce electric energy (GENCOs), then the transmission companies (TRANSCOs) own and operate transmission lines. The distribution companies (DISTCOs) own and operate distribution lines. As of this writing, TRANSCOs and DISTCOs may not be forced to divest from each other, as they are both regulated companies. The energy service companies (ESCOs) purchase electricity acting as agents for consumers. [18]

This chain is started from generation companies whose have the most part in cost study; even the worked time is in different gapes the analysis is done respecting the time duration; [12]

Time duration	***Control process***	***Optimized function***
Seconds	Automatic generation control	Minimize area control error, subject to system dynamic constraints
Minutes	Optimal power flow	Minimize instantaneous cost of operation or other indexes, e.g., pollution
Hours and days	Unit commitment, hydrothermal	Minimize cost of operation
Weeks	Grid interchange co-ordination	Minimize cost with reliability constraints
Months	Maintenance scheduling	Minimize cost with reliability constraints
Years	Generation planning	Minimize expected investment and operational costs

All these research topics are based on some DATAs given from the generator's construction and fuel type, the BRITISH THERMAL UNIT is the heat fuel that generated power is expressed by its value. This cost function is defined as nonlinear function of pant generation; normally graph is given between the heat values of fuel in MBTHU and power generation in MW and knowing the cost of fuel, 'H' we can definitively determine the fuel cost as a function of generations of each thermal plant.[3]

H: Btu per hour het input o the unit or MBtu/h

F: Fuel cot times H is the ₽ per hour (₽/h) input to the unit for fuel

In discussion of the producing generated power cost, the criterion that the function has chosen is the *dollar/hour;* the selection is due to market's transaction (or the dinar I preferred for Algeria) and other reasons such as the meaningful of this devise, unambiguous and reasonably to measure.

Consider an n generation point in a network and any generator has a function C for the cost of power delivered, hence the total cost is the direct sum of each cost of all generators or stations…

The reactive power generated by the same generators has not any measurable influence on the cost value because they re controlled by varying the field currents, since the major influence is for the real power [4]

The general natures of the cost functions are the same for coal, oil, gas… Nuclear stations can also be included. Hydro stations cannot be applied in the thermal unit cost generation powers.

3-3 Definition And Formulation Of Optimal Operating System

Losses can not neglected in the network, so the set of the function that one search to optimize, since the optimization means minimize or maximize upon problem to be treated, we mean always the former; is dependent to the total losses, the demand powers, the generated ;further one will talk about constraints.

The equations those describe the losses as the equality constraints are the SLFE equations, in searching the optimum of Pg and make sure that the SLFE equations are satisfied is rather formidable mathematical problem.

$h(P_{G1}, P_{G2},,, P_{Gn}) \triangleq \sum_{i=1}^{n} P_{Gi} - P_D - P_L$ Where

$P_D = \sum_{i=1}^{n} P_{Di}$ In the previous formula we have divorced the reactive powers from our optimization problem, in road of reducing the number of equality constraints in the half (from 2n to n), and sometime the reduction of variables goes to neglect the losses, which constitute a separated case …

The generations' capacities are either the constraints, in inequality form because you can not find a generator without limits or operated in open conditions; they must be operated above its rating or below some minimum power and also it has a max in delivering energy!

There were two other inequalities in terms of voltage magnitude and reactive power with limitations between 2 specified values.

The optimum dispatch strategy is related in the simplest case to a simple geometrical example (case of 2 generators) when put the total cost function C an function of the two generator outputs and plotting in the 3 x space axes, the costs of two output generations C1 and C2 are functions of Pg1 and Pg2; the three

dimensional coordinate representation gives an surface that's indicate the minimum cost can be obtained, but is clearly that it is by zero powers outputs.
It is impossible to operate in this condition since we must satisfy the constraint of equality.

The problem now is oriented to solve the main function with the equality and inequality constraints, in other words find the equivalent points in chosen surfaces according to a chosen coordinate system.

Then, two optimum dispatch strategies are possible, when neglect or take in consideration the inequality constraints.

The OPF problem may be formulated as follows:

$$\text{Minimize: } f(\mathbf{x}, \mathbf{u})$$

subject to:

$$\mathbf{g}(\mathbf{x}, \mathbf{u}) = 0$$

$$\mathbf{h}_{min} \le \mathbf{h}(\mathbf{x}, \mathbf{u}) \le \mathbf{h}_{max}$$

where
u - the set of control variables
x - the set of dependent variables
$f(\mathbf{x}, \mathbf{u})$ - a scalar objective function
$\mathbf{g}(\mathbf{x}, \mathbf{u})$ - the power flow equations
$\mathbf{h}(\mathbf{x}, \mathbf{u})$ - the limits of the control variables and operating limits of power system components. [8]

3-4 Minimizing A Function With Constraints (Equality And Inequality)

When searching point of specified function with 2 or more variables, it may be the function that maximize the function, when another equality exist, the procedure can be resolved by special methods called of optimization,

Let F_T function to minimize (F_T is the sum of F1, F2, F3… Fn), it makes the subject to the constraint that the sum f powers generated must equal the received load.

