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STATCOM: Theoretical Aspects & Experimental Study

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Abstract

Flexible AC Transmission System (FACTS) is the name given to the application of power electronics devices to control the power flow & other quantities in the power system. In general, there are four types of the FACTS controllers i.e. series, shunt, combined series-shunt & combined series-series controllers. They are also categorized on the basis of converter technology like Voltage Source Converter & Current Source Converter. The Experimental model described in this paper is dependent on Voltage Source Converter based FACTS controller. The experimental model consist of Voltage Source Converter based FACTS devices. There are four general types of the VSC based FACTS devices viz. STATCOM, SSSC, UPFC, & IPFC. VSC based FACTS devices provides an efficient solution to the problem of, deteriorating power quality & AC to DC bidirectional power transformation requirement in the power system. The main objective of this paper is to study the STATCOM theoretically.

Operation of STATCOM

A schematic representation of the one-phase STATCOM is shown in fig(1) . It is composed of a voltage source converter (VSC), and it's associated with shunt connected transformer. The transformer is used as a link between the VSC and the system. The basic of the STATCOM operation is that the amplitude and phase angle of the voltage drop , can be controlled, by defining the amount and direction of active and reactive power flows through the reactance Under normal operation conditions, a small amount of active power must flows into the VSC to compensate for the power losses that exist in its interior. Basically the STATCOM is the VSC connected in the shunt with the transmission line with the help of shunt transformer.

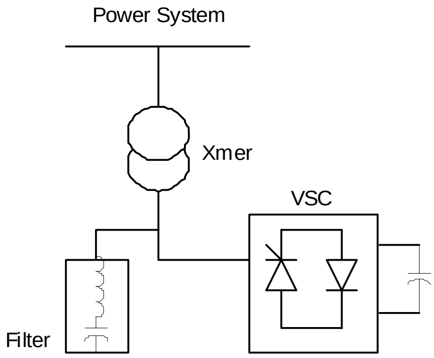

Figure 1: schematic representation of single phase STATCOM.

Operation of VSC

Fig shows three phase VSC, it consist of three phase leg which are 120° apart from each other. Consider the first leg, in which the T_1 & T_4 are 180° apart .when T_1 is on T_4 is off. & vice- versa. The diode D1 & D2 enables the conduction of current in reverse direction. The voltage waveform across first leg is as shown in fig below

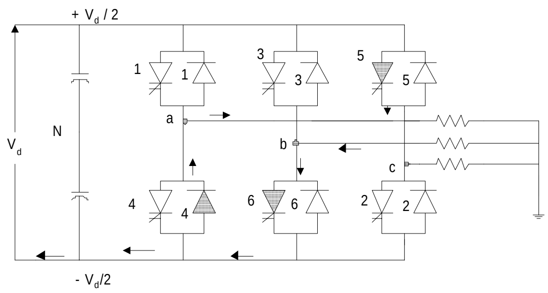

Figure 2: Voltage Source Converter.

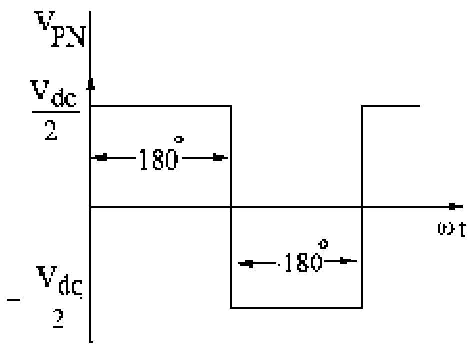

Figure 3: voltage waveform across first leg.

At the instant when T_1 is on, the current (Ir) inductive current is flowing through the circuit (which is negative), after the 90° the current through the T1 becomes zero. It rises above zero & becomes positive. The diode D1 takes over the conduction. Similarly it occurs when T4 is turns on & off. When the current (Ir) is capacitive, the current Ir is positive at the instant of turning on T1 & flows through diode D1. after 90° the current reverses & its sign. & flows through T1.

At the time when T1 is switched off, the current through it is at peak value. Thus we need the self commuted devices such as IGBT . the diode D1 & D4 turns off automatically when the parallel device (T1 & T4) turns off . also the capacitors can also charge from the source through diodes.

