# Static Synchronous Compensator (STATCOM) for the improvement of the Electrical System performance with Non Linear load

MADHYAMA V. WANKHEDE Department Of Electrical Engineering G. H. Raisoni College of Engineering, Nagpur 440016, India madhyamawankhede@gmail.com

V. K. CHANDRAKAR Department Of Electrical Engineering G. H. Raisoni College of Engineering, Nagpur 440016, India

*Abstract:* - This paper investigates performance of Static Synchronous Compensator for the transient stability improvement of the two area multi machine electrical power system with nonlinear load. The improvement of transient stability of a two-area multi-machine power system, by using STATCOM (Static Synchronous Compensator) which is a superior Flexible AC Transmission System (FACTS) tool capable of controlling the active and reactive power flowing in a transmission line by controlling appropriate parameters. Simulations are accompanied in Matlab/Simulink environment for the two-area multi-machine power system model with and without STATCOM to analyze the effects of STATCOM on transient stability performance of the system under the different conditions with and without nonlinear load. The simulation results demonstrate the effectiveness and hardiness of the proposed STATCOM on transient stability improvement of the system for the nonlinear load.

*Keywords*— FACTS, STATCOM, Nonlinear load, arc type, Matlab/Simulink, Two-area Two machine power system and PSS.

### **1** Introduction

A load is considered as a non-linear type of load if its impedance varies with the supplied voltage. The variable impedance means that the nature of the current which is drawn by the Non linear load will not be sinusoidal even when it is given a sinusoidal voltage. The nature of the none sinusoidal currents contains harmonic currents that interacts with the impedance of the power distribution system and create voltage distortion that can affect the distribution system equipment as well as the loads connected to it. Previously, non-linear loads were mainly found in heavy Industrial applications such as Electric Arc Furnaces, heavy rectifiers for Electrolytic refining, large Variable Frequency Drives (VFD) etc. Nowadays a very popular type of load which is used in the industry is EAF i.e., electric arc furnace type of load which is highly nonlinear in nature. Conversion of Electrical Energy into Mechanical Energy is done by Electric Arc Furnaces (EAF). Electric Arc Furnaces (EAF) are widely used in the iron and steel industry for melting the metal. Presently, 40% of the steel production is given by EAF and it is expected that this proportion will rise up to fifty percent in 2050. In the industry's most of the electrical energy is utilized by EAF, and therefore efficiently use of electrical energy in EAF systems is very important problems at present. EAF causes many power quality problems as they are time varying and nonlinear type of loads. The power quality issues caused by EAF are imbalances, inter harmonics, odd and even harmonics, voltage drops and flicker in the electrical power systems. Disturbances in the waveform are the main factors in the power quality which is getting worse and these disturbances are generated by stochastic behavior of electric arc furnace [2]. The Electricity developers and the customers are trying to reduce as much as the negative effects which are caused by EAF [1].

The power quality issues can be solved by many techniques, in this paper we are using Static Synchronous Compensator that is STATCOM for mitigation of the voltage flickering and reduction of the total harmonic distortion. The voltage control at the required bus can be done by the first generation FACTS device Static VAR Compensator (SVC) which results in the improvement of the voltage profile of power system. The main function of SVC is used to maintain the voltage at a particular bus with the help of reactive power compensation (acquired by changing the firing angle of the thyristors) [4]. Compared with classical shunt compensation, SVCs have been used for voltage control of high performance steady state and transient condition. By optimized reactive power control SVCs are also applied for damping power swings, improve transient stability and reduce system losses [3]. The next generation of flexible ac transmission system (FACTS) devices is Static Synchronous Compensator (STATCOM). The STATCOM is used in the electrical power system such for different purposes as line loss minimization, reactive power compensation, power oscillation damping etc. The Static Synchronous Compensator is a combination of voltage source converter in parallel with the capacitor which acts as a DC energy source link tied to the transmission Almost Sinusoidal current of varying line. magnitude at the PCC (point of connection) is injected by the STATCOM. This injected current is almost in  $90^{\circ}$  phase with the line voltage, which helps in emulating an inductive or a capacitive reactance at the point of common coupling with the transmission line. Although the functions of STATCOM and SVC are same, but STATCOM has more advantages as compared to SVC which are,

- Responds faster.
- Space required is less as bulky passive components (such as reactors) are eliminated.
- It is inherently relocatable and modular.
- It can be interfaced with real power sources such as fuel cell, battery or Superconducting magnetic energy storage (SMES).
- As the reactive current can be maintained constant STATCOM has high quality performance during the low voltage condition. In SVC, the capacitive reactive current drops in linear manner with the voltage at the limit.
- Under transient conditions, it is even possible to increase the reactive current in a STATCOM if the devices are rated for transient overload whereas in SVC, the maximum reactive current is determined by rating of the passive components reactors and capacitors.[4]

As the STATCOM is more advantageous as compared to SVC, therefore it is preferred over SVC. If STATCOM is designed well, then it serves as an advantageous Investment for the power companies. Therefore it can bring Productive Gains for the company as well as customers.

