# Major causes of voltage instability

# I. INTRODUCTION

Power system stability is defined as the characteristics of a power system to remain in a state of Equilibrium at normal operating conditions and to restore an acceptable state of equilibrium after a disturbance. The power systems are heavily stressed due to the increased loading and this leads to voltage stability problem. Voltage Stability can also be called as the “ load stability”. A power system lacks the capability to transfer an infinite amount of electrical power to the load. The main factor causing voltage instability is inability of the power system to meet the demands for reactive power in the heavily stressed systems to keep desired voltages. Voltage instability in the system generally occurs in the form of a progressive decay in voltage magnitude at some of the buses. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other elements by their protective system leading to cascading outages. FACTS devices have been used, both for steady state power flow control and dynamic stability control. Using controllable components, such as controllable series capacitors and phase shifters, line flows can be changed in such a way that thermal limits are not violated and losses are minimized. These also increases stability margin, help in fulfilling contractual requirement, without violating system operating limits.

# II. VOLTAGE STABILITYANALYSIS

## Continuation Power Flow

Continuation power flow was introduced to solve this singularity problem. The continuation power flow can be described as a power flow solution that can maintain the stability of the power system under normal and disturbances conditions. Therefore the main purpose of Continuation Power Flow is to find the continuity of power flow solution for a given load change.

It employs the predictor-corrector scheme with an addition of load parameter Î» and the technique used is local parameterization.

## Figure 1 Predictor and Corrector illustration in CPF

As shown in Fig. 1, it starts from a known solution and uses a tangent predictor to estimate a subsequent solution corresponding to a different value of the load parameter. This estimate is then corrected using the same NR technique employed by a conventional power flow. The local parametization provides a means of identifying each point along the solution path and plays an integral part in avoiding singularity in the Jacobian.

First let Î» represent the load parameter such that

0 â‰¤ Î» â‰¤ Î» critical

Where Î»= 0 corresponds to base load and Î»= Î» critical corresponds to critical load. We incorporate Î» into conventional Newton Raphson load flow equations. Load change in PLi and QLi terms are modified by breaking each term into two components- one corresponds to original load and other represents load change brought about by a change in load parameter Î». Thus

**PLi= PLi0 + Î»(kLi SÎ” base cos Î¨i) (1)**

**QLi= QLi0 + Î»(kLi SÎ” base sinÎ¨i) (2)**

Where the following definitions are made;

PLio, QLio – original load at bus i, active and reactive respectively.

kLi – multiplier to designate the rate of load change at bus i as Î» changes

Î¨i – power factor angle of load change at bus i

SÎ” base- a given quantity of apparent power which is chosen to provide appropriate scaling of Î» In addition, the active power generation is modified as:

**PGi = PGio (1+Î» kGi ) (3)**

Where PGio is the active generation at bus i in the base case and kGi is a constant used to specify the rate of generation as Î» varies. Now the Jacobian gets modified with the addition of a new element dÎ». The tangent vector is calculated and the predicted solution is determined. With the local parametrization technique corrected solution is obtained.

B. Contingency Ranking

1) Static Loading Margin

Contingencies such as unexpected line outages often contribute to voltage collapse blackouts. These contingencies generally reduce or even eliminate the voltage stability margin. To maintain security against voltage collapse, it is desirable to estimate the effect of contingencies on the voltage stability margin. Action can then be taken to increase the margin so that likely contingencies do not cause blackout.

Contingency can be defined as to a condition which involves removal of line, disconnection of generator or transformer. This creates a condition which disturbs the normal state of the system and may lead to voltage instability. A number of methods have been proposed for static voltage stability based contingency ranking. However there exists a need of efficient method requiring minimum computational time to accurately rank the contingencies based on static voltage stability

# Figure 2 Static loading margin

The system contingencies have been ranked based on post contingency VAR requirement using two methods-Static Loading Margin (SLM) and Reactive Compensation Index (RCI). True ranking of the various contingencies have been obtained considering post-contingency static loading margin. The foremost step is to perform continuation power flow by using PSAT software. The static loading margin is the distance between the base case operating point and the nose point. A contingency having smaller value of the static loading margin can be considered more severe.

2) Reactive Compensation Index

Reactive compensation index is used to perform voltage stability based contingency ranking by measuring severity of the outages. It is based on the premise that the distance between the normal case (pre contingency) nose point (max loadability point) and the post-contingency case nose point can be approximated by the total reactive injection required at the load buses to maintain similar voltages. The ranking obtained by reactive compensation index is compared with the true ranking.

III. FACTS DEVICES

The flexible AC transmission systems controllers have been established as an effective means in improving the system stability including voltage stability, enhancing loadability and also providing voltage control.

TCSC

Figure 1 shows the simple diagram of TCSC comprised of a series capacitor bank, shunted by a Thyristor Controlled Reactor (TCR), to provide a smoothly variable series capacitive reactance. It is a one-port circuit in series with transmission line; it uses natural commutation; its switching frequency is low; it contains insignificant energy storage and has no DC port. Insertion of a capacitive reactance in series with the line's inherent inductive reactance lowers the total, effective impedance of the line and thus virtually reduces its length. As a result, both angular and voltage stability gets improved. However, the sub synchronous series resonant frequency is produced that introduces negative damping of generator models leading to unstable system. That is the reason for not placing TCSC between lines having generators at both the ends.

**Figure4 Equivalent circuit of TCSC**

SSSC

Static Synchronous Series Compensator (SSSC) is a voltage sourced converter based series FACTS device that provides capacitive or inductive compensation independent of line current. The SSSC is a synchronous voltage type compensator which is analogous to an ideal electromagnetic generator that produces a set of alternating voltages at the desired fundamental frequency with controllable amplitude and phase angle. The operating principle is based on conventional series capacitive compensation which is used as a means of reducing the line impedance, which in turn increases voltage, current and transmitted power across given physical line. The SSSC offers fast control and it is inherently neutral to sub-synchronous resonance.