$F_T = F_1 + F_2 + F_3 + \cdots + F_N = \sum_{i=1}^{N} F_i(P_i)$

Now;

P_R is the is the load, so

$\phi = 0 = P_R - \sum_{i=1}^{N} P_i$, this is a called a constrained optimization problem, by involving the Lagrange multipliers. The general formulation called Lagrange function to be solved is $\mathcal{L} = F_T + \lambda\phi$, in this case there are N+ 1 variable, the N variables of power output P_i plus the undetermined Lagrange multiplier lambda. One derivate of the Lagrange function and we take the partial derivate with respect the power output values one at time give the set of equations

$$\frac{\partial \mathcal{L}}{\partial P_i} = \frac{dF_{i(P_i)}}{dP_i} - \lambda = 0$$

$$0 = \frac{dF_i}{dP_i} - \lambda$$

In addition the power output of each generator must be greater than or equal to the minimum power permitted, and must be less than or equal to the maximum power permitted on that particular unit. These conditions of inequalities may be summarized as the following

$\frac{dF_{i(P_i)}}{dP_i} - \lambda = 0$ N equations

$P_{i,min} \leq P_i \leq P_{i,max}$ 2N equations

$P_R - \sum_{i=1}^{N} P_i = 0$ 1 constraint

To simplify the set of equations, the set will expanded to

$\frac{dF_{i(P_i)}}{dP_i} = \lambda$ for $P_{i,min} \leq P_i \leq P_{i,max}$

$\frac{dF_{i(P_i)}}{dP_i} \leq \lambda$ for $P_i = P_{i,max}$

$\frac{dF_{i(P_i)}}{dP_i} \geq \lambda$ for $P_i = P_{i,min}$

to understand let consider the following example $f(x,y) = -x^2 - y^2$

Under the constraint of $h(x,y) = 3x + 4y = 25$ we shall search the x and x those maximize x and verify h;

The solution of this problem is done like;

$L(x,y,\lambda) = f(x,y) - \lambda \, . \, h(x,y)$ this is known as Lagrange method

The new equation obtained, can be partially derivate and affected to zero

$$\partial L/_{\partial x} = -2x - 3\lambda = 0 \Rightarrow x = -{}^{3}/_{2}\,\lambda$$

$$\partial L/_{\partial y} = -2y - 4\lambda = 0 \Rightarrow y = -2\lambda$$

$$\partial L/_{\partial \lambda} = h(x,y) = 0 \Rightarrow 3x + 4y - 25 = 0$$

When substituting the values of x and y in the derivate with lambda in the constraint inequality we can easily find λ , then substitute in the first equations to calculate x and y.

The method consists of doing the equivalence between the derivates of main function and lambda; solve the n+1 set of equations to obtain λ and then the x values.

Let consider the objective function F_T with the losses P_L o the constraint function will be

$\phi = 0 = P_R + P_L - \sum_{i=1}^{N} P_i$, with application of he same procedure, then we obtain the coordination equations

$$\mathcal{L} = F_T + \lambda\phi$$

$$\frac{\partial \mathcal{L}}{\partial P_i} = \frac{dF_{i(P_i)}}{dP_i} - \lambda\left(1 - \frac{\partial P_L}{\partial P_i}\right) = 0 \qquad \Longrightarrow \frac{dF_{i(P_i)}}{dP_i} + \lambda\frac{\partial P_L}{\partial P_i} = \lambda$$

$$P_R + P_L - \sum_{i=1}^{N} P_i = 0$$

This method is called the gradient; the lambda iteration method is another efficient method to solve the problem.

3-5 Optimal Power Flow Resolution With INTERIOR POINT METHOD

Nonlinear Interior Point Optimal Power Flow Method uses the mathematically tools to minimize the cost function; firstly

$$\Delta P_i = P_{gi} - P_{di} - P_i$$

$$\Delta Q_i = Q_{gi} - Q_{di} - Q_i$$

where *Pgi* and *Qgi* are real and reactive powers of generator at bus *i*, respectively; *Pdi* and *Qdi* the real and reactive load powers, respectively; *Pi* and *Qi*

the power injections at the node and are given by: [8]

$$P_i = V_i \sum_{j=1}^{n} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij})$$

$$Q_i = V_i \sum_{j=1}^{n} V_j (G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij})$$

Those are the power mismatch equations in rectangular coordinates at each bus.

Mathematically, as an example the objective function of an OPF may minimize the total operating cost as follows:

Minimize

$$f(x) = \sum_{i}^{Ng} \left(\alpha * P_{gi}^2 + \beta * P_{gi} + \gamma\right)$$

Nonlinear inequality constraints

$$h_j^{min} \leq h_j(x) \leq h_j^{max}$$

Nonlinear equality constraints:

$$\Delta P_i = P_{gi} - P_{di} - P_i\,(t, e, f)$$

$$\Delta Q_i = Q_{gi} - Q_{di} - Q_i\,(t, e, f)$$

Where

$x = [Pg, Qg, t, \theta, V]^T$ is the vector of variables

$\alpha\ \beta\ \gamma$ Coefficients of production cost functions of generator

$\Delta P(x)$ bus active power mismatch equations

$\Delta Q(x)$ bus reactive power mismatch equations

$h(x)$ functional inequality constraints including line flow and voltage magnitude constraints, simple inequality constraints of variables such as generator active power, generator reactive power, transformer tap ratio

Pg the vector of active power generation

Qg the vector of reactive power generation

t the vector of transformer tap ratios

θ the vector of bus voltage magnitude

V the vector of bus voltage angle

Ng the number of generators

By applying Fiacco and McCormick's barrier method, the OPF problem equation of f(x) and the inequality constraint come –after the transformation to the equivalent system-

$$Min\{f(x) - \mu \sum_{j=1}^{M} ln(sl_j) - \mu \sum_{j=1}^{M} ln(su_j)\} \qquad \text{Eq.3-1}$$

Subject to the following constraints:

$$\Delta P_i = 0$$

$$\Delta Q_i = 0$$

$$h_j - sl_j - h_j^{min} = 0$$

$$h_j - su_j - h_j^{max} = 0 \qquad \text{Eq.3.2}$$

Where sl > 0 and *su* > 0.

Thus the Lagrangian function for equalities optimization of equations (3.1)-(3.2) is given by introducing the Lagrange multipliers.

