ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

Optimal Location of STATCOMS using FVSI

Avinash. R[1], Savyasachi. G. K[2],Gowtham. N[3],Rakshith. P[4]

Assistant Professor,VidyaVardhaka College of Engineering,Mysuru,India[1,2,3,4]

Abstract: The rapid development of the high-power electronics industry has made Flexible AC Transmission System (FACTS) devices viable and attractive for utility applications. FACTS devices have been shown to be effective in controlling power flow and damping power system oscillations.

In recent years, new types of FACTS devices have been investigated that may be used to increase power system operation flexibility and controllability, to enhance system stability and to achieve better utilization of existing power systems.

The Static Synchronous Compensator (STATCOM) is one of the most important FACTS devices and it is based on the principle that a voltage-source inverter generates a controllable AC voltage source behind a transformer-leakage reactance so that the voltage difference across the reactance produces active and reactive power exchange between the STATCOM and the transmission network.

This paper proposes a case study to improve the voltage profile of power system by incorporating STATCOM. In this study we are considering a standard 5-bus network and IEEE 30-bus network for the analysis. We are mainly focusing on finding out the best location for inserting STATCOMS in the system, so that the optimal power flow is obtained which in turn increases the stability of the system.

Power flow equations are solved using Newton Raphson's algorithm and the simulation studies are implemented in MATLAB. Also FVSI method of line stability indication is also used for weakest bus prediction. The results of the network with and without STATCOM are compared in terms of voltages and the line losses in the transmission lines to analyze the performance of STATCOM.

Keywords: Statcom, Fvsi, Voltage Stability Indices, Optimal Power Flow.

I. OVERVIEW

The electricity supply industry is undergoing a profound transformation worldwide. Market forces, scarcer natural resources, and an ever increasing demand for electricity are some of the drivers responsible for such an unprecedented change.

Against this background of rapid evolution, the expansion programs of many utilities are being thwarted by a variety of well-founded, environmental, land-use, and regulatory pressures that prevent the licensing and building of new transmission lines and electricity generating plants.

An in-depth analysis of the options available for maximizing existing transmission assets, with high levels of reliability and stability, has pointed in the direction of power electronics. There is general agreement that novel power electronics equipment and techniques are potential substitutes for conventional solutions, which are normally based on electromechanical technologies that have slow response times and high maintenance costs

An electrical power system can be seen as the interconnection of generating sources and customer loads through a network of transmission lines, transformers, and ancillary equipment. Its structure has many variations that are the result of a legacy of economic, political, engineering, and environmental decisions.

Based on their structure, power systems can be broadly classified into meshed and longitudinal systems.

II. FACTS

In its most general expression, the FACTS concept is based on the substantial incorporation of power electronic devices and methods into the high-voltage side of the network, to make it electronically controllable. Many of the ideas upon which the foundation of FACTS rests evolved over a period of many decades. Nevertheless, FACTS, an integrated philosophy, is a novel concept that was brought to fruition during the 1980s at the Electric Power Research Institute (EPRI), the utility arm of North American utilities.

FACTS looks at ways of capitalizing on the many breakthroughs taking place in the area of high-voltage and high current power electronics, aiming at increasing the control of power flows in the high voltage side of the network during both steady-state and transient conditions.

The new reality of making the power network electronically controllable has started to alter the way power plant equipment is designed and built as well as the thinking and procedures that go into the planning and operation of transmission and distribution networks. These developments may also affect the way energy transactions are conducted, as high-speed control of the path of the energy flow is now feasible.

Some of the tools that have received research attention and, to a greater or lesser extent, have reached a high degree of modeling sophistication are:

1. Positive sequence power flow
2. Three-phase power flow
3. Optimal power flow
4. State estimation
5. Transient stability
6. Dynamic stability

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

7. Electromagnetic transients
8. Power quality

FACTS CONTROLLERS

Power flow control has traditionally relied on generator control, voltage regulation by means of tap-changing and phase-shifting transformers, and reactive power plant compensation switching. Phase-shifting transformers have been used for the purpose of regulating active power in alternating current (AC) transmission networks. In practice, some of them are permanently operated with fixed angles, but in most cases their variable tapping facilities are actually made use of.

