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Importance of Load Flow Analysis in Voltage Stability Studies

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Abstract

Power or electricity is one of the most critical components of infrastructure affecting economic growth and well-being of nations. India is one of the world's major producers and consumer of electricity. Of our entire infrastructure, the electrical power grid is the most fragile. On 30th and 31st July, 2012, twenty one Indian states plunged into darkness as the northern, north-eastern and eastern grids collapsed15. The problem is that the Indian Electrical Grid was designed for a 50 years life span. For the "Make in India" policy to be successful, a stable power network is very essential. And to achieve that, situations like grid collapse, voltage collapse etc., have to be eliminated. Voltage collapses usually occur on power systems which are heavily loaded or faulted or have shortage of reactive power. Power flow analysis is one of the necessary tools used worldwide to study the voltage profile of a transmission network. This paper aims to study the various power flow methods used to obtain the line flows and enhancement of voltage profile using FACTS devices.

Keywords: FACTS, Power Flow, Voltage Collapse, Voltage Stability

1. Introduction

Power systems across the world today are subjected to heavy demands owing to widespread expansions in the networks. Rapid development of a nation in every sphere is interlinked with its power transmission capability. Therefore it is essential for a developing nation like India to increase its transmission capacity. This can be done by adding new lines and by upgrading existing ones by adding new devices like FACTS. A stable power transmission network ensures prosperity of a nation like India. Voltage instability in any network may lead to system collapse, when the bus voltage drops to such a level from which it cannot recover. In such a situation, complete system blackouts may take place. Hence voltage stability analysis is very important for successful operation and planning of the power system and for reduction of system losses.

In this context, Load Flow Analysis has been found by researchers to be useful in Voltage Stability Studies and Contingency Analysis.

2. Voltage Stability

Voltage stability is the ability of a power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance[1].

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Voltage instability results in voltage collapse. Voltage collapse is the process by which the voltage falls to a low, unacceptable value as a result of an avalanche of events accompanying voltage instability[2].

Voltage collapse typically occurs in power systems which are usually heavily loaded, faulted and/or has reactive power shortages[3].

In recent years voltage instability has attracted the attention of power system planning and operating engineers as well as researchers. This is due to the frequent voltage collapse incidents occurring in different parts of the world. Therefore Voltage Stability Analysis is important for researchers and power system planners to prevent such incidents from occurring.

3. Methods for Voltage Stability Analysis[2,4]

The different methods used are:

- P-V curve method.
- V-Q curve method and reactive power reserve.
- Methods based on singularity of power flow Jacobian matrix at the point of voltage collapse.
- Continuation power flow method.
- Optimization Method

4. Load Flow Analysis

To begin the Voltage Stability Analysis of a power system, computation of the complex voltages at all the buses is essential. After this, power flows from a bus and the power flowing in all the transmission lines are to be calculated. A computational tool for this purpose is Load Flow Analysis. This analysis helps compute the steady state voltage magnitudes at all the buses, for a particular load condition.

Load flow is mainly used in planning studies, for designing a new network or expansion of an existing one. The next step would be to compare the calculated values of powerflows and voltage with the steady state device limits, to estimate the health of the network

4.1 Objectives of Load Flow Study

- Power flow analysis is very important in planning and designing the future expansion of power systems or addition to existing ones like adding new generator sites, meeting increase load demand and locating new transmission sites.
- The load flow solution yields the nodal voltages and the phase angles, the power injection, power flows and the line losses in a network.
- The best location, as well as the optimal capacity of a generating station, substation and new lines can be determined by load flow study.
- Minimization of System transmission losses and prevention of line overloads. The operating voltages of the buses being determined, it aids in voltage stability analysis and voltage levels at certain buses can be kept within the closed tolerances.

The power flow problem is formulated assuming the power system network to be linear, bilateral and balanced. However, the power and voltage constraints impose non-linearity in the power flow formulation and iterative techniques are essential for the solution. The different conventional techniques for solving the power flow problem are:

- Gauss-Seidel (GS) Method
- Newton Raphson (NR) Method
- Fast Decoupled Load Flow (FDLF)

In this paper, a 5- bus power system network is considered to perform the load flow using Gauss-Seidel (GS) and Newton-Raphson (NR) method. This 5 bus power system has three generators at buses 1, 2 and 3. Bus 4 and 5 are load buses.

A matlab program is used to perform the load flow on the 5- bus system. The results have been used to compare the performance of these methods with respect to Voltage stability analysis. When GS method is performed, the number of iterations for convergence is 22, which has been represented by the graph in Figure 1.

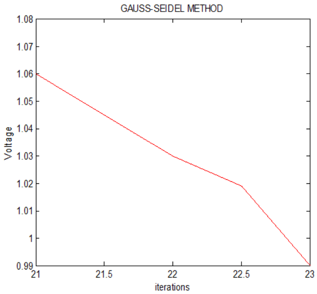

Figure 1. Graph showing the no. of iterations Vs Voltage (pu) for Gauss Seidel Method.

Figure 2 presents the graph which is obtained as a result of NR method and load flow is converged at 4 iterations.

Table 1 presents the comparison between the three methods of load flow analysis. From this comparison NR method is found to be suitable for load flow analysis of power system networks.

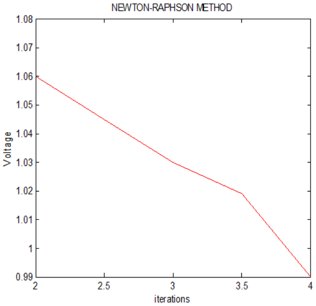

Figure 2. Graph showing the no. of iterations Vs Voltage (pu) for Newton Raphson Method.

