DC Load Flow Studies of DC link for Power System Planning

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***Abstract*— High Voltage Direct Current (HVDC) technology has characteristics that make it especially attractive for certain transmission applications like bulk power over a long distance with minimum losses. It has inherent beauty to connect the grid who operates at different frequencies called as asynchronous interconnections, also HVDC used in long submarine cable crossings and fast power controllability. Then, the HVDC transmission has proved its potential to be an interesting alternative or complement to the AC transmission. AC transmission line control is more complicated because of the frequency and dependency of power transfer on Power Angle. DC transmission does not have these limitations, which has led to build long High Voltage Direct Current (HVDC) transmission lines. Similar to AC load flow analysis, DC load flow analysis is also important. The load flow equations and the methods of load flow analysis need to be modified while using them in DC load flow analysis.**

***Index Terms*-- HVDC links, Load flow studies, DC link, Optimal power flow.**

I. Introduction

Alternating current (AC) is widely used in industries and residential areas, but for the long transmission line (more than 600 Km) AC transmission is more expensive than direct current (DC). Technically, AC transmission line control is more complicated because of the frequency and dependency of power transfer on angle difference between the voltage phasors at the two ends. DC transmission does not have these limitations, which has led to build long High Voltage Direct Current (HVDC) transmission lines HVDC technology is a high power electronics technology used in electric power systems to transfer bulk power over long distances. The DC transmission requires conversion at two ends, from AC to DC at the sending end and DC to AC at the receiving end. This conversion is done at converter stations. By simple control action, converter can be switched from rectifier to inverter and vice-versa. Thus facilitating power reversal. A brief information about HVDC transmission system, it's different configurations, main components of HVDC system, assumptions used, the modifications that are needed to carry out while using the load flow study for HVDC etc. are included in this report. Power flow studies using Newton-Raphson Method, Gauss Seidal Method are also performed [1].

II. HVDC Transmission System

There are different types of DC links as given in the configuration [1].

A. *Configuration of HVDC [1]*

1. Monopolar HVDC system
2. Bipolar HVDC system
3. Homopolar HVDC system
4. Back-to-back HVDC system
5. Multiterminal HVDC system

B. *Components of HVDC system [1]*

1. Converters: Perform AC/DC and DC/AC conversion. The valve bridges consists of high voltage valves connected in a 6-pulse or 12-pulse arrangements. It consists of thyristor and such power electronics devices generates the harmonics and consume reactive power in the system [2].
2. Transformers: Normally, the converters are connected to the AC system via transformers. The most important function of the transformers is to transform the voltage of the AC system to a level suitable for the converter.
3. Smoothing reactors: These are large reactors having inductance as high as 1.0 H connected in series with each pole of each converter station which serves following purposes: i) Decrease harmonic voltages and currents in the DC line. ii) Prevent current from being discontinuous at light load. iii) Limit the crest current in the rectifier during short-circuit on the DC line.
4. AC Filters: The AC voltage output contains harmonic components, caused by the switching of the Thyristors/IGBTs. The harmonics emitted into the AC system have to be limited to prevent them from causing malfunction of AC system equipment or radio and telecommunication disturbances.
5. Electrodes: Most DC lines are designed to use earth as a neutral conductor for some time. The connection to the earth requires a large-surface-area conductor to minimize current densities and surface voltage gradients. This conductor is referred to as an electrode.
6. AC Circuit Breakers: For clearing faults in the transformer and for taking the DC line out of service, circuit-breakers are used on the AC side.

7. DC Lines: These may be overhead lines or cables.

III. POWER FLOW STUDIES

Power flow analysis aims at determination of system parameters like voltage, current, power factor and power (real and reactive) at various points in the electric system under existing conditions of normal operation. In case of abnormal condition the voltage and frequency deeps and causes cascade blackout of the grid[3]. Hence, this analysis helps in determining the scope of faults and future expansion of the system. 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.

IV. SIGNIFICANCE OF LOAD FLOW STUDY

1. Determination of current, voltage, voltage angle, active power, reactive power etc. at various buses in power system operating under normal steady state or static condition.
2. To plan best operation and control of existing system.
3. To plan future expansion to keep pace with load growth.
4. Help in ascertaining the effect of new load, new generating stations, new lines and new interconnections before they are installed [5].
5. Due to this information system losses are minimized and also check is provided on system stability.
6. Provides the proper pre fault power system analysis to avoid system outage due to the fault also installation of reactive power compensating devices at appropriate place[4].