A number of FACTS controllers have been commissioned. Most of them perform a useful role during both steady-state and transient operation, but some are specifically designed to operate only under transient conditions, FACTS controllers intended for steady-state operation are as follows

1. **Thyristor-controlled phase shifter (PS)**
2. **Thyristor-controlled reactor (TCR)**
3. **Thyristor-controlled series capacitor (TCSC)**
4. **Interphase power controller (IPC)**
5. **Static compensator (STATCOM)**
6. **Solid-state series controller (SSSC)**
7. **Unified power flow controller (UPFC)**
8. **Static var compensator (SVC)**
9. **High-voltage direct-current (HVDC) link**

III. VOLTAGE STABILITY INDICES

Voltage stability indices are invaluable tools for gauging the proximity of a given operating point to voltage instability. Fast voltage stability indices can be successfully applied to online dynamic voltage stability assessment. The objective of the voltage stability indices is to quantify how close a particular point is to the steady state voltage stability margin.

The following can be considered the main contributing factors to the problem:

1. Stressed power system; i.e. high active power loading in the system.
2. Inadequate reactive power resources.
3. Load characteristics at low voltage magnitudes and their difference from those traditionally used in stability studies.
4. Transformers tap changer responding to decreasing voltage magnitudes at the load buses.
5. Unexpected and or unwanted relay operation may occur during conditions with decreased voltage magnitudes.

Voltage stability is concerned with the ability of a power system to maintain acceptable voltage level at all nodes in the system under normal and contingent conditions. A power system is said to have a situation of voltage instability when a disturbance causes a progressive and uncontrollable decrease in voltage level. The voltage instability progress is usually caused by a disturbance or change in operating conditions, which create increased demand for reactive power and. This increase in electric power demand makes the power system work close to their limit conditions such as high line current, low voltage level and relatively high power angle differences which indicate the system is operating under heavy loading conditions. Such a situation may cause losing system stability, islanding or voltage collapse.

METHODS OF VOLTAGE STABILITY ANALYSIS

Many algorithms have been proposed in the literature for voltage stability analysis. Most of the utilities have a tendency to depend regularly on conventional load flows for such analysis. Some of the proposed methods are concerned with voltage instability analysis under small perturbations in system load parameters. The analysis of voltage stability, for planning and operation of a power system, involves the examination of two main aspects:

1. How close the system is to voltage instability (i.e. Proximity).
2. When voltage instability occurs, the key contributing factors such as the weak buses, area involved in collapse and generators and lines participating in the collapse are of interest (i.e. Mechanism of voltage collapse).

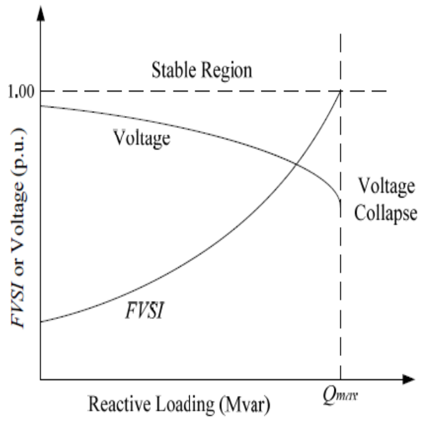
The different methods available for voltage stability analysis are

- **Q-V curve method**
- **P-V curve method**
- **Modal or eigenvalues analysis method**
- **FVSI method**

FAST VOLTAGE STABILITY INDEX METHOD

The line stability index FVSI proposed by I.Musirin is based on a concept of power flow through a single line.

Consider a typical transmission line shown below,



Where
V1, V2 =Voltage on sending and receiving buses.
P1, Q1 = active and reactive power on the sending bus P2, Q2 = active and reactive power on the receiving bus
S1, S2 = apparent power on the sending and receiving Buses

Then the stability index is calculated by

$$\mathbf{FVSI_{IJ} = \frac{4Z^2Q_J}{V_I^2X}}$$

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

Where Z is the line impedance,
X is the line reactance,
Q_j is the reactive power flow at the receiving end and
V_i is the sending end voltage.

The line that gives index value closest to 1 will be the most critical line of the bus and may lead to the whole system instability. The calculated FVSI can also be used to determine the weakest bus on the system. The determination of the weakest bus is based on the maximum load allowed on a load bus. The most vulnerable bus in the system corresponds to the bus with the smallest maximum permissible load.