Advantages of STATCOM over SVC

1. The response is much faster to changing system conditions.
2. It does not contribute to short circuit current.
3. It has a symmetric lead-lag capability.
4. It has no moving parts and hence the maintenance is easier.
5. It has no problems of loss of synchronism under a major disturbance.

Following factors make VSC-based transmission attractive

1. Independent control of reactive and active power.
2. Reactive control independent of other terminal(s).
3. Simpler interface with ac system.
4. Compact filters.
5. Provides continuous ac voltage regulation.
6. No minimum power restriction.
7. Operation in extremely weak systems.
8. No commutation failures.
9. No restriction on multiple in feeds.
10. No polarity reversal needed to reverse power.

Control Aspect of STATCOM

Basically there are two types of controller[3],[4]:

1. Type II Controller
2. Type I controller

These controllers of STATCOM are based on the d-q controlled strategies.

Type II Controller

In Type II controller [3] only the phase angle of injected voltage (α) is controlled. The active current (I_p) is in phase with the source voltage & the reactive current (I_r) lags the source voltage by an angle 90°. The reactive current (Ir) is which is drawn by by STATCOM is controlled by adjusting the firing angle α. The detailed three-phase model of a STATCOM is developed by modeling the converter operation by switching functions [3], [4]. The modeling of two- and three-level VSC is discussed in detail in [3]. The system equation for three phase STATCOM is describe as [5],

$$e_a \cong V_{dc}\frac{2}{\pi}\sin(w_0 t + \theta + \alpha) \quad (1)$$

$$e_a \cong V_{dc}\frac{2}{\pi}\sin(w_0 t + \theta + \alpha - \frac{2\pi}{3}) \quad (2)$$

$$e_a \cong V_{dc}\frac{2}{\pi}\sin(w_0 t + \theta + \alpha - \frac{4\pi}{3}) \quad (3)$$

We can also derive the equation in D-Q variables such as[5],

$$L\frac{di_p}{dt} + Ri_p + w_0 Li_r = V_s - kV_{dc}cos\alpha \quad (4)$$

$$L\frac{di_r}{dt} + Ri_r + w_0 Li_p = kV_{dc}sin\alpha \quad (5)$$

$$C\frac{dV_{dc}}{dt} + GV_{dc} = k(i_p cos\alpha + i_r sin\alpha) \quad (6)$$

Where k is modulation index, which is given as

$$k = 2\sqrt{6}/\pi$$

α is the angle by which the fundamental component of converter output voltage leads the STATCOM bus voltage Vs. from the above analysis[5] we obtain the reactive current control transfer function as,

$$\frac{\Delta I_r(s)}{\Delta\alpha(s)} = \frac{K[(s+\sigma_z)^2 + {w_{nz}}^2]}{(s+p_1)[(s+\sigma_p)^2 + {w_{np}}^2)]} \quad (7)$$

From the analysis it is conclude that as the value of Δα is changing there is change in the value of Δα. The reactive current control can be achieved by varying α alone.

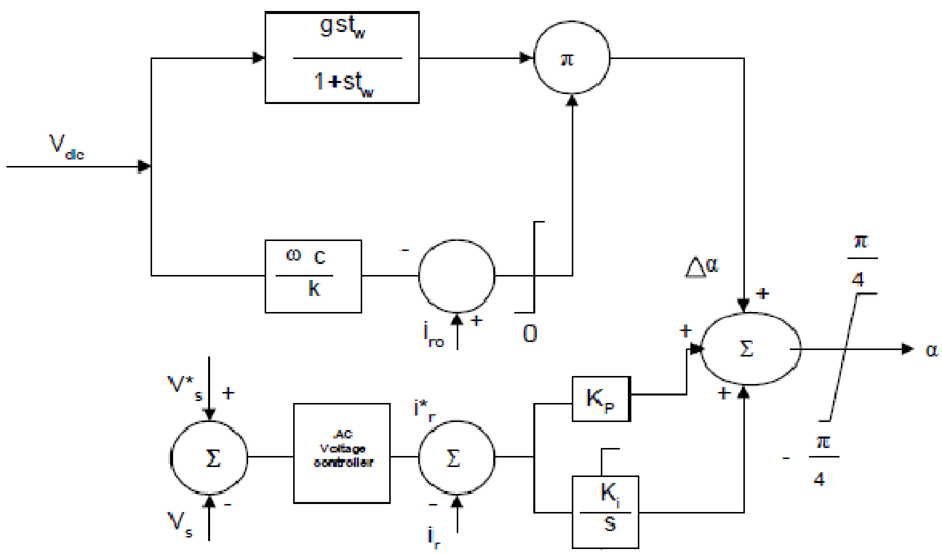

Figure 4: Type II Controller.