V. NEWTON-RAPHSON METHOD

Real and Reactive power injections at each bus is given by

$$P_i = |V_i|^2 G_{ii} + \sum_{k=1,k\neq i}^{n} |Y_{ik} V_i V_k| \cos(\theta_{ik} + \delta_k - \delta_i)$$

$$Q_i = -|V_i|^2 B_{ii} - \sum_{k=1,k\neq i}^{n} |Y_{ik} V_i V_k| \sin(\theta_{ik} + \delta_k - \delta_i)$$

And Jacobian Matrix is divided into sub matrices as

$$[J] = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}$$

$$J_{11} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \cdots & \frac{\partial P_2}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_2} & \cdots & \frac{\partial P_n}{\partial \delta_n} \end{bmatrix}$$

$$J_{12} = \begin{bmatrix} |V_2| \frac{\partial P_2}{\partial |V_2|} & \cdots & |V_{1+np}| \frac{\partial P_2}{\partial |1+np|} \\ \vdots & \ddots & \vdots \\ |V_2| \frac{\partial P_n}{\partial |V_2|} & \cdots & |V_{1+np}| \frac{\partial P_n}{\partial |V_{1+np}|} \end{bmatrix}$$

$$J_{21} = \begin{bmatrix} |V_2| \frac{\partial Q_2}{\partial |V_2|} & \cdots & |V_{1+np}| \frac{\partial Q_2}{\partial |1+np|} \\ \vdots & \ddots & \vdots \\ |V_2| \frac{\partial Q_n}{\partial |V_2|} & \cdots & |V_{1+np}| \frac{\partial Q_n}{\partial |V_{1+np}|} \end{bmatrix}$$

$$J_{22} = \begin{bmatrix} \frac{\partial Q_2}{\partial \delta_2} & \cdots & \frac{\partial Q_2}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial \delta_2} & \cdots & \frac{\partial Q_n}{\partial \delta_n} \end{bmatrix}$$

As P_2 *and* Q_2 are independent of δ, J_{11} and J_{22} become zero. Also the reactive component is absent hence J_{21} is also zero. Therefore J only consist of J_{12}.

For DC, the transmission line offers no shunt capacitance or series inductive reactance so the admittance matrix reduces to conductance matrix as line offers only resistive impedance. Moreover, for a DC source or load the reactive power supplied and consumed is zero and also there will be no phase or power angle between the voltages of the buses. Hence Newton Raphson formulation for our DC system reduces to:

$$P_i = \sum |V_i| |V_j| |Y_{ij}|$$

VI. GUASS SEIDAL METHOD

The Gauss-Seidel method is a technique for solving the n equations of the linear system of equations $\mathbf{Ax = b}$ one at a time in sequence, and uses previously computed results as soon as they are available,

$$x_i^{(k)} = \frac{b_i - \sum_{j<i} a_{ij} x_i^{(k)} - \sum_{j>i} a_{ij} x_i^{(k-1)}}{a_{ii}}$$

There are two important characteristics of the Gauss-Seidel method should be noted. Firstly, the computations appear to be serial. Since each component of the new iterate depends upon all previously computed components, the updates cannot be done simultaneously as in the Jacobi method. Secondly, the new iterate $x^{(k)}$ depends upon the order in which the equations are examined. If this ordering is changed, the *components* of the new iterates (and not just their order) will also change.

In terms of matrices, the definition of the Gauss-Seidel method can be expressed as,

$$X^{(k)} = (D - L)^{-1}(UX^{(k-1)} + b)$$

where the matrices D, $-L$, and $-U$ represent the diagonal, strictly lower triangular, and strictly upper triangular parts of A, respectively.

The Gauss-Seidel method is applicable to strictly diagonally dominant, or symmetric positive definite matrices A.

VII. OPTIMIZATION OF POWER FLOW

The optimal Power Flow (OPF) problem is a powerful tool for power system operation and planning. In general, OPF problem is a nonlinear programming (NLP) problem that is used to determine the "optimal" control parameter settings to minimize a desired objective function, subject to certain system constraints. The OPF problem represents a variety of optimization problems include fuel or active power cost optimization, active power loss minimization, maximum transfer capability, MVAR cost minimization, minimum of total emission.

VIII. CHARACTERISTIC FEATURES OF OPF

The main features of an OPF is its ability to include the detailed network configuration and bus-wise demand balance for both active and reactive power. The OPF can include many operating constraints and model other issues also. Specifically limits on reactive power generation in addition to real power generation, power flow limits on the transmission lines and limits on the bus voltages ensure that the system is operated in a secure manner.

IX. OPF APPLICATIONS

1. One of the main feature of the OPF is that it is a flexible analytical tool, which allows the use of different objective functions to solve different problems. The objective functions commonly used for operation and planning studies are as follows
2. Minimize cost of operation
3. Minimize the deviation or minimize control shift
4. Loss minimization
5. Minimize the cost of installation of new capacitors and reactors and/or cost of MVAr supplied
6. Maximum transfer capacity
7. Minimize the emissions, and so on.

X. CONCLUSION

HVDC system is used for certain application where AC transmission line fails to do. Hence the DC load flow analysis of DC link for the power system planning in DC grid is required. DC load flow studies has following things that conclude.

1. The Load flow calculation is simplified due to fact that DC analysis does not involve any vector calculations.
2. In NR method the size of Jacobian Matrix reduces to almost half of Original Matrix because As P_2 *and* Q_2 are independent of δ, J_{11} and J_{22} become zero. Also the reactive component is absent hence J_{21} is also zero. Therefore J only consist of J_{12}. Therefore space as well as time complexity of the NR method decreases many folds.
3. In practice of DC load flow techniques are sometimes applied to AC system to perform contingency analysis but the results may not very accurate.

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