48 Pulse STATCOM for Improving Voltage Profile and Harmonic Reduction based on PI Controller

Tusharkumar S Jadav[1] Dharmesh M. Gehlot[2] Mayank M. Tandel[3] Prof. Mitesh J. Sathvara[4]
[1, 2, 3] Student

Abstract---STATCOM can provide effective and fast reactive power support to maintain power system voltage stability. In this paper gives a 48 pulse statcom with detailed analysis.48 pulse statcom consist of four 3 level converter inked by four zig- zag transformer which exhibits a low harmonic rate on AC side. so 48pulse statcom is used in high power application. Without controller voltage profile reached to unrecoverable stage. In this paper working of PI controller is given. PI controller of statcom is used and simulation of statcom for voltage regulation is there to understand how voltage profile is improved.

I. INTRODUCTION

AIN THE last decade, commercial availability of Gate Turn-Off (GTO) thyristor switching devices with high-power handling capability and the advancement of the other types of power-semiconductor devices such as IGBTs have led to the development of fast controllable reactive power sources utilizing new electronic switching and converter technology. These switching technologies additionally offer considerable advantages over existing methods in terms of space reductions and fast effective damping [1].

The GTO thyristors enable the design of the solid-state shunt reactive compensation and active filtering equipment based upon switching converter technology. These Power Quality Devices (PQ Devices) are power electronic converters connected in parallel or in series with transmission lines, and the operation is controlled by digital controllers. The interaction between these compensating devices and the grid network is preferably studied by digital simulation. Flexible alternating Current transmission systems (FACTS) devices are usually used for fast dynamic control of voltage, impedance, and phrasal manuscripts must be in English. These guidelines include complete descriptions of the fonts, spacing, and related information for producing your angle of high-voltage ac lines. FACTS devices provide strategic benefits for improved transmission system power flow management through better utilization of existing transmission assets, increased transmission system security and reliability as well as availability, increased dynamic and transient grid stability, and Increased power quality for sensitive industries. The advent of FACTS systems is giving rise to a new family of power electronic equipment for controlling and optimizing the dynamic performance of power system, e.g., STATCOM, SSSC, and UPFC. The use of voltage-source inverter (VSI) has been widely accepted as the next generation of flexible reactive power compensation to replace other conventional VAR compensation, such as the thyristors-switched capacitor (TSC) and thyristors controlled reactor (TCR) [2], [3].

This paper deals with a novel cascaded multilevel converter model, which is a 48-pulse (three levels) source converter [4]. The voltage source converter described in this paper is a harmonic neutralized, 48-pulse GTO converter. It consists of four three-phase, three-level inverters and four phase-shifting transformers. In the 48-pulse voltage source converter, the dc bus Vdc is connected to the four three-phase inverters. The four voltage generated by the inverters are applied to secondary

Windings of four zig-zag phase-shifting transformers connected Y in Δ or. The four transformer primary windings are connected in series, and the converter pulse patterns are phase shifted so that the four voltage fundamental components sum in phase on the primary side

II. 48-PULSE VOLTAGE SOURCE GTO-CONVERTER

Two 24-pulse GTO-converters, phase-shifted by 7.5 from each other, can provide the full 48-pulse converter operation. Using a symmetrical shift criterion, the 7.5 are provided in the following way: phase-shift winding with -3.75 on the two coupling transformers of one 24-pulse converter and +3.75 on the other two transformers of the second 24-pulse converter. The firing pulses need a phase-shift of +3.75, respectively.

The 48-pulse converter model comprises four identical 12-pulse GTO converters interlinked by four 12-pulse transformers with phase-shifted windings. Fig. 1 depicts the schematic diagram of the 48-pulse VS-GTO converter model. The transformer connections and the necessary firing-pulse logics to get this final 48-pulse operation are modelled. The 48-pulse converter can be used in high-voltage high-power applications without the need for any ac filters due to its very low harmonic distortion content on the ac side. The output voltage have normal harmonics $n = 48r \pm 1$,where r=0,1,2,........,i.e.,47^{th} ,49^{th} ,95^{th} ,97^{th} ,.., with typical magnitudes (47^{th} ,49^{th} ,95^{th} ,97^{th} ,..,),respectively, with respect to the fundamental; on the dc side ,the lower circulating current harmonic content is 48^{th}.