From above & [3], [4]. It is to be noted that the above condition will be satisfied When iro < 0 (when the converter is in Capacitive mode) & When iro > 0 the problem of instability arises. This type of situation is comes only When converter is operating in inductive mode. This problem of instability during inductive mode can be Overcome by using the nonlinear feedback controller. The block diagram is as shown below. This nonlinear controller is activated only when

$$i_{r0} < \frac{wC}{K} V_{dc0} \tag{8}$$

& only during transient condition. In steady state (when Vdc is constant), the output of multiplier (Δα) is zero.

Phase Lock Loop: This provides the basic synchronization signal which is phase angle of line voltage θ. the line. Voltage is compared with the reference voltage & voltage regulator provides the required reactive Current of STATCOM. The STATCOM reactive current Iq is compared with the Iqref & PI controllers provide the required phase displacement Δα.

Type I Controller

In type I controller the two quantities are varied, first one is the firing angle α & k it is the factor [4] , which is used to control the magnitude of AC voltage which is injected by converter through modulation. In this type of converter [3],[4] both the α & k varied for control purposes. The below fig shows the block diagram of type I controller[4].

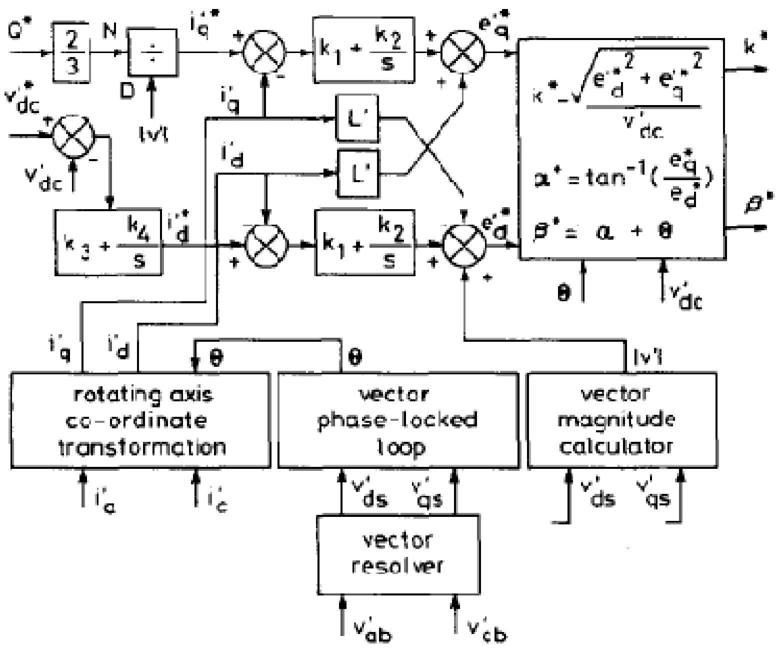

Figure 5: Block diagram of Type I controller.

The values of k & α are calculated as,

$$k^* = \frac{\sqrt{e_d^{*2} + e_q^{*2}}}{V_{dc}'} \tag{9}$$

$$\alpha^* = \tan^{-1}\left(\frac{e_d^*}{e_q^*}\right) \tag{10}$$

$$\beta^* = \alpha + \theta \tag{11}$$

the detailed modeling & analysis of Type I controller is explained in [3] & [4].