GS method requires more computation time with the increase of system size. Though it is slow in

Table 1. Comparison of Load Flow Methods

Load Flow Technique	*No. of Iterations Reqd.*	*Remarks*
Gauss Seidel Method	23	Convergence slow Easily programmed no. of iterations increases directly with the no. of buses in the system
Newton Raphson Method	04	Convergence faster No. of iterations independent of the size of the system Solution to a high accuracy obtained Not sensitive to the choice of slack bus
Fast Decoupled	--	Although superior in terms of speed and storage, this method is ignored for voltage stability studies as the the Jacobian used here is voltage independent; unlike Newton Raphson Jacobian, which is voltage dependent[8]

convergence it requires low computer memory.

NR method has a good quadratic convergence rate. Computation time of NR method increases linearly with system size. For a better rapid converged solution NR method can be used.

5. Voltage Stability and Line Compensation

One of the prime causes leading to voltage instability is reactive power imbalance in the power system network. This occurs when there is a sudden and unpredicted increase or decrease in reactive power demand in the system. Occurrence of voltage collapse can only be prevented by either reducing the reactive power load or by providing additional supply of reactive power before the system reaches the point of voltage collapse. During situations of outage in some critical lines, the generators are capable of supplying limited reactive power. But in the process, the real powers of the generators are compromised while supplying this reactive power.

In long transmission lines, the line length and the degree of shunt compensation are the most important factors affecting the power frequency voltages under normal and fault conditions[5].

An open ended or unloaded line experiences a rise in the receiving end voltage relative to a sinusoidal input voltage, known as Ferranti effect[5].

On the other hand, an overloaded line experiences a sequential reduction in voltage leading to voltage collapse at the weakest bus. To stabilize the line voltage, reactive power (VAR) compensation is required, which is control of reactive power to enhance power system network performance. The two important features of reactive power compensation are:

(i) Load Compensation and (ii) Voltage Support.

The aim of voltage support is to reduce the voltage variations at a given terminal of a transmission line. Line inductance compensation is done by means of series capacitors and the line capacitance to earth by shunt reactors. Optimal placement of series capacitors are at different places along the line, whereas that of the shunt reactors is in the stations at the end of the line. In this way, the voltage drop/rise between the ends of the line can be reduced both in amplitude and phase angle.

An example is considered here for line compensation. A 300 Km long line energized with 400 kV sending end voltage is terminated in an open circuit. In this unloaded situation, without any compensating devices, the receiving end voltage will rise appreciably. This rise is controlled with the help of a shunt reactor at the receiving end of the line. The voltage profile of a 400 kV, 300 Km unloaded line for uncompensated and compensated condition is shown in Figure 3, with and without the use of compensating devices. For the uncompensated line, there is an increase in voltage with line length. Compensation is then provided in the form of shunt reactors at the receiving end. With line compensation, the voltage profile improves considerably. If the same line is heavily loaded, the voltage will exhibit a tendency to collapse at a critical point. In that case static VAR control, shunt capacitor and synchronous condensers are used to improve voltage profile, power transfer and stability of the system.

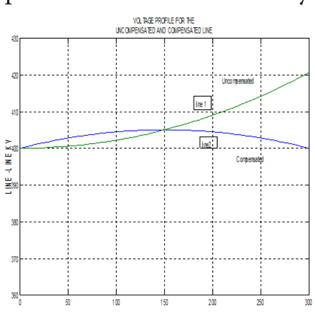

Figure 3. Voltage profile of a 300 Km unloaded line.

(Line 1: uncompensated, Line 2: compensated)

Traditional utilities have used fixed compensators, in the form of fixed capacitors and inductors for reactive power compensation. But the nature of modern loads makes such compensation less relevant. Therefore, a fast acting, efficient and variable source of reactive power compensation is required.

6. FACTS

Flexible AC Transmission Systems (FACTS) devices are being used for improving overall performance of the power system network. FACTs devices help improve voltage profile, provides flexibility to system operation and manipulate power flows, without compromising the reliability and security of the system.

FACTS devices have been Classified as:[15]

- Series Controller : TCSC, SSSC
- Shunt Controller : SVC, STATCOM
- Series-Series Controller : IPFC
- Shunt-Series Controller : UPFC, TCPST etc.[15]

A comparative study can be made in order to use them effectively for the purpose of Voltage Stability Analysis, keeping in mind their characteristics and limitations.

6.1 Comparison of FACTS Devices as Compensators[7,9,11,13,14]

- Parallel FACTS devices provide higher voltage stability margin than series FACTS devices.
- At light load, voltage profile of the weakest bus using SVC and STATCOM is the same.
- As load is increased, STATCOM provides better compensation than SVC. The SVC operates like a fixed capacitor, when maximum limit is reached.
- UPFC provides better compensation for lower value of capacitance, but better results are achieved by using STATCOM for higher capacitance.
- STATCOM has the ability to provide lagging or leading VAR into the system, depending on the voltage profile and the loading conditions. STATCOM remains in floating condition if the output of the converter is the same as the line voltage

7. Conclusion

This paper summarizes the comparison between the load flow methods using a 5- bus system.

From the comparison results, it has been found that for a large system NR method is the most popular and suitable for power flow analysis. For Voltage stability analysis NR method gives the quadratic convergent characteristics and Jacobians can be used for voltage sensitivity analysis.

This paper also highlights some of the necessary points of FACTS devices.

Apart from using conventional compensating devices, FACTS devices can be used for line compensation and voltage stability analysis for a power system network.

Improving the voltage profile of an existing power system network may also help to build a better environment for industrialization and per capita consumption of electrical energy of our nation.

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