IV. STATCOM

STATCOM is a very popular FACTS controller application effective in transmission system voltage control. Since 1980, when the first STATCOM (rated at 20 Mvar) using force-commutated thyristor inverters was put into operation in Japan, Many examples have been installed and the ratings have been increased considerably

STATCOMs are used in applications which require

A. Dynamic voltage control

B. Increased power transmission capability

C. Optimizing power quality over existing transmission and distribution circuits

STATCOM has very high dynamic response, and the ability for active filtering of harmonics. This enables a maximizing of system availability and power transfer capability over existing as well as new lines. It further more enables the feeding of high speed railways as well as heavy industry such as steel works without violating power quality requirements, without any need to reinforce the grid just to meet power quality demands and without causing nuisance to others in the grid. The STATCOM is usually placed in existing substations and is put into service within two years, i.e. a very efficient return on investment.

Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability.

STATCOM TOPOLOGY

In most practical applications it employs the DC to AC converter, which can also be called a Voltage Source Inverter (VSI) in 3-phase configuration as the primary block.

The basic theory of VSI is to produce a set of controllable 3-phase output voltages/ currents at the fundamental frequency of the AC bus voltage from a DC input voltage source such as a charged capacitor or a DC energy supply device. By varying the magnitude and phase angle of the output voltage and current, the system can exchange active/reactive power between the DC and AC buses, and regulate the AC bus voltage.

In STATCOM, **Voltage Source Converter (VSC)** and **Insulated Gate Bipolar Transistor (IGBT)** technologies have been brought together to offer good options for increased performance.

The STATCOM consists of one VSC and its associated shunt-connected transformer. It is the static counterpart of the rotating synchronous condenser but it generates or absorbs reactive power at a faster rate because no moving parts are involved. In principle, it performs the same voltage regulation function as the SVC but in a more robust manner because, unlike the SVC, its operation is not impaired by the presence of low voltages.

In steady-state fundamental frequency studies the STATCOM may be represented in the same way as a synchronous condenser, which in most cases is the model of a synchronous generator with zero active power generation. A more flexible model may be realized by representing the STATCOM as a variable voltage source E_{vR}, for which the magnitude and phase angle may be adjusted, using a suitable iterative algorithm, to satisfy a specified voltage magnitude at the point of connection with the AC network.

BASIC CONFIGURATION OF STATCOM

A STATCOM provides voltage regulation and dynamic reactive power reserve by using a VSC to synthesize a voltage waveform of variable magnitude with respect to the system voltage. The STATCOM branch offers both reactive power absorption and production capability whereas an SVC requires separate branches for each. The STATCOM, especially when controlled with PWM, allows faster response and thereby improves power quality. This is very useful to mitigate flicker from disturbances caused by electric arc furnaces at steel mills.

POWER FLOW MODEL

The power flow equations for the STATCOM are derived below from first principles and assuming the following voltage source representation:

$$E_{vR} = V_{vR}(\cos\delta_{vR} + \mathrm{j}\sin\delta_{vR}).$$

Based on the shunt connection shown in Figure, the following may be written:

$$S_{vR} = V_{vR}I_{vR}^* = V_{vR}Y_{vR}^*\left(V_{vR}^* - V_k^*\right).$$

After performing some complex operations, the following active and reactive power equations are obtained for the converter and bus k, respectively

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR} V_k \left[G_{vR}\cos(\delta_{vR} - \theta_k) + B_{vR}\sin(\delta_{vR} - \theta_k)\right],$$

$$Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR} V_k \left[G_{vR}\sin(\delta_{vR} - \theta_k) - B_{vR}\cos(\delta_{vR} - \theta_k)\right],$$

$$P_k = V_k^2 G_{vR} + V_k V_{vR}\left[G_{vR}\cos(\theta_k - \delta_{vR}) + B_{vR}\sin(\theta_k - \delta_{vR})\right],$$

$$Q_k = -V_k^2 B_{vR} + V_k V_{vR}\left[G_{vR}\sin(\theta_k - \delta_{vR}) - B_{vR}\cos(\theta_k - \delta_{vR})\right].$$