# 2 Static Synchronous Compensator (STATCOM)

Fig. 1 shows the configuration of STATCOM, which consists of a solid state synchronous voltage source converter (VSC), a coupling transformer and a dc capacitor. The solid state synchronous voltage source converter (VSC) generates a balanced bunch of 3 sinusoidal voltages at the fundamental frequency with rapidly controllable amplitude and phase angle.



Fig.1 Static Synchronous Compensator (STATCOM)

## 3. Multi Machine Power System Model

The system model considered for analysis is a two area multi machine system which is shown in the fig 3. And the system data is shown in the Table 1.



Fig. 3 Single line diagram

| DEVICE              | PATING                   |
|---------------------|--------------------------|
| DEVICE              | KATINO                   |
| Generator1          | 1000MVA                  |
| Generator2          | 5000MVA                  |
| Transformer 1       | 1000MVA, 13.8/500KV      |
| Transformer 2       | 5000MVA, 13.8/500KV      |
| Transformer 3       | 1000MVA, 500KV/ 100KV    |
| Transmission Line 1 | 350km                    |
| Transmission Line 2 | 350km                    |
| Three Phase Load    | 5000MW                   |
| Non Linear Load     | 100MW (0.7 power factor) |

#### Table1. Data sheet for the system model

The system model consists of 3 phase hydraulic generation plant at the two ends along with the 3 phase transformers which are connected by transmission lines of 500km. The hydraulic generation plant at the one end is of 1000 MVA capacity whereas the other hydraulic generation plant is of 5000 MVA capacity. The system model consists of two step up transformers which step ups the voltage from 13.8KV to 500 KV. There are three buses which are connected with the help of transmission lines of 350 km long. At the third bus, three phase load is connected which is of 5000 MW capacity. The non-linear type of load is connected at the bus 3 with the help of a three phase transformer. The nonlinear type of load is of 100MW capacity. The performance of the system under the different load conditions along with the different types of faults such as ground fault, three phase fault etc., is observed.

#### 4. Non Linear Load:-

A load is considered as Non-Linear if the load impedance changes with the applied voltage. The changing impedance can be defined as the current given by the Non-Linear load will not be sinusoidal even when it is connected to a sinusoidal voltage. These Non-Sinusoidal currents consists of harmonic currents that interacts with the impedance of the electrical power distribution system and create voltage distortion that can affect both the distribution system equipment as well as the loads which are connected to it. Previously, Non-Linear loads were primarily found in heavy Industrial applications such as electric arc furnaces, large variable frequency drives (VFD), heavy rectifiers for electrolytic refining, etc [1].

In this paper a very popular load which is EAF that is Electric Arc Furnace load which is highly Non-linear in nature is presented along with its equivalent circuit and Simulink model.

# **4.1** Equivalent Circuit of the Electricity System Supplying to Electric Arc Furnace



Fig. 4 Equivalent Circuit of EAF

The the equivalent circuit of EAF is shown in the figure above. In the primary circuit a step down transformer is used which will reduce the value of the voltage and then that voltage level is regulated for that regulator is used. The secandary circuit EAF transformer is used which will lower the value of the voltage as per the voltage required by the EAF load. For production of huge amount of heat the elctrodes are connected. The MATLAB/simulink model for the EAF is shown below.

The MATLAB simulink model of arc type of load is shown in the fig below



#### Fig 5. MATLAB/ Simulink Model

The arc type of characteristics can be obtained with the help of MATLAB simulink model which is shown in the figure. The above MATLAB simulink model gives the nature of characteristics shown in the figure which gives the characteristics of the arc type of load. The x axis represents voltage axis, whereas y axis represents current axis. As shown in the figure non linearity of the load varies in both the polarities



Fig6. V-I characteristics



Fig 7. Arc currents and arc voltages

The nature of the arc current and arc voltage is shown in the fig. From the fig we can see that for the very minimum span of time the arc current and arc voltage varies rapidly. This nature of the arc type of characteristics can cause many problems such as voltage drop different power quality issues, etc. Therefore these type of non linearities should be reduced in order to minimize the bad effects which may be occurred in the power system due to these non linearity. We can reduce these type of non linearity by using Static Synchronous Compensator.