Experimental Panel

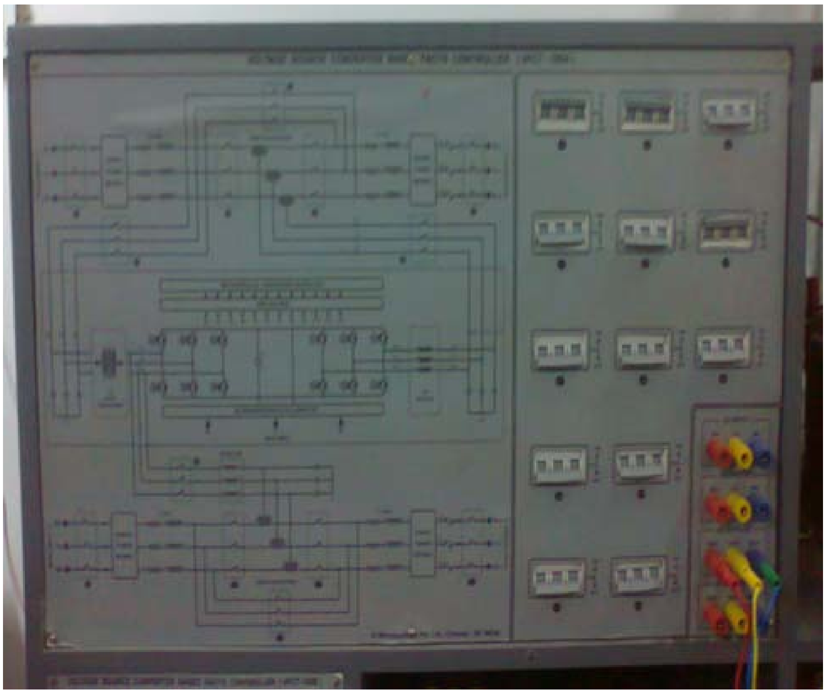

Figure 4: Block Diagram of Experimental Panel.

Specification of Experimental panel

This set up is designed to study the following power system component in three phase transmission line. STATCOM , SSSC, UPFC & IPFC .This set up consist of the following component to test/simulate the above power system.

1. Transmission line simulator module
2. Voltage source Converter
3. Transformer with LC filter
4. Digital meters & loads Setup.

1. **Transmission Line Simulator Module**: - Suitable L&C provided for simulating three phase transmission line
   Input voltage: - 3ph, 115
   Power: - 1 A per phase.

2. **Voltage Source Converter:** -It Consist of two no's ofIGBT based Three phase Inverter for STATCOM, SSSC, application.

It consists of the Following:
   IGBT based power module - 2 no,
   TMS20F2407 based DSP
   Controller – 1 no

3. **Transformer with LC Filter: -** a) 1 KVA transformer act as shunt transformer with capacitor filter provided for STATCOM applications. b) 1 KVA transformer act as series transformer with capacitor filter provided for SSSC applications.

Digital meters & Load setup

a. Digital meters provided to indicate sending end, receiving end parameters feed back to DSP controllers
b. Sending end/ Receiving end Parameters such as Voltage, Current, Power factor, Active power, Reactive Power.
c. Three-phase RLC load provided.

Working of the Experimental Panel

As mentioned above, the Experimental panel of VSC based FACTS devices will be used. This panel consists of various elements such as Voltage Source Converter, Transmission line set up, 3ph Shunt Transformer, 3ph series Transformer, Switches, inductor, Capacitor etc. The above scheme represents the panel diagram of the Experimental Model. Voltage Source Converter based devices provide an Efficient solution to the problem of deteriorating power quality & AC to Dc bidirectional power transformation requirement in the system. Improvement in power quality obtained by employing suitable controller to the VSC, like STATCOM, SSSC, UPFC, & IPFC. By using the appropriate switches on the Model, we can easily make the use of these VSC based FACTS devices. By connecting the VSC in shunt with the transmission line, it work as a STATCOM & in series it act as SSSC. By making the use of appropriate, switches we can use this devices according to the requirement.

Experimental Results

Sample Readings from the Panel without & with STATCOM

Sr.No.	Vs (V)	Vr (V)	Is (A)	θ°	Vdc
1	**115**	**105**	**0.7**	**0°**	**0**
2	115	105	0.7	2°LD	105
3	115	104	0.8	10°LD	90
4	115	101	0.9	14°LD	45
5	115	98	1.2	20°LD	15
6	115	109	0.9	28°LG	165
7	115	112	1.2	33°LG	195
8	115	114	1.6	40°LG	240
9	115	114	1.7	42°LG	255
10	115	115	2.2	50°LG	300

PWM Converter

In general the PWM converter is not used in the power system, But in this experimental panel PWM converter is used. In two level or three level converter turn on and turn off is possible only one's in a cycle, but in case of PWM it happens no. of times in one cycle. It leads to higher switching losses in the system. That's why it is used for the low power application only.