Using these power equations, the linearized STATCOM model is given below, where the voltage magnitude VvR and phase angle δvR are taken to be the state variables:

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k} V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k} V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}} V_{vR} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \frac{\Delta V_k}{V_k} \\ \Delta \delta_{vR} \\ \frac{\Delta V_{vR}}{V_{vR}} \end{bmatrix}$$

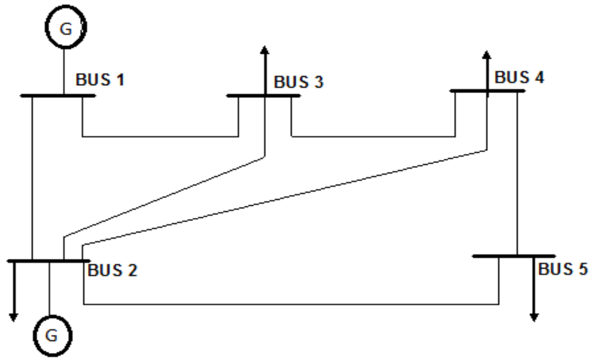
PROPOSED METHODOLOGY:-

The following steps are implemented to find the optimal location of STATCOM.

- Run the load flow program using Newton-Raphson method for the base case.
- Evaluate the FVSI value for each and every line in the system using the equation below.
- Gradually increase the reactive power loading at a chosen load bus until the load flow solution fails to give results. Calculate FVSI values for every load variation.
- Extract the line index that has the highest value; this line is called as the most critical line with respect to a bus.
- Choose another load bus and repeat steps 1 to 4.
- Extract the maximum reactive power loading for the maximum computable FVSI for every test bus. It can be obtained from step 4. The maximum reactive power loading is referred to as the maximum loadability of a particular bus.
- Sort the maximum loadability obtained from step 6 in ascending order. The bus having the smallest maximum loadability is ranked the highest implying the weakest bus in the system.
- Install STATCOM at the weakest bus and run load flow to determine the voltage profile and losses in the system.
- Improvement in voltage profile and reduction in line losses are observed.

V. CASE STUDY

The figure shows the single line diagram of a 5-Bus test system which was considered for the analysis. Here Bus-1 is the slack bus and Bus-2 is the generator bus and the rest are the load buses. The load flow analysis was performed for the base case and the results required for calculating FVSI values were obtained and these values were used to calculate the FVSI values of all the 7 lines in the 5-Bus system and based on FVSI values the weakest bus was selected to be 5 as it has the FVSI value nearer to 1.



RESULTS FOR 5-BUS TEST SYSTEM WITH AND WITHOUT STATCOM

FVSI VALUES

FROM BUS	TO BUS	WITHOUT STATCOM	WITH STATCOM AT BUS-3	WITH STATCOM AT BUS-4	WITH STATCOM AT BUS-5
1	**3**	0.4382	0.0095	0.4503	0.4503
2	**3**	0.3693	**0.0080**	0.3794	0.3794
2	**4**	0.3153	0.3225	**0.0080**	0.3225
2	**5**	0.3119	0.3244	0.3244	**0.0053**
3	**4**	0.0537	0.0537	**0.0013**	0.0546
4	**5**	0.6412	0.6562	0.6489	**0.0109**

BUS VOLTAGES

BUS NO	WITHOUT STATCOM		AFTER INSERTING STATCOM AT					
			BUS 3		BUS 4		BUS 5	
	VM	VA	VM	VA	VM	VA	VM	VA
1	1.0600	0	1.0600	0	1.0600	0	1.0600	0
2	1.0000	-1.9765	1.0000	-2.0533	1.0000	-2.0553	1.0000	-2.0633
3	0.9895	-4.5281	1.0000	-4.8379	0.9996	-4.8288	0.9926	-4.7132
4	0.9864	-4.8350	0.9944	-5.1073	1.0000	-5.2107	0.9911	-5.0576
5	0.9745	-5.5847	0.9752	-5.7975	0.9771	-5.8269	1.0000	-6.2147

