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Research Article

Power Flow Study on Alternating Current (Ac) Power System

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Abstract:- **Major challenges confronting the power system engineers and operators include the ease to determine the real and reactive power losses, power flows,and ability to plan ahead. This paper accentuates the use of power flow study to solve the above articulated problems in the electric power systems. It examines the causes and effects of embarking upon power flow study on ac power system, and suggests possible techniques and methods of executing power flow study.**

Keywords: **Power flow, admittance, slack bus, $Y_{bus.}$**

I. INTRODUCTION

In recent years, the demand for electric power has increased substantially without commensurate increase in power generation and transmission due to meager financial resources, limited fuel resources and environmental restrictions. Successful operation of electrical power system depends on the following requirements:

- Generation must supply the demand (load) plus losses,
- Bus voltage magnitude must remain close to rated values,
- Generators must operate within real and reactive power limit,
- Transmission lines and transformers must not be overloaded for long periods.

Power flow study is systematic mathematical approach that models a set of simultaneous nonlinear algebraic equations for the determination of various voltages, currents, phase angles, losses, active and reactive power flows through different buses, generators and loads under steady state conditions [1]. The consequences of excessive demand of electricity is overloading of transmission lines and subsequent evacuation limiting factors that make the entire system unstable. Sequel to high demand for electric energy, there is need to design new power system and expand the existing one. The solution to the above problem is primarily based on the power flow study of the power system..

Power flow study is used to determine the steady state operating condition of a power system. It is an excellent tool for power system planning. A number of operating procedures can be analysed, including contingency conditions, losses in generators, transmission lines or transformers [2] [3] [4]. Power flow studies will alert the users to the conditions that may cause equipment overload or poor voltage levels. It can be sued to determine the optimal size and location of capacitor for power factor improvement. The power flow study is very useful in determining bus voltages under condition of sudden connection or disconnection of loads. The result of the power flow study is also a stating point for the stability study. The study also determines if system voltages remain within specified limits under various contingency conditions, and whether equipment such as transformers and conductors are overloaded. Power study are often used to identify the need for additional generation, capacitive, or inductive Var support, or the placement of capacitors and/or reactors to maintain system voltages within specified limits.

Power flow results are necessary for planning, design and operating of the power system. The study analyses the effects of changes in equipment configuration as well as evaluation of the effect of any possible contingencies such as loss of generating unit, loss of transmission line, or failure of any single component of the system [5] [6]. Since power flow is considered under steady state balanced condition, a positive sequence model of the power grid is adopted for power flow solution.

Therefore, it is imperative to determine the voltages, currents, power flows, circuit loading and power losses in an electrical power system, and this can be achieve effectively and efficiently by means of power flow study , which the present study attempted to explore.

II. OBJECTIVE OF THE STUDY

The power flow study has the following objectives:

To determine the voltage magnitude of each bus and its phase angle

To determine the real and reactive power flows.

To evaluate the power system losses.

To provide information for planning ahead.

III. POWER FLOW METHODS

There are two traditional and popular numerical methods for solving the power flow problems, namely, the Gauss-Seidel (G-S) method and Newton-Raphson (N-R) method. Gauss-Seidel method is the earliest devised method. It shows slower rates of convergence compared to other iterative methods, but it uses very little memory and does not need to solve a matrix system. Most current methods are based on N-R. The N-R method is superior to G-S method because it exhibits fast convergence characteristic. The disadvantage of N-R method is that a 'flat start' is not always possible since the solution at the beginning can oscillate without converging toward the solution [11]. To circumvent this problem, the load flow solution is often started with G-S algorithm followed by the N-R algorithm after little iteration [7] [8] [9]. Recently, an approximate but faster method for the power flow solution emerged. It is an extension of N-R method, known as fast-decoupled method, which is the brain child of Stott and Alsac in 1974 [2] [4]. This method exploits the approximate decoupling of active and reactive flows in well-behaved power networks, and additionally fixes the value of the Jacobian during the iteration in order to avoid costly matrix decompositions.

In recent years, a novel general purpose solution method for power flow equations has erupted. It is an advanced concept derived from holomorphicity, known as holomorphic embedding power flow method (HEPLM) The HEPLM was the brain child of Antonio Trais. He presented this concept in 2007 [10]. This recently developed method was based on advanced techniques of complex analysis. It directs and guarantees the calculation of the correct (operative) branch, out of the multiple solutions present in the power flow equations.

IV. POWER FLOW OF BUSES

The solution to the power flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. Each bus in power system can be classified as shown in the chart below.

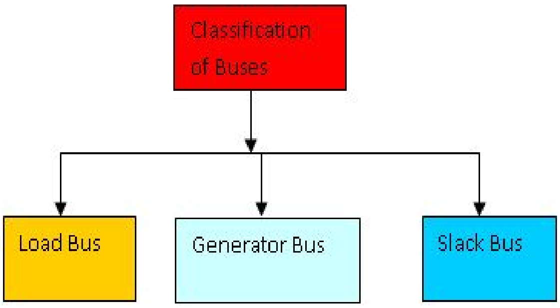

Figure1.0. Classification of buses

Load Buses (PQ bus): Is a bus at which the real and reactive power are specified, while the bus voltage and phase angle will be calculated. The real and reactive powers supplied to a power system are defined to be positive, while the powers consumed from the system are defined to be negative. In the power system, buses without generators are load busses, they generated real power P, and reactive power Q are taken as zero. The load drawn by these buses are defined by real power -P and reactive power -Q in which the negative sign accommodates for the power flowing out of the bus. Because of this reason, this bus is sometimes referred to as P-Q bus.