Then The Karush-Kuhn-Tucker (KKT) first order conditions for the Lagrangian function obtained ,give an equation matrix that's the Jacobian is made by the partial derivates see Flexible AC Transmission Systems: Modelling And Control for more details ,after the equation are written, the solving of the set of system will evaluate the correction vector and so obtain the value of new iteration by an complicated method consist of one of the methods of solution for the nonlinear systems with the elimination of the variables of Lagrange and finally obtain the barrier parameter mu ,the procedure is with more exactly steps ,should be followed and respected to extract the searched parameters . The PSAT solver gives in conclusion the final results as shown in the application;

Since Newton method is used to solve the set of matrix form of equation it will sort the values of θ ,$V\lambda_p$ and λ_q and they are the variables of slack bus and when optimization is included as real power the costs are easily calculated.

The major parts of searchers include in the algorithm the steps by eliminating the dual variables and more work of some variables that's the discussion has more mathematically characteristics.

The IPM is very utilizable in power optimization because it is based at the conserving of the point in interior of the points those constitute the form to be minimized or maximized.

The number of iteration may be greater but within a small steps calculation the IPM come the most preferred method terms of mathematical programming or computer operating or power system treatment .

The analysis of the method in electric study, that means in economic dispatch was included later in 1999 and performed to ensure the founding of the minimized cost in term of losses or by neglecting the losses –it will be better than the neglect, the consideration of losses as a variable of generated powers (real) more than the consideration of constant losses; because it is related to the network, lines and transformers structure.

CHAPTER FOUR \ APPLICATION

4-1 SONELGAZ NETWORK DATA

For the application part, the available data from the SG center for us is the oust Algerian network, this data comes from an article published in the second international conference on electrical systems (proceeding volume 1) at Oum el Bouaghi (university of Larbi en M'Hidi, the article is presented by L. Benasla M. Rahli A. Belmadani and M. Benyahia. The data tables are;

With the following topology;