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

RESULTS FOR IEEE 30-BUS SYSTEM WITH AND WITHOUT STATCOM

FVSI VALUES

LINE NO.	FROM BUS	TO BUS	(WITHOUT)	(WITH)
L1	1	3	0.0476	0.0169
L2	2	4	0.0829	0.0548
L3	3	4	0.0185	0.0125
L4	2	6	0.0493	0.0000
L5	4	6	0.0116	0.0000
L6	5	7	0.1324	0.1330
L7	6	7	0.0880	0.0893
L8	6	9	0.0223	0.0000
L9	6	10	0.1521	0.1330
L10	9	10	0.0682	0.0597
L11	4	12	0.1008	0.1327
L12	12	14	0.0781	0.0764
L13	12	15	0.0543	0.0532
L14	12	16	0.0370	0.0363
L15	14	15	0.1522	0.1490
L16	16	17	0.0952	0.0954
L17	15	18	0.0355	0.0356
L18	18	19	0.0646	0.0659
L19	19	20	0.0080	0.0079
L20	10	20	0.0229	0.0229
L21	10	17	0.0411	0.0411
L22	10	21	0.0739	0.0749
L23	10	22	0.0007	0.0000
L24	21	23	0.0042	0.0043
L25	15	23	0.0350	0.0356
L26	22	24	0.1093	0.1120
L27	23	24	0.1455	0.1495
L28	24	25	0.0007	0.0000
L29	25	26	0.0924	0.0943
L30	25	27	0.0103	0.0000
L31	28	27	0.0147	0.0000
L32	27	29	0.0541	0.0543
L33	**27**	**30**	**0.3211**	**0.0308**
L34	**29**	**30**	**0.2509**	**0.0234**
L35	8	28	0.0064	0.0000

BUS VOLTAGES

SL.NO.	VM (without)	VM (with)
1	1.0600	1.0600
2	1.0430	1.0430
3	1.0379	1.0277
4	1.0291	1.0199
5	1.0100	1.0100
6	1.0183	1.0134
7	1.0059	1.0028
8	1.0100	1.0100
9	1.0313	1.0263
10	1.0100	1.0052
11	1.0820	1.0820
12	1.0345	1.0279
13	1.0710	1.0710
14	1.0171	1.0109
15	1.0109	1.0052
16	1.0168	1.0110
17	1.0066	1.0015
18	0.9983	0.9926
19	0.9939	0.9884
20	0.9972	0.9918
21	0.9953	0.9910
22	0.9982	0.9958
23	0.9953	0.9912
24	0.9822	0.9828
25	0.9763	0.9888
26	0.9587	0.9706
27	**0.9812**	**1.0016**
28	**0.9948**	**1.0002**
29	0.9619	0.9957
30	**0.9507**	**1.0000**

VI. CONCLUSION

This paper illustrates in detail application of STATCOM for optimal power flow. STATCOM system can be used for reactive power compensation in the industrial network grid and under distorted mains voltage conditions,

We have examined the performance of STATCOMs in electric power systems cases say 5-BUS test system and IEEE standard 30-bus system. Based on the analytical and simulation studies, the impact of STATCOMs on the studied power system is presented.

In this study we considered a standard 5-bus test network and IEEE 30-bus network for the analysis.

We found that the best location for inserting STATCOMS in

- **5-bus system was at bus-5 IEEE 30-bus was**
- **Bus no 30 for good results, Bus no's 30 and 26 for best results**

So that the optimal power flow is obtained this in turn increases the stability of the system. Hence voltage instability problem is solved.

The proposed methodology can handle voltage security and congestion management problems via a new generation of FACTS devices. STATCOM can improve the voltage security margin as well as it can maintain reactive power flow within the limits. Simulation results through a IEEE 30-bus validates the effectiveness of the STATCOMs performance when placed at optimal locations. Single STATCOM is installed in the system to improve voltage profile.

REFERENCES

1. Venkataramana Ajjarapu, Colin Christy, 1992. "*The continuation power flow a tool for steady state voltage stability analysis*", IEEE Transactions on Power Systems, Vol.7, No. 1. February.
2. R. Natesan G. Radman, 2004. "*Effects of STATCOM, SSSC and UPFC on voltage stability*", IEEE proceedings.
3. Arthit Sode-Yome and Nadarajah Mithulananthan (2005) '*Static Voltage Stability Margin Enhancement using STATCOM, TCSC AND SSSC*', IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China.