1st 12-Pulse Converter:

It is shown in the equation at the bottom of the page. The resultant output voltage generated by the first 12-pulse converter is

$$v_{ab12}(t)_1 = 2[v_{ab1}\sin(\omega t + 30°) + v_{ab11}\sin(11\omega t + 195°) + v_{ab13}\sin(13\omega t + 255°) + v_{ab23}\sin(23\omega t + 60°) + v_{ab25}\sin(25\omega t + 120°) + \cdots..] \quad (1)$$

2nd 12-Pulse Converter:

It is shown in the second equation at the bottom of the previous page. The resultant output voltage.

Generated by the second 12-pulse converter is

$$v_{ab12}(t)_1 = 2[v_{ab1}\sin(\omega t + 30°) + v_{ab11}\sin(11\omega t + 15°) + v_{ab13}\sin(13\omega t + 255°) + v_{ab23}\sin(23\omega t + 60°) + v_{ab25}\sin(25\omega t + 120°) + \cdots..] \quad (2)$$

3rd 12-Pulse Converter:

It is shown in the first equation at the bottom of the page. The resultant output voltage generated by the third 12-pulse converter is

$$v_{ab12}(t)_1 = 2[v_{ab1}\sin(\omega t + 30°) + v_{ab11}\sin(11\omega t + 285°) + v_{ab13}\sin(13\omega t + 345°) + v_{ab23}\sin(23\omega t + 240°) + v_{ab25}\sin(25\omega t + 300°) + \cdots..] \quad (3)$$

4th 12-Pulse Converter:

It is shown in the second equation at the bottom of the page. The resultant output voltage generated by the fourth 12-pulse converter is

$$v_{ab12}(t)_1 = 2[v_{ab1}\sin(\omega t + 30°) + v_{ab11}\sin(11\omega t + 105°) + v_{ab13}\sin(13\omega t + 165°) + v_{ab23}\sin(23\omega t + 240°) + v_{ab25}\sin(25\omega t + 300°) + \cdots..] \quad (4)$$

These four identical 12-pulse converters provide shifted ac output voltages, described by (1)–(4), are added in series on the secondary windings of the transformers. The net 48-pulse ac total output voltage is given by

$$v_{ab48}(t) = v_{ab12}(t)_1 + v_{ab12}(t)_1 + v_{ab12}(t)_1 + v_{ab12}(t)_1 \quad (5)$$

The line-to-neutral 48-pulse ac output voltage from the STATCOM model is expressed by

$$v_{an48}(t) = \frac{8}{\sqrt{3}} v_{abn}\sin(n\omega t + 18.75°n - 18.75°i) \quad (6)$$

$n = 48r \pm 1$ r=0, 1, 2...

Voltages $v_{bn48}(t)$ and $v_{cn48}(t)$ have a similar near sinusoidal shape with a phase shifting of 120° and 240° , respectively, from phase a. Fig. 4 depicts the net resultant 48-pulse line-to-line output voltage of the 48-pulse GTO-Converter scheme.