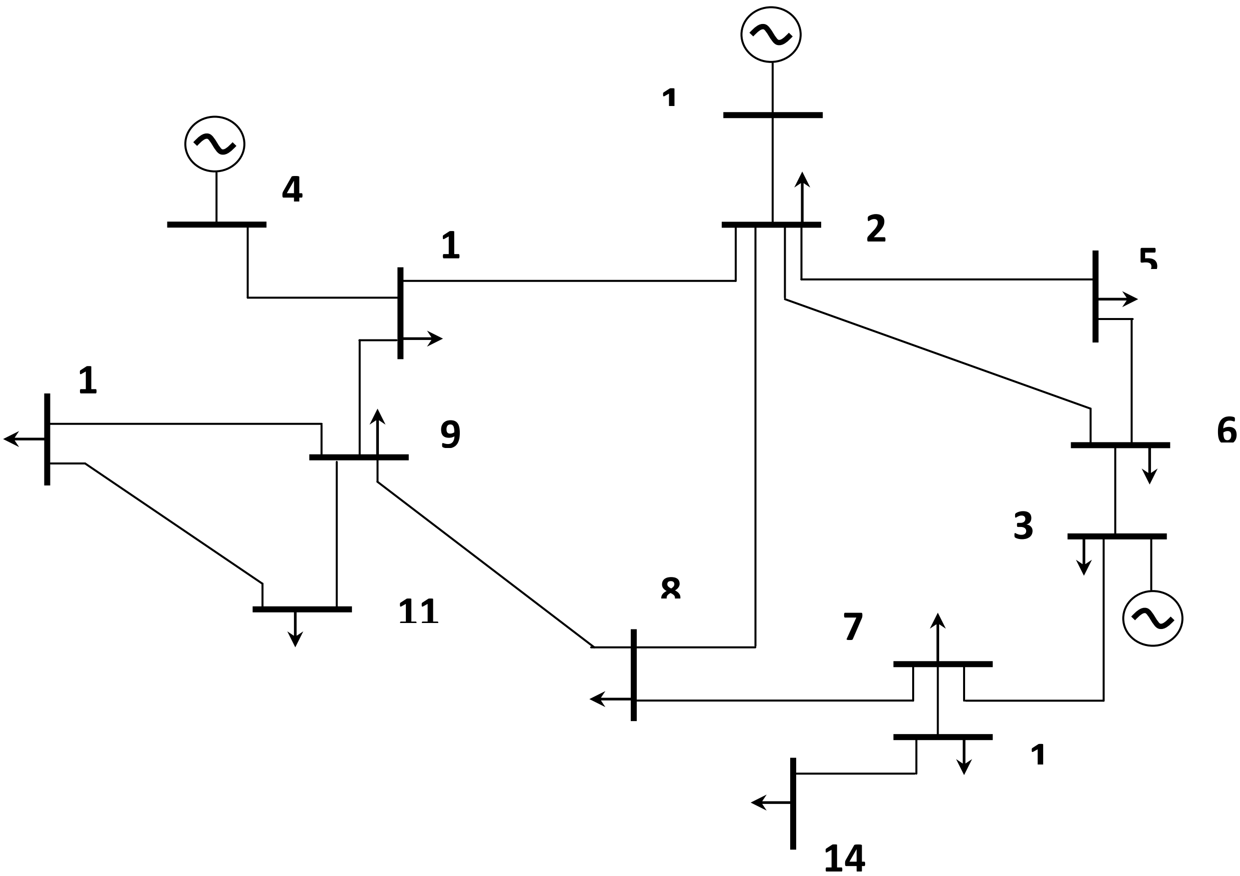


Fig 2 SONELGAZ west network topology

From bus	To bus	Resistance	Inductance	Susceptance	Branch no
1	2	0.0002	0.0012	0.00750	1
2	5	0.0178	0.0866	0.06450	2
2	6	0.0260	0.1289	0.09590	3
2	8	0.0138	0.0670	0.04980	4
2	12	0.0069	0.0335	0.02500	5
3	6	0.0164	0.0799	0.05970	6
3	7	0.0220	0.1072	0.07970	7
4	12	0.0080	0.0277	0.01960	8
5	6	0.0126	0.0610	0.04550	9
7	8	0.0146	0.0705	0.05250	10
7	13	0.0274	0.1697	0.09765	11
8	9	0.0150	0.0735	0.05480	12
9	10	0.0112	0.0540	0.04030	13
9	11	0.0139	0.0483	0.03420	14
9	12	0.0289	0.1012	0.07120	15
10	11	0.0118	0.0410	0.02900	16
13	14	0.0557	0.0234	0.09980	17

N° bus	voltage magnitude	angle	Power generated Active	Reactive	Demand power Active	Reactive	Type of bus
1	1.07	0.00	00	00	000	00	1
2	1.00	0.00	00	00	188	46	3
3	1.0812	0.00	280	30	000	00	2
4	1.00	0.00	60	50	52	24	3
5	1.00	0.00	00	00	62	24	3
6	1.00	0.00	00	00	64	32	3
7	1.00	0.00	00	00	39	18	3
8	1.00	0.00	00	00	38	18	3
9	1.00	0.00	00	00	31	15	3
10	1.00	0.00	00	00	130	60	3
11	1.00	0.00	00	00	48	22	3
12	1.00	0.00	00	00	60	36	3
13	1.00	0.00	00	00	30	15	3
14	1.00	0.00	00	00	40	20	3

For the optimal power flow data it is added the 3 formulas of costs

$$F(P_{G1}) = 2000 + 150P_{G1} + 0.85{P_{G1}}^2$$

$$F(P_{G3}) = 850 + 75P_{G3} + 0.4{P_{G3}}^2$$

$$F(P_{G4}) = 3000 + 250P_{G4} + 1.7{P_{G4}}^2$$

4-2 Matlab Computer Language Programming

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. The name MATLAB stands for matrix laboratory. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows the user to solve technical computing problems, especially those with matrix and vector formulations.

MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow the user to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others. [11]

This language constitutes the essential one for the engineers, and they covet to learn and utilize in problem’s solving. There are many persons profit the codes written by the others ,to learn algorithm ,to develop the old programs , to exploit the work with different cases ,there were and special link at the matlab central oriented to file exchange in an vast forum ,that called open source of programs.

For example Mr. Federico Milano has developed a toolbox for power system analysis on form of virtual laboratory, and many users and countries around the world utilize this software like Algeria …

4-3 ***Power System Analysis Toolbox***, PSAT

The computer and language theory have more simplified the programming problem by an important task; MATLAB is one of these languages with a high performance of technical computing than the others.

The matrix laboratory language MATLAB is divided to more than two major application ,the most known are programming and Simulink, the use of one of the last domains is due to problem analysis, design and mathematical formulation to know the suitable orientation to be utilized in the application to theorist topics.

When a code or some of codes are written and tested ,to resolve a special part of electric engineering ,it may be a package that all of the users can exploit it to obtain results for the different desired DATAs ;PSAT is one of the famous packages ,its name becomes from the abbreviation of the ***Power System Analysis Toolbox*** ,that is an open source Matlab and GNU/Octave based software package for analysis and design of small to medium size electric power systems, started in 2002.

In general SOFTWARE packages for power system analysis can be basically divided into two classes of tools: commercial softwares and educational/research-aimed softwares. PSAT is educational toolbox for electric power system analysis and control. It can handle a wide variety of Power Systems: from small scale educational networks to medium size realistic power systems. PSAT is also GNU Octave compatible in it is command line version.
Being PSAT and open code software it is suitable for research since it allows to modify the existing models/routines and/or to include new models/routines.

The GUIs and Simulink library make it easy to use, thus, it's adequate for educational purposes such as teaching and self study; besides being free!

PSAT makes a full use of Matlab vectorized computations and sparse matrix functions, this gives an optimal performance.

PSAT philosophy

PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Power Flow,
2. Bifurcation Analysis (i.e. Continuation Power Flow),
3. Optimal power flow,
4. SSS ;Small Signal Stability Analysis,
5. Time Domain Simulations,
6. Phasor Measurement Unit (PMU) placement.

The two domains those are the object of our study are PF and OPF, so the needed applications are power flow and optimal power flow and the choice of data is preferred to be from the given ones.

PSAT provides several options to solve Power Flow, such as Newton-Raphson method, the method of NRLF do part of the project, so this software will make the illustration of the analysis done in the study.

The Optimal Power Flow is defined as a nonlinear constrained optimization problem. PSAT uses the Interior Point Method (IPM) with a Mehrotra's predictor-corrector method to solve the OPF problem, which constitute the third method discussed in the chapter number 3. Either in this case the PSAT was the preferred package to discover IPM and enrich the knowledge on the optimization of electric power systems.

In order to perform accurate power system analysis, PSAT supports a variety of static and dynamic component models, one cite from them just:

Power Flow Data: Bus bars, transmission lines and transformers, slack buses, PV generators, constant power loads, and shunt admittances.

Optimal Power Flow Data: Power supply bids and limits, generator power reserves, generator ramping data, and power demand bids and limits.

Each one of two applications is specified by a complete chapter in the help documentation file.

Getting Started

This chapter explains how to download, install and run PSAT. The structure of the toolbox and a brief description of its main features are also presented.