Generator bus (PV bus or Voltage Controlled Bus): This is a bus where generator is connected. At this bus, the real power and voltage magnitude are specified, while the reactive power and phase angle will be calculated. The voltage magnitude is kept constant by adjusting the field current of the synchronous generator. The power in PV bus is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Thereby keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator. The reactive power supplied by the generator depends on the system configuration. Increasing the prime mover's governor set points increases the power that generator supplies to the power system. Therefore, the magnitude of the bus voltage and real power supplied can be controlled and specified.

Slack bus (Swing or reference Bus): This is an arbitrarily-selected bus generator serving as the reference bus for the power system. Its voltage is assumed to be fixed in both magnitude and phase (for instance, $1\angle 0^\circ$ pu). The real and reactive powers are uncontrolled and are unknown, while the voltage magnitude and phase angle are specified. The bus supplies whatever real or reactive power needed to make the power flows in the system to balance. Slack bus sets the angular reference for all the other buses. The angle difference between two voltage sources that dictates the real and reactive power flow between them, so, the particular angle of the slack bus is not important. It also sets the reference against which angles of all the other bus voltages are measured. Hence, the angle of this bus is usually chosen as 0°.

Uniqueness Of Slack Bus

In a power system in which all the load demands are known. If the power generation matches the sum total of the demand exactly, the mismatch between generation and load will persist because of the transmission line I^2R losses. Since the I^2R loss of a line depends on the line current which, in turn, depends on the magnitudes and angles of voltages of the two buses connected to the line, it is rather difficult to estimate the loss without calculating the voltages and angles. It is assumed that the generator connected to this bus will supply the balance of the real power required and the line losses. A generator bus is usually chosen as the slack bus without specifying its real power. Four variable associated with each bus are shown in table 1.

Table.1. Summary of bus classification and variable associated with each bus

BUS TYPE	SPECIFIED VARIABLE	UNKNOWN VARIABLE
Load bus	P, Q	$\|V\|$, δ
Generator bus	P, $\|V\|$	Q, δ
Slack bus	$\|V\|$, δ	P, Q

V. FORMULATION OF POWER FLOW PROBLEM

Power flow equations can be formulated using either the impedance matrix or bus admittance matrix. Due to economic reasons relating to computer time and memory, the nodal admittance matrix Y_{bus} formulation, using nodal voltages as independent variables is usually used. Power flow equations are non-linear, so, cannot be solve analytically. A numerical iterative algorithm is required to solve the power flow equations. A standard procedure is specified as follows:

1. Creation of a bus admittance matrix Y_{bus} for the power system.
2. Making initial estimate of the voltages (both magnitude and phase) at each bus in the system.
3. Substituting the power flow equations and determine the deviations from solution.
4. Update the estimated voltages based on commonly known numerical algorithms like Gauss-Seidel or Newton-Raphson.
5. Repeat the above process until the deviations from solution are minimal.

Given that a 3-ϕ power system has the following components: injected generated power S_{Gi}, demanded power S_{Di}, voltage magnitude V, phase angle δ, in the ith bus. The injected and loaded powers are;

$S_{Di} = P_{Gi} + jQ_{Gi}$

$S_{Di} = P_{Di} + j_{Di}$

Net complex power injected in the bus is:

$S_i = P_i + jQ_i = (P_{Gi} - P_{Di}) + j(Q_{Gi} - Q_{Di})$

The real and reactive power injected into the ith bus:

$Pi = P_{Gi} - P_{Di}$

$Q_i = Q_{Gi} - Q_{Di}, \quad \mathbf{i = 1, 2, 3, \ldots, \ n}$

However, power balance equations can be written for real and reactive power for each bus. The real power balance equation is:

$$0 = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik})$$

Where:

P_i = the net power injected at bus i,

G_{ik} = the real part of the element in the bus admittance matrix Y_{BUS} corresponding to the ith row and kth colum.

B_{ik} = the imaginary part of the element in the Y_{BUS} corresponding to the ith row and kth column.

θ_{ik} = the difference in voltage angle between the ith and kth buses.

The reactive power balance equation is:

$$0 = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})$$

Where:

Q_i = the net reactive power injected at bus i.

$\theta_{ik} = \delta_i - \delta_k$.

The above equations included are the real and reactive power balance equations for each Load Bus and the real power balance equation for each Generator Bus

VI. APPLICATION OF POWER FLOW STUDIES

- Load-flow studies are performed to determine the steady-state operation of an electric power system. It calculates the voltage drop on each feeder, the voltage at each bus, and the power flow in all branch and feeder circuits.
- Determine if system voltages remain within specified limits under various contingency conditions, and whether equipment such as transformers and conductors are overloaded.
- Load-flow studies are often used to identify the need for additional generation, capacitive, or inductive VAR support, or the placement of capacitors and/or reactors to maintain system voltages within specified limits.
- Losses in each branch and total system power losses are also calculated.
- Necessary for planning, economic scheduling, and control of an existing system as well as planning its future expansion

VII. CON LUSION

Power flow study is a veritable tool for analyzing and planning the power systems. It ensures adequate economic scheduling and control of existing power system, as well as ensuring effective and efficient operation of the power system. Therefore, knowledge of power flow study is a sine-qua-non for power system engineers and operators.

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