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Cascaded Control of Multilevel Converter based STATCOM for Power System Compensation of Load Variation

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ABSTRACT

The static synchronous compensator (STATCOM) is used in power system network for improving the voltage of a particular bus and compensate the reactive power.It can be connected to particular bus as compensating device to improve the voltage profile and reactive power compensation. In this paper, a multi function controller is proposed and discussed. The control concept is based on a linearization of the d-q components with cascaded controller methods. The fundamental parameters are controlled with using of proportional and integral controller. In closed loop method seven level cascaded multilevel converter (CMC) is proposed to ensure the stable operation for damping of power system oscillations and load variation.

Keywords*:* FACTS, PWM, CMC , STATCOM

1. INTRODUCTION

The STATCOM operated as a shunt connected static VAR compensator whose capacitive or inductive output current can be controlled by controller[1]. The customers connected the loads to that bus would be supplied by a set of distorted voltages and unregulated, even when their loads are not contributing to the bus voltage variation. Similarly more number of buses are affected and having poor voltage regulation and reactive power losses. The STATCOM can be used at this bus to regulate the voltage and reduce the reactive power also[2]. cascaded Multilevel converter(CMC) is provided to offer bus voltage control and reactive power compensation. The Multifunction controller is provided to offer DC bus voltage control, reactive power compensation and AC voltage control of the bus.

2. PRINCIPLES OF OPERATION

The STATCOM provides reactive power compensation and voltage regulation by acting as a controlled current source connected in parallel with the system bus. The controlled current source in the proposed system is realized using a current-controlled CMC. A typical configuration of a CMC based STATCOM is shown in Fig.1. The system consists of three bus grid which bus B2 is considered as source point for STATCOM. The CMC based STATCOM is connected through bus B2 with coupling transformer and harmonics elimination filter[3]-[5].

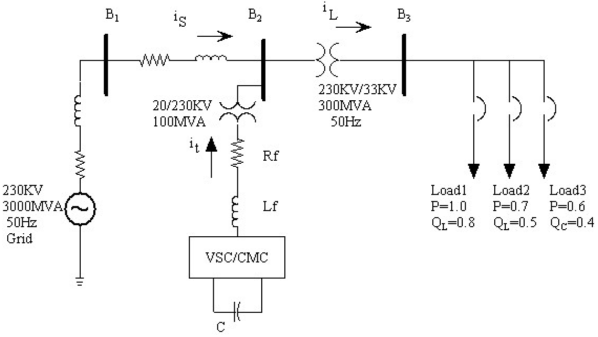


Figure 1