2.1 Download

PSAT can be downloaded at:

http://thunderbox.uwaterloo.ca/~fmilano or following the link available at:

http://www.power.uwaterloo.ca

2.2 Installation

Extract the zipped files from the distribution tarball in a new directory.

2.3Launching PSAT

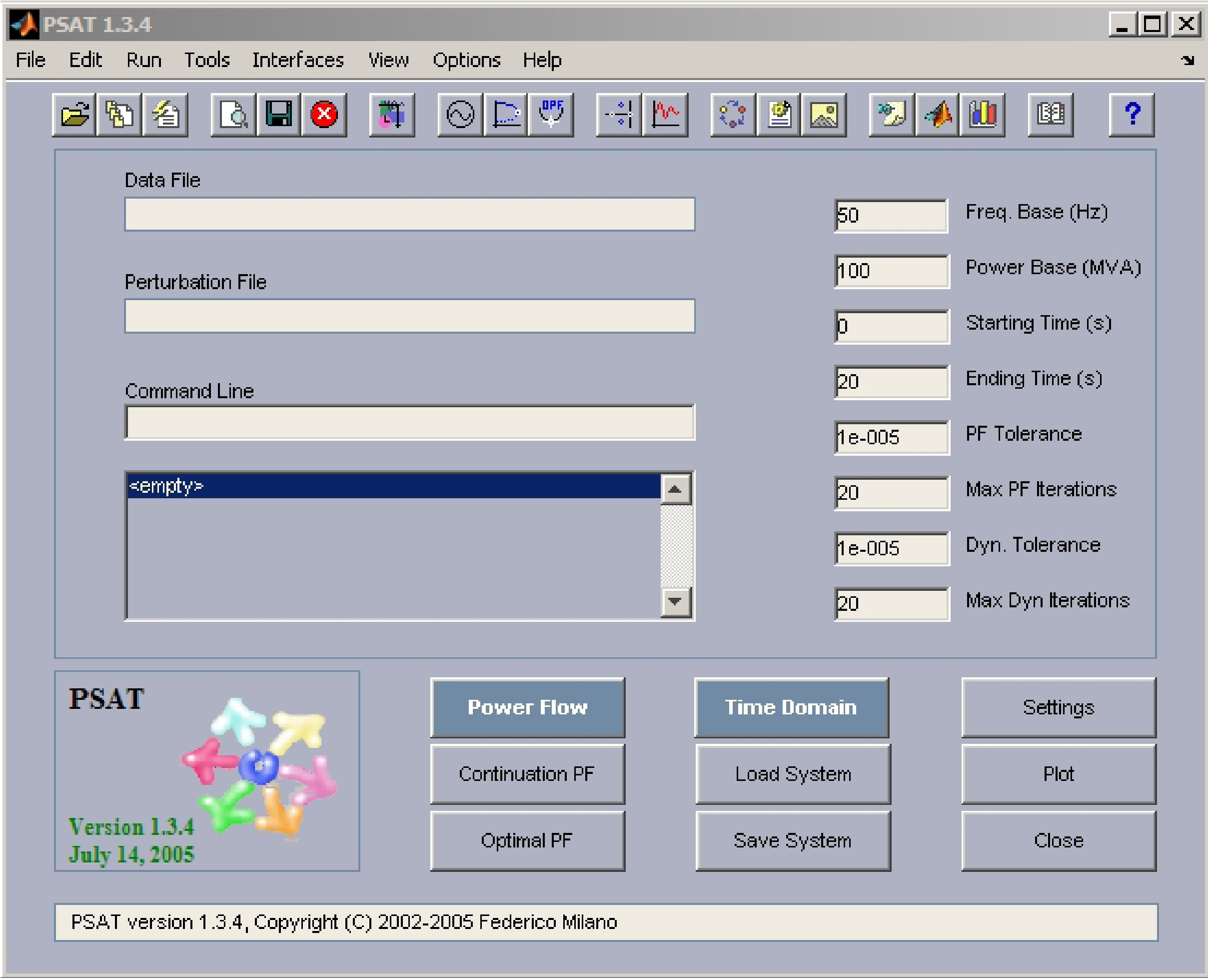
After setting the PSAT folder in the Matlab path, type from the Matlab prompt:

>> psat

This will create all the structures required by the toolbox, as follows:

Matlab is case sensitive, so don't type PSAT and be sure to Caps lock

You can specify the code psat and run it from the editor



On the matlab command window it will be displayed the following;

< P S A T >

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Version 1.3.4

July 14, 2005

PSAT comes with ABSOLUTELY NO WARRANTY; type 'gnuwarranty' for details. This is free software, and you are welcome to redistribute it under certain conditions; type 'gnulicense' for details.

Host: Matlab 6.5.0.180913a (R13)

Session: date and time

Usage: Graphical User Interface

Path: C:\MATLAB6p5\work\psat

2.4 Loading Data:

To load a file simply double click on this edit text, or use the first button of the tool-bar, the menu File/Open/Data File or the shortcut <Ctrl-d> when the main window is active. The data file can be either an .m file in PSAT format or a Simulink model created with the PSAT library. Then select the directory of tests (contain the default cases of 4, 6, 9 and 14 buses agreed of IEEE).

2.5 Running the Program:

Select one of the majors' treatments ,Power Flow or Optimal PF ,then the package runs the problem ,and it will displayed the time that the solver finite the case.

2.6 Displaying Results:

Results can be generally displayed in more than one way, either by means of a graphical user interface in Matlab or as an ASCII text file. For example power flow results, or whatever is the actual solution of the power flow equations of the current system, can be inspected with a GUI (in the main window, look for the menu View/Static Report or use the shortcut <Ctrl-v>). Then, the GUI allows saving the results in a text file. Other results requiring a graphical output, such as continuation power flow results, multi-objective power flow computations or time domain simulations, can be depicted and saved in .eps files with the plotting utilities (in the main window, look for the menu View/Plotting Utilities or use the shortcut <Ctrl-w>). Finally it is possible to save the report in .txt format or other, and not forget that PSAT offers some setting for the most applications.