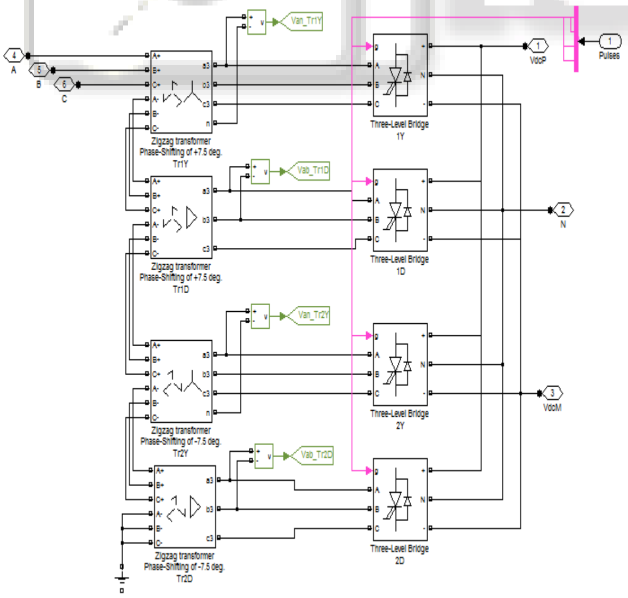


Fig. 1: Pulse STATECOM

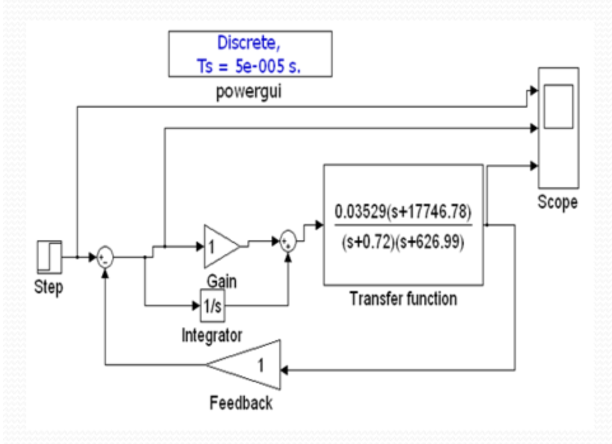
III. PI CONTROLLER

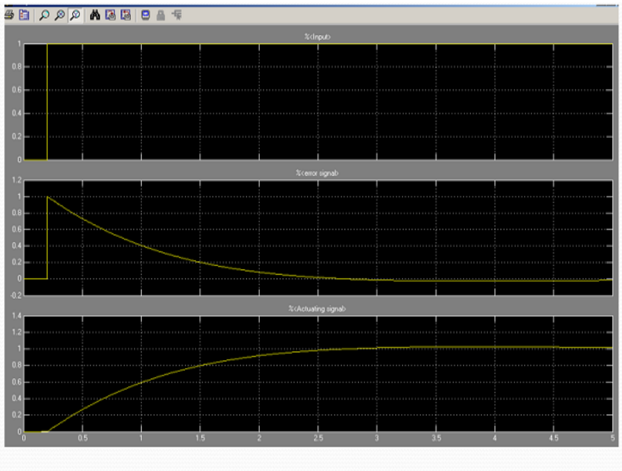
PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively.

However, introducing integral mode has a negative effect on speed of the response and overall stability of the system.

Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

PI controllers are very often used in industry, especially when speed of the response is not an issue.





IV. SYSTEM CONFIGURATION

The equivalent circuit of the STATCOM is shown in Fig. 1. In this power system, the resistance Rs in series with the voltage source inverter represents the sum of the transformer winding resistance losses and the inverter conduction losses. The inductance *Ls* represents the leakage inductance of the transformer. The resistance *Rc* in shunt with the capacitor *C* represents the sum of the switching losses of the inverter and the power losses in the capacitor. In Fig. 1 Vas,Vbs , and Vcs are the three-phase STATCOM output voltages; Val ,Vbl , and Vcl are the three phase bus voltages; ,Ias , Ibs and Ics are the three-phase STATCOM output currents.

V. STATCOM DYNAMIC MODEL

The three-phase mathematical expressions of the STATCOM can be written in the following form