### 5. Simulation Results

The simulation is done in the MATLAB Simulink software and observations are done under the different conditions. The behavior of the system under the different condition are observed which are explained below.

# 5.1 Case 1:- Under the normal condition, without STATCOM & without Nonlinear load

As shown in the figure Vb1, Vb2 & Vb3 are the bus voltages in PU at the buses 1, 2 & 3 respectively. The second curve is of line power in MW. ô is the rotor angle in degrees.  $\infty 1$  &  $\infty 2$  are the rotor speeds in PU. Vt1 and Vt2 are the terminal voltages in PU.

As shown in the figure, as there is no non linear load present in the system the bus voltages and the line power are at the required value which are giving the stable results. Similarly the rotor angle and the terminal voltages are also giving the stable results as there is normal condition.



Fig 8. Simulation Results when under the normal condition, without STATCOM & without nonlinear load

# 5.2 Case 2:- Without STATCOM and With Non linear load

The second case we have taken is when there is no STATCOM but nonlinear load is connected into the system. As soon as nonlinear load is connected the disturbances can be seen in the simulation results. The arc type of load is highly nonlinear and because of that the bus voltages are affected, and the system parameters are fully disturbed which are shown in the figure. Now next task is to reduce these disturbances caused by the nonlinear load which is done in the next case.



Fig 9. Simulation Results when without STATCOM and With Nonlinear load

# 5.3 Case 3:- With STATCOM and Nonlinear load

In the third case there is a nonlinear load and the STATCOM is now connected into the system. The results are shown in the simulation results where the disturbances which are caused by the nonlinear are reduced to some extent the bus voltages are coming to the 1 PU. Similarly, the other system parameters are also getting balanced after few seconds. Therefore the effect of STATCOM can be seen in the simulation results which are balanced results.



Fig.10 Simulation Results when without STATCOM and With Nonlinear load

### 6. Conclusion

This Paper deals with the applications of Static Synchronous Compensator for the performance improvement of the Electrical Power System for the nonlinear load. The detailed model of STATCOM was implemented and tested in MATLAB/Simulink environment. The verification of the STATCOM under the steady state condition is tested in the MATLAB/Simulink environment. The system behavior is observed under the various conditions with STATCOM and without STATCOM along with the nonlinear load. The behavior of the system parameters are then observed. The system parameters are the bus voltages in per unit, line power in MW, rotor angle in degree, rotor speeds in per unit and terminal voltages in per unit. The system model is applicable for voltage stability analysis. The effects of STATCOM installed in power transmission path are analyzed in this paper and the conclusion as follows:

Under the normal condition the system behavior is balanced but when the nonlinear load is connected in the system the disturbances are observed. As the parameters are fully disturbed, therefore the disturbances gets reduced when the STATCOM is connected into the system. Therefore the power quality issues which are caused by the nonlinear load is resolved with the help of STATCOM.

#### References:

- Mustafa Şeker, Arif Memmedov, "Investigation of Voltage Quality in Electric Arc Furnace with Matlab/Simulink ", International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-2, Issue-11, November 2014, pp 274-284
- [2] Rafael Collantes-Bellido, Tomas Gomez, "Identification and modelling of a Three Phase Arc Furnace for Voltage Disturbance Simulation.", *IEEE Transactions on Power Delivery, Vol. 12, No. 4, October 1997*, pp 1812-1817
- [3] Prity Bisen and Amit Shrivastava, "Comparison between SVC and STATCOM FACTS Devices for Power System Stability Enhancement", *International Journal on Emerging Technologies*, pp 101-109

- [4] K. R. Padiyar, "FACTS CONTROLLERS IN POWER TRANSMISSION AND DISTRIBUTION", NEW AGE INTERNATIONAL PUBLISHERS, pp 173-177
- [5] Prabha Kundur, "Power System Stability And Control", *TATA McGRAW-HILL EDITION*, pp 335
- [6] V. K. Chandrakar, A.G. Kothari, "Fuzzy-based Static Synchronous Compensator (STATCOM) for improving transient stability performance", *Int. J. Energy Technology and Policy*, Vol. 5, No. 6, 2007, pp 692-707
- [7] B. Singh, R. Saha, A. Chandra, K. Al-Haddad, "Static synchronous compensators (STATCOM): a review", *The Institution of Engineering and Technology* 2009, pp 297-324
- [8] Gary W. Chang, Fellow, Min-Fu Shih, Yi-YingChen, and Yi-Jie Liang," A Hybrid Wavelet Transform and Neural-Network-Based Approach for Modelling Dynamic Voltage-Current Characteristics of Electric Arc Furnace", IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 29, NO. 2, APRIL 2014, pp 815-824