4-4 Applications

In the PSAT help documentation file, the Part II describes the routines and algorithms for power system analysis (PF & OPF).

The illustrated models and data formats of all components included in PSAT are explained in the Part III. Dr Milano inserted the Test System Data in Appendix F.

The models of PSAT and the DATA formats

Power Flow Data

It is formed by 9 data's those describe the parameters and variables of;

Bus, Transmission Line, Transformers, Slack Generator, PV Generators, PQ Load, PQ Generator, Shunt, Area.

Each one of the matrixes has like columns those cited in the Chapter 10 of the documentation, available at the Milano's site. Some of the columns are optional or not available in the version, and to be prepared for the next version, then it is recommended to put the value of zero when the column is not used or impossible to exploit it in the solving.

OPF Data

It constitutes 5 data's, which are;

Generator Supply, Generator Reserve, Generator Power Ramping, Load Demand, Load Ramping.

Either all the matrixes those talk about are shown with detail in the Chapter 11. The data file has a special name like “d_009_mdl” founded in the directory ‘’tests’’ and should contain the indispensable and suitable (not all) matrixes in the extension of “.con” for example, the Transmission Line parameters are inputted in the matrix called “Line.con” which format that should respected is shown in the table indicated by: **Table 10.2: Line Data Format (Line.con) from** the help file. The important vector for the sense of any model is “Varname.bus” with the following structure for the 9 bus case;

Varname.bus = {...

'Bus1'; 'Bus2'; 'Bus3'; 'Bus4'; 'Bus5'; 'Bus6'; 'Bus7'; 'Bus8'; 'Bus9'};

Case of 6 buses from IEEE \

```
Bus.con = [...
  1    400     1     0   2   1;
  2    400     1     0   2   1;
  3    400     1     0   2   1;
  4    400     1     0   2   1;
  5    400     1     0   2   1;
  6    400     1     0   2   1;
 ];

Line.con = [...
  2   3    100    400    60    0    0   0.05   0.25   0.06    0    0  0.3082    0    0 ;
  3   6    100    400    60    0    0   0.02    0.1   0.02    0    0   1.397    0    0 ;
  4   5    100    400    60    0    0    0.2    0.4   0.08    0    0  0.1796    0    0 ;
  3   5    100    400    60    0    0   0.12   0.26   0.05    0    0  0.6585    0    0 ;
  5   6    100    400    60    0    0    0.1    0.3   0.06    0    0     0.2    0    0 ;
  2   4    100    400    60    0    0   0.05    0.1   0.02    0    0   1.374    0    0 ;
  1   2    100    400    60    0    0    0.1    0.2   0.04    0    0  0.2591    0    0 ;
  1   4    100    400    60    0    0   0.05    0.2   0.04    0    0  0.9193    0    0 ;
  1   5    100    400    60    0    0   0.08    0.3   0.06    0    0  0.8478    0    0 ;
  2   6    100    400    60    0    0   0.07    0.2   0.05    0    0  0.9147    0    0 ;
  2   5    100    400    60    0    0    0.1    0.3   0.04    0    0  0.7114    0    0 ;
 ];

SW.con = [...
  2    100    400    1.05     0    1.5   -1.5    1.1    0.9    1.4     1 ;
 ];

PV.con = [...
  1    100    400    0.9    1.05    1.5   -1.5    1.1    0.9     1 ;
  3    100    400    0.6    1.05    1.5   -1.5    1.1    0.9     1 ;
 ];

PQ.con = [...
  4    100    400    0.9    0.6    1.1    0.9  0;
  5    100    400      1    0.7    1.1    0.9  0;
```

```
  6    100    400    0.9    0.6    1.1    0.9  0;
 ];

Demand.con = [...
  4    100   0.25  0.1667    0.25   1e-05    0    0    12    0    0    0    0  0    0
0     0;
  5    100    0.1   0.07     0.1   1e-05    0    0   10.5    0    0    0    0  0    0
0     0;
  6    100    0.2 0.06667    0.2   1e-05    0    0    9.5    0    0    0    0  0    0
0     0;
 ];

Supply.con = [...
  1    100    0.2    0.2    1e-05    0    0    9.7    0    0    0    0  0    0    1    1.5
-1.5    0     0 ;
  2    100   0.25   0.25    1e-05    0    0    8.8    0    0    0    0  0    0    1    1.5
-1.5    0     0 ;
  3    100   0.22    0.2    1e-05    0    0     7     0    0    0    0  0    0    1    1.5
-1.5    0     0 ;
 ];

Varname.bus = {...
'Bus1'; 'Bus2'; 'Bus3'; 'Bus4'; 'Bus5'; 'Bus6'};
```

For example the matrix ‘SW.con’, swing bus variables the column 4 indicates according to Table 10.6 Voltage magnitude V_0 in p.u. (equal 1.05)…etc

For the application of PF to 6buses from IEEE PSAT give the following results

Firstly the MATLAB Command Window it displays the following

PSAT folder has been added to the Matlab path.
Data file "C:\MATLAB6p5\work\psat\tests\d_006_mdl" set

Newton-Raphson Method for Power Flow Computation
Data file "C:\MATLAB6p5\work\psat\tests\d_006_mdl"
Writing file "fm_call" ...
PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1   Maximum Convergency Error = 0.071466
Iteration = 2   Maximum Convergency Error = 0.0035582
Iteration = 3   Maximum Convergency Error = 1.5431e-005
Iteration = 4   Maximum Convergency Error = 2.96e-010
Power Flow completed in 0.157 s

When viewing and saving the static report it display

Writing the report file...