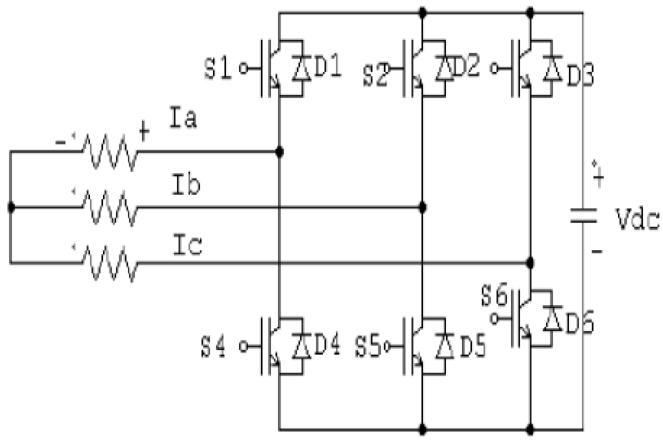

Figure 4: Configuration of 6-pulse VSC.

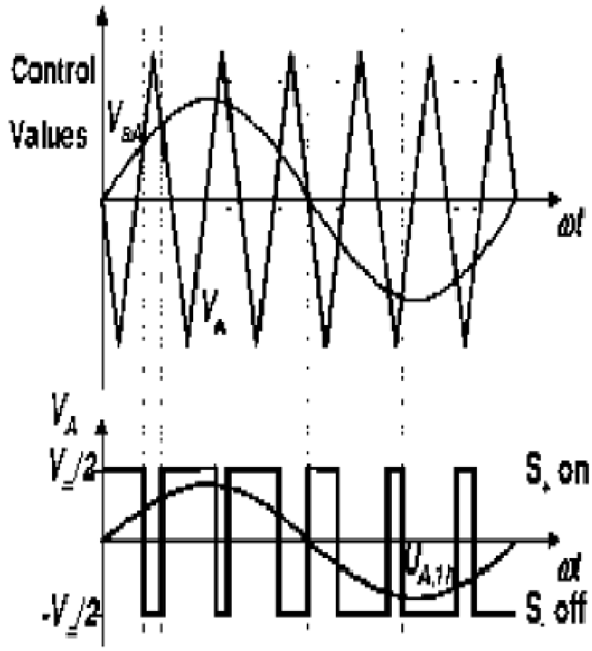

Figure 5: pulse width modulation.

Conclusion

Hence the STATCOM were studied theoretically & Control Aspects were studied. Experiments was carried out. The System used is Open loop system. The PWM is used for above Panel. The effect of STATCOM controllers in enhancing power system performance has been examined.The Experimental Panel of VSC based FACTS Devices Consisting of Transmission module, voltage source converter and transformer with LC filter has been studied. And the Operation of STATCOM has been studied. Pulses are given as per the PWM technique. The voltage and the phase angle of the line at the connection point is improved by using STATCOM.

References

[1] Hingorani N.G. and Gyugyi L., Understanding FACTS: Concepts and Technology of flexible AC Transmission Systems, Institute of Electrical and Electronic Engineer, New York 2000.
[2] Padiyar K.R., Power System Dynamics: Stability and Control, John Wiley & Sons, 1995.
[3] K. R. Padiyar, "FACTS Controllers In Power Transmission and Distribution", New Age International, 2009.
[4] C. Schauder and H. Mehta, \Vector analysis and control of advanced static VAR compensators",IEE Proc.- C, v. 140, n.4, July 1993, pp.299-306

[5] K. R. Padiyar and N. Prabhu, "Analysis of sub synchronous resonance with three level twelve -pulse VSC based SSSC," in Proc. IEEE TENCON-2003, Oct. 14–17, 2003.

[6] A. H. Norouzi, and A. M. Sharaf, "Two Control Scheme to Enhance the Dynamic Performance of the STATCOM and SSSC," IEEE Transaction on power Delivery, Vol-20, No.1, Jan 2005.

[7] Sen, K. K., "STATCOM-Static Synchronous Compensator: Theory Modelling, and Applications," 99WM706, Proceedings of IEEE/PES Winter Meeting, New York, 1999.

[8] Amir H. Norouzi, " Flexible AC Transmission Systems: Theory , Control and Simulation of the STATCOM and SSSC", MSc Thesis, University of New Brunswick, March 2003.