**Figure 5 Equivalent circuit of SSSC**

## IV. SENSITIVITY ANALYSIS

For optimal placement of series FACTS devices, linear sensitivity of loading factor (Î») with respect to line reactance has been computed using MATLAB coding technique. The calculation of the index is done such that transformers and lines connected between generators at both ends are excluded. The line having the most negative value of the Æ📈Î»/Æ📈Xij sensitivity factor for the critical contingency cases has been identified for optimal series FACTS devices placement.

Sensitivities are calculated under severe outage conditions at a stressed point near to maximum loadability point i. e. the values of voltage, angle and power factor are taken at the critical point as obtained from Continuation Power Flow results. The optimal location of TCSC placement has been considered in a line producing maximum in each line A criterion for the optimal placement of TCSC, in this work, has been that it should not be placed in aq line connecting two generator buses.

## V. DYNAMIC ANALYSIS

Dynamic voltage stability is analyzed by monitoring the Eigen values of the linearized system as a power system is progressively loaded. When the Î» parameter varies, the equilibrium points of the dynamic system also vary accordingly, and so do the Eigen values of the corresponding state matrix ASYS. The equilibrium points are asymptotically stable if all the Eigen values have negative real parts. The point where a complex conjugate pair of Eigen values reaches the imaginary axis with respect to changes in Î» is known as Hopf Bifurcation point.

Power system oscillations are associated with a pair of complex Eigen values of equlibria crossing the imaginary axis of the complex plane, from the left half plane to the right half plane, when the system undergoes sudden changes. If this particular dynamic problem is studied using gradual changes it can be viewed as Hopf bifurcation problem. Thus by predicting these types of bifurcations well in advance, a possible dynamic instability problem may be avoided.

**Figure 6 Hopf Bifurcation point**

VI. RESULT AND DISCUSSIONS

To implement the optimal placement two case studies were taken of IEEE 14 bus system and 39 bus New England system. The software packages used in the system analysis are MATLAB, and PSAT (power system analysis toolbox)

A. STATIC ANALYSIS:

Continuation power flow for intact system was performed and SLM was found to

State of the system

Divergence point

Weakest Bus

Intact

2. 88

5

With TCSC

3. 10

4

With SSSC

3. 20

4

## Table 2 Comparison of loadability of the 14 bus system

Line outages

SLM

True Ranking

RCI

Ranking

1-2

*

1

0. 308

1

2-3

0. 5593

2

0. 2798

2

1-5

0. 5596

4

0. 1292

3

5-6

0. 65508

3

0. 1271

4

7-9

0. 7066

5

0. 0815

5

## Table 1 Contingency based ranking for SLM and RCI for 14 bus system

## Fig7 PSAT simulink model of IEEE14 bus Test system

For the placement of series FACTS devices sensitivity index for various cases is calculated and it is inferred that line 1-5 is the optimum location as the index is having most negative value for it. Newton Raphson load flow was performed on the 14 bus system and the values of P load were incremented in steps of 0. 2 percentage of loading with NR load flow being performed again on the modified system. The NR diverged at 2. 88 times of loading and system suffered voltage collapse. The weakest bus observed to be is the 5m bus followed by 4m bus. With TCSC placement, the NR diverges at 3. 1times loading while it does the same for 3. 2 when SSSC is incorporated. Thus proving that compensation provided by series FACTS devices enhances the capacity of the system to bear stress in the form of increased load. The improvement in the voltage profile for the 5th bus is better with SSSC as compared to TCSC.

B. DYNAMIC ANALYSIS:

The test case considered for the dynamic analysis is IEEE 14 bus system. The approach to study the stability is Hopfield Bifurcation as already mentioned.

For the analysis of dynamic stability, dynamic model of 14 bus system was made which includes synchronous generators and AVR connected at the PV buses apart from the other static components. After obtaining the Hopf bifurcation of the system for the weakest bus the optimal location of the FACTS devices is determined and they are placed accordingly to provide stability to the system.

The power flow is performed for the intact system and the Eigen values are found to be negative with PL = 0. 076 p. u. at bus 5. When the PL is increased to 2. 419 times of the initial load, two Eigen values cross the imaginary axis leading to Hopf bifurcation and instability. To render stable conditions, TCSC is optimally placed in line 1-5 based on the sensitivity index already calculated and it is found that the load can be increased till 5. 58 times of the actual load before reaching the Hopf bifurcation point. The comparison of the stable and unstable system due to increased loading effect is depicted by the Figures 9 and 10.

The placement of SSSC is not possible as it produced negative compensation in the system which can be related to the presence 3 synchronous condensers in the IEEE 14 bus system. This is inferred from the fact that

SSSC, also acting as a VAR generator at times, adds to the reactive power generated from the other dynamic components present in the system.

## VII. CONCLUSION:

Static voltage instability in the system may occur due to deficit of reactive power. The reactive power requirement of the system may increase under severe contingencies. Therefore, contingency ranking based on Static voltage stability criterion, can be obtained based on the extra reactive support requirement from existing sources.

Dynamic voltage instability, on the other hand has been attributed to Hopf bifurcation when one pair of Eigen values of the system’s state matrix reaches imaginary axis, following change in the system parameters such as load.

FACTS devices prove to be an effective remedy in enhancing system voltage stability. But due to high cost of FACTS controllers their placement should be such as to improve both static and dynamic voltage stability. The comparison between the placement of TCSC and SSSC has been shown for both the static and dynamic analysis. SSSC is found to be best suited for the static stability enhancement whereas the dynamic stability improvement incorporates only TCSC.