Opening the report file...

Report of Static Results saved in text file

"C:\MATLAB6p5\work\psat\tests\d_006_mdl.txt"

The static report is saved in the directory shown and contain the following results

POWER FLOW REPORT

P S A T 1.3.4

Author: Federico Milano, (c) 2002-2005

e-mail: fmilano@thunderbox.uwaterloo.ca

website: http://thunderbox.uwaterloo.ca/~fmilano

File: C:\MATLAB6p5\work\psat\tests\d_006_mdl

Date: 25-Jun-2008 06:02:07

NETWORK STATISTICS

Buses: 6

Lines: 11

Generators: 3

Loads: 3

SOLUTION STATISTICS

Number of Iterations: 4

Maximum P mismatch [p.u.] 0

Maximum Q mismatch [p.u.] 0

Power rate [MVA] 100

POWER FLOW RESULTS

Bus	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus1	1.05	0.02534	0.9	0.31409	0	0
Bus2	1.05	0	1.3988	0.65025	0	0
Bus3	1.05	-0.03529	0.6	0.70318	0	0
Bus4	0.98592	-0.04064	0	0	0.9	0.6
Bus5	0.96854	-0.07261	0	0	1	0.7
Bus6	0.99121	-0.0735	0	0	0.9	0.6

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus2	Bus3	1	0.15013	-0.06035	0.00106	-0.06087
Bus3	Bus6	2	0.50254	0.51335	0.00957	0.027
Bus4	Bus5	3	0.07867	-0.03415	0.00128	-0.07385
Bus3	Bus5	4	0.24653	0.19035	0.01178	-0.02548
Bus5	Bus6	5	-0.01938	-0.09487	0.00051	-0.05607
Bus2	Bus4	6	0.60904	0.3658	0.02326	0.02578
Bus1	Bus2	7	0.11245	-0.0765	0.00142	-0.04127
Bus1	Bus4	8	0.40302	0.22486	0.01013	-0.00097
Bus1	Bus5	9	0.38453	0.16574	0.0136	-0.01023
Bus2	Bus6	10	0.44108	0.14075	0.01415	-0.01169
Bus2	Bus5	11	0.30954	0.16881	0.01199	-0.00483

LINE FLOWS

From Bus To Bus Line P Flow Q Flow P Loss Q Loss

			[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus3	Bus2	1	-0.14907	-0.00052	0.00106	-0.06087
Bus6	Bus3	2	-0.49297	-0.48635	0.00957	0.027
Bus5	Bus4	3	-0.07739	-0.0397	0.00128	-0.07385
Bus5	Bus3	4	-0.23475	-0.21583	0.01178	-0.02548
Bus6	Bus5	5	0.0199	0.0388	0.00051	-0.05607
Bus4	Bus2	6	-0.58578	-0.34002	0.02326	0.02578
Bus2	Bus1	7	-0.11103	0.03524	0.00142	-0.04127
Bus4	Bus1	8	-0.39289	-0.22583	0.01013	-0.00097
Bus5	Bus1	9	-0.37093	-0.17597	0.0136	-0.01023
Bus6	Bus2	10	-0.42692	-0.15245	0.01415	-0.01169
Bus5	Bus2	11	-0.29755	-0.17363	0.01199	-0.00483

GLOBAL SUMMARY REPORT

TOTAL GENERATION

REAL POWER [p.u.] 2.8988

REACTIVE POWER [p.u.] 1.6675

TOTAL LOAD

REAL POWER [p.u.] 2.8

REACTIVE POWER [p.u.] 1.9

TOTAL SHUNT

REAL POWER [p.u.] 0

REACTIVE POWER (IND) [p.u.] 0

REACTIVE POWER (CAP) [p.u.] 0

TOTAL LOSSES

REAL POWER [p.u.] 0.09875

REACTIVE POWER [p.u.] -0.23248

For the running of optimal power flow the toolbox go to display the following sentences at Matlab command window

```
--------------------------------------------------------------
Interior Point Method for OPF Computation
Social Benefit Objective Function
Data file "C:\MATLAB6p5\work\psat\tests\d_006_mdl"
--------------------------------------------------------------
Iter. = 1    mu = 0.00101  |dy| = 16.6453  |f(y)| = 1.4238   |dG(y)| = 1
Iter. = 2    mu = 0.00189  |dy| = 3.6234   |f(y)| = 1.4119   |dG(y)| = 0.12741
Iter. = 3    mu = 0.00194  |dy| = 0.98743  |f(y)| = 1.3604   |dG(y)| = 0.16241
Iter. = 4    mu = 0.00263  |dy| = 0.6737   |f(y)| = 1.163    |dG(y)| = 0.20093
Iter. = 5    mu = 0.00084  |dy| = 0.40184  |f(y)| = 0.73028  |dG(y)| = 0.03205
Iter. = 6    mu = 0.00019  |dy| = 0.1573   |f(y)| = 0.06951  |dG(y)| = 0.02654
Iter. = 7    mu = 2e-005   |dy| = 0.0731   |f(y)| = 0.03576  |dG(y)| = 0.03594
Iter. = 8    mu = 0        |dy| = 0.00916  |f(y)| = 0.00203  |dG(y)| = 0.00169
Iter. = 9    mu = 0        |dy| = 0.00073  |f(y)| = 0.00011  |dG(y)| = 0.00017
Iter. = 10   mu = 0        |dy| = 4e-005   |f(y)| = 1e-005   |dG(y)| = 1e-005
Iter. = 11   mu = 0        |dy| = 0        |f(y)| = 0        |dG(y)| = 0
--------------------------------------------------------------
IPM-OPF completed in 0.438 s
```