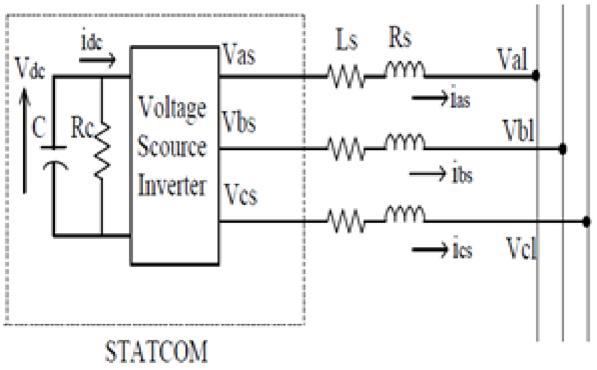


Fig. 2: Equivalent circuit of STATECOM

$$Ls\,\frac{di_{as}}{dt} = -Rsi_{as} + V_{as} - V_{al} \quad (7)$$

$$Ls\,\frac{di_{bs}}{dt} = -Rsi_{bs} + V_{bs} - V_{bl} \quad (8)$$

$$Ls\,\frac{di_{cs}}{dt} = -Rsi_{cs} + V_{cs} - V_{cl} \quad (9)$$

$$\frac{d}{dt}\left(\frac{1}{2}cV_{dc}^2(t)\right) = -[V_{as}i_{as} + V_{as}i_{as} + V_{as}i_{as}i_{as}] - \frac{V_{dc}^2}{Rc} \quad (10)$$

In order to conveniently analyze the balanced three-phase system, the three-phase voltages and currents are converted to synchronous rotating frame by *abc*/*dq* transformation. By this rotation, the control problem is greatly simplified since the system variables become DC values under the balanced condition. Further, multiple control variables are decoupled such that the use of classic control method is possible. The transformation from phase variables to *d* and *q* coordinates is given as follows

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ 0 \end{bmatrix} = [C]\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \quad (11)$$

where *ids* and *iqs* are the *d* and *q* currents corresponding to *ias*, *ibs*, and *ics*; *Vd*s and *Vqs* represent the *d* and *q* voltages corresponding to *Vas*, *Vbs*, and *Vcs*.

The output voltage of the STATCOM can be expressed as

$$V_{ds} = KV_{dc}\cos\alpha \quad (12)$$

$$V_{qs} = KV_{dc}\sin\alpha \quad (13)$$

where *K* is a factor that relates the DC voltage to the peak phase-to-neutral voltage on the AC side; *Vdc* is the DC-side voltage; α is the phase angle which the STATCOM output voltage leads the bus voltage. By using the *abc*/*dq* transformation, the equations from (1) to (4) can be rewritten as:

$$P_l = \frac{3}{2}V_{dl}i_{ds} \quad (14)$$

$$q_l = \frac{3}{2}V_{ql}i_{qs} \quad (15)$$

where ω is the synchronously rotating angle speed of the voltage vector; *Vdl* and *Vql* represent the *d* and *q* axis voltage corresponding to *Val*, *Vbl*, and *Vcl*. Since *Vql* =0, based on the instantaneous active and reactive power definition, can be obtained as follows:

Based on the above equations, the traditional control strategy can be obtained, and the STATCOM control block diagram is shown in Fig. 3

As shown in Fig. 3, the phase locked loop (PLL) provides the basic synchronizing signal which is the reference angle to the measurement system. Measured bus line voltage *Vm* is compared with the reference voltage *Vref* and the voltage regulator provides the required reactive reference current *Iqref*. The droop factor, *Kd*, is defined as the allowable voltage error at the rated reactive current flow through the STATCOM. The STATCOM reactive current *Iq* is compared with *Iqref* and the output of the current regulator is the angle phase shift of the inverter voltage w.r.t. the system voltage. The limiter is the limit imposed on the value of control with the consideration of the maximum reactive power capability of the STATCOM.
STATCOM.

The scheme for implementing the PI control loop is shown in Fig-3. The voltage regulator is a PI controller with Kp=12 and Ki=3000. The current regulator is also PI controller with Kp=5 and Ki=40. The Phase-Locked Loop (PLL) system generates the basic synchronizing-signal which is the phase angle, θ of the transmission system voltage, VB and the selected regulation-slope; k determines the Compensation behaviour of the STATCOM device.

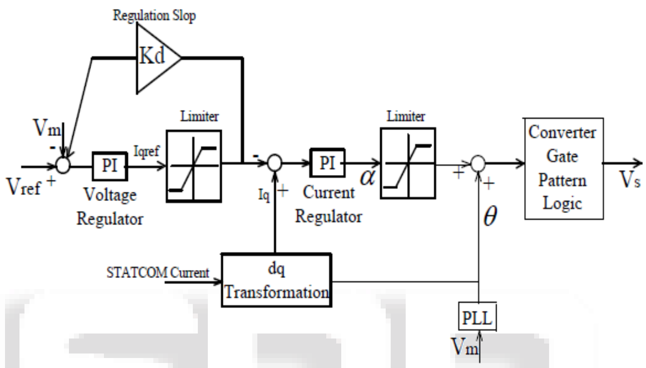


Fig. 3: STATCOM PI control block diagram

VI. SIMULATION AND RESULTS

This model shown on SPS Model of the 100 Mvar STATCOM on a 500 kV Power System (study system) represents a three-bus 500 kV system with a 100 Mvar STATCOM regulating voltage at bus B1.

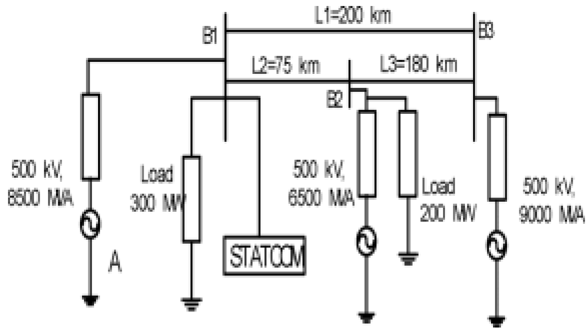


Fig. 4: SPS Model

VII. STEADY-STATE AND DYNAMIC PERFORMANCE OF THE STATCOM

In this study system initially the programmable voltage source is set at 1.0491 pu, resulting in a 1.0 pu voltage at bus B1 when the STATCOM is out of service. As the reference voltage Vref is set to 1.0 pu, the STATCOM is initially floating (zero current). The DC voltage is 19.3 kV. At t=0.1s, voltage is suddenly decreased by 4.5% (0.97 pu of nominal voltage). The STATCOM reacts by generating reactive power (Q=+70 Mvar) to keep voltage at 0.979 pu.

The 95% settling time is approximately 47 ms. At this point the DC voltage has increased to 20.4 kV.

Then, at t=0.2 s the source voltage is increased to1.045 pu of its nominal value. The STATCOM reacts by changing its operating point from capacitive to inductive to keep voltage at 1.021 pu. At this point the STATCOM absorbs 72 Mvar and the DC voltage has been lowered to 18.2 kV. Observe on the first trace showing the STATCOM primary voltage and current that the current is changing from capacitive to inductive in approximately one cycle.

Finally, at t=0.3 s the source voltage in set back to its nominal value and the STATCOM operating point comes back to zero Mvar.

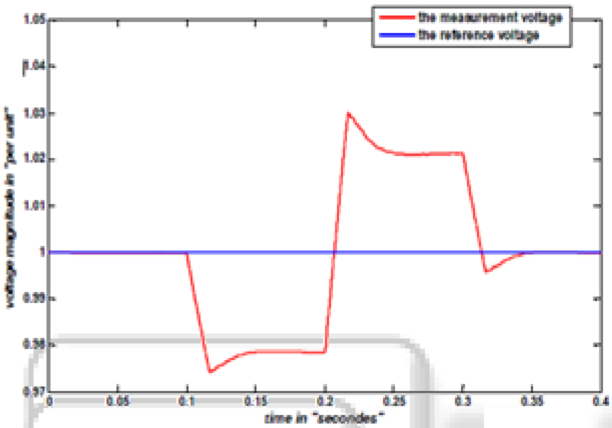


Fig. 5: Voltage Measurement

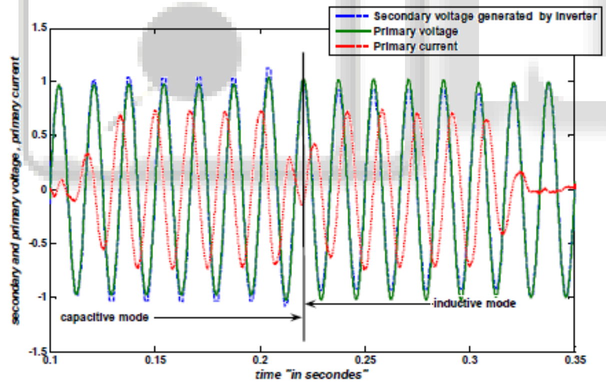


Fig. 6: the Dynamic Response

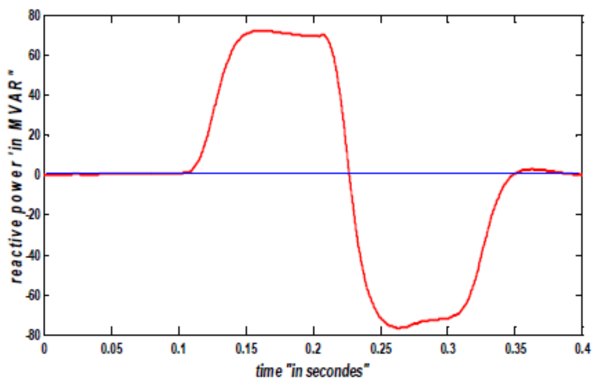


Fig. 7: Change of Reactive Power

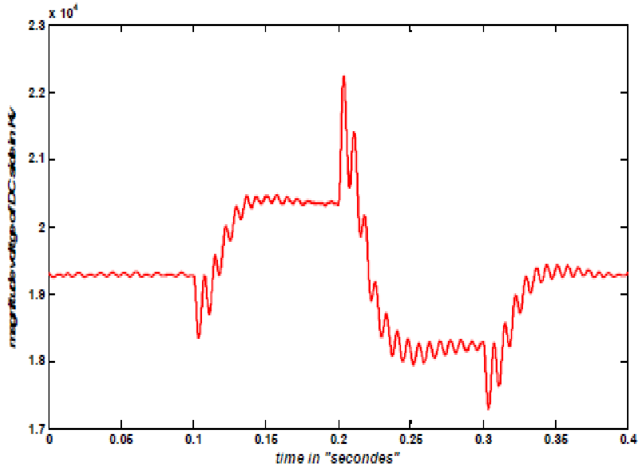


Fig. 8: DC Voltage behaviour

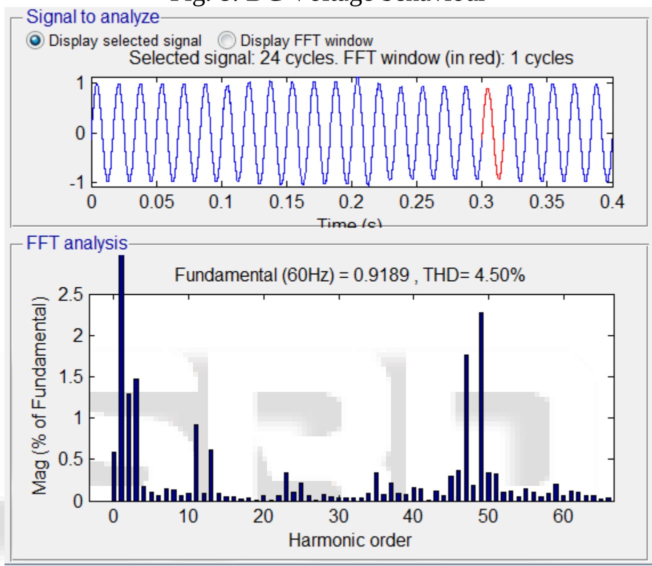


Fig 9: harmonic reduction using 48 pulse STATCOM

VIII. Conclusion

The statcom is a shunt connected device used to improve voltage profile in the transmission system. Statcom generate or absorb reactive power through voltage source converter. Converter is available in different configuration. Multi pulse converter configuration is able to reduced harmonic content in generated wave form. so filter are not required. In this paper PI controller is used which reduced steady state error to zero and its less costlier then PID.

The dynamic response of statcom is fast and easily moves from a capacitive mode of operation to an inductive mode of operation. When AC voltage reduces, the statcom as a capacitor and generate reactive power, so DC voltage is reduces; on the other hand when the AC voltage increases then statcom act as inductor and absorbs the reactive power. So DC voltage decreased.

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