When viewing and saving the static report it display

```
Opening the report file...
Report of Static Results saved in text file
"C:\MATLAB6p5\work\psat\tests\d_006_mdl.txt"
```

The static report saved is ;

OPTIMAL POWER FLOW REPORT

(Standard OPF)

P S A T 1.3.4

Author: Federico Milano, (c) 2002-2005

e-mail: fmilano@thunderbox.uwaterloo.ca

website: http://thunderbox.uwaterloo.ca/~fmilano

File: C:\MATLAB6p5\work\psat\tests\d_006_mdl

Date:

NETWORK STATISTICS

Buses: 6

Lines: 11

Generators: 3

Loads: 3

Supplies: 3

Demands: 3

SOLUTION STATISTICS

Objective Function [$/h]: -121.6473

Active Limits: 8

Number of Iterations: 11

Barrier Parameter: 0

Variable Mismatch: 0

Power Flow Equation Mismatch: 0

Objective Function Mismatch: 0

POWER SUPPLIES

Bus	mu min	Ps min [MW]	Ps [MW]	Ps max [MW]	mu max
Bus1	0.67963	0.001	0.001	20	0
Bus2	0	0.001	25	25	0.18047
Bus3	0	0.001	20	20	2.1455

POWER DEMANDS

Bus	mu min	Pd min [MW]	Pd [MW]	Pd max [MW]	mu max
Bus4	0	0.001	25	25	2.1749
Bus5	0	0.001	10	10	0.56119
Bus6	0	0.001	8.0692	20	0

REACTIVE POWERS

Bus	mu min	Qg min [MVar]	Qg [MVar]	Qg max [MVar]	mu max
Bus2	0	-150	76.2095	150	0
Bus1	0	-150	44.6252	150	0
Bus3	0	-150	72.0848	150	0

VOLTAGES

Bus	mu min	V min [p.u.]	V [p.u.]	V max [p.u.]	mu max	phase [rad]
Bus1	0	0.9	1.1	1.1	1.4534	0.01405
Bus2	0	0.9	1.1	1.1	0.73629	0
Bus3	0	0.9	1.1	1.1	0.30314	-0.02463
Bus4	0	0.9	1.0211	1.1	0	-0.05066
Bus5	0	0.9	1.013	1.1	0	-0.07318

Bus6	0	0.9	1.0404	1.1	0	-0.06759

POWER FLOW

Bus	P [MW]	Q [MVar]	rho P [$/MWh]	rho Q [$/MVArh]	NCP [$/MWh]	Pay [$/h]
Bus1	90.001	44.6252	9.0204	0	-0.04509	-812
Bus2	164.8754	76.2095	8.9805	0	0	-1481
Bus3	80	72.0847	9.1455	0	0.07117	-732
Bus4	-115	-76.67	9.563	0.39309	0.19391	1100
Bus5	-110	-77	9.6535	0.40762	0.27128	1062
Bus6	-98.0692	-62.6899	9.4284	0.21472	0.22339	925

FLOWS IN TRANSMISSION LINES

From bus	To bus	I_ij [p.u.]	I_ij max [p.u.]	mu I_ij
Bus2	Bus3	0.11693	0.3082	0
Bus3	Bus6	0.731	1.397	0
Bus4	Bus5	0.07149	0.1796	0
Bus3	Bus5	0.33729	0.6585	0
Bus5	Bus6	0.11578	0.2	0
Bus2	Bus4	0.84777	1.374	0
Bus1	Bus2	0.08127	0.2591	0
Bus1	Bus4	0.49409	0.9193	0
Bus1	Bus5	0.39214	0.8478	0
Bus2	Bus6	0.4327	0.9147	0
Bus2	Bus5	0.35683	0.7114	0

FLOWS IN TRANSMISSION LINES

From bus To bus I_ji I_ji max mu I_ji

		[p.u.]	[p.u.]	
Bus3	Bus2	0.10451	0.3082	0
Bus6	Bus3	0.74506	1.397	0
Bus5	Bus4	0.06342	0.1796	0
Bus5	Bus3	0.36729	0.6585	0
Bus6	Bus5	0.0635	0.2	0
Bus4	Bus2	0.85812	1.374	0
Bus2	Bus1	0.06232	0.2591	0
Bus4	Bus1	0.51837	0.9193	0
Bus5	Bus1	0.42224	0.8478	0
Bus6	Bus2	0.45115	0.9147	0
Bus5	Bus2	0.3779	0.7114	0

TOTALS

TOTAL LOSSES [MW]: 11.807

BID LOSSES [MW] 1.932

TOTAL DEMAND [MW]: 43.0692

TTL [MW]: 323.0692

IMO PAY [$/h]: 62.1205

4-5 interpretation and conclusion

In the past the generation companies do not make any minimization of the generation cost of fuel from primary energy sources ,but nowadays the engineers uses the optimization at many levels with different methods ,this economic operating studies take the indispensable part of power systems analysis ,the optimal power flow solve the problem in the minimal possible cost according to the optimization methods ,by using the mathematical formulation of the objective function most of searchers introduce many new methods ,the interior point method is the most responded one because of the time small in calculation the difference between the power flow and the optimal is that the satisfying the load is done by the minimal cost , the economic dispatch has more levels than cost such as stability ,the use of software package is very useful and the exploitation of higher language computing is the indispensable thing in the study

The electric energy systems are very large in the application of engineering , so each domain is separated to the other but the most part require the power flow study ,

The cost of any thing is referred to the manner that we utilize ,energy must be utilized in the suitable methods by applying the economic dispatch and unit commitment that engineer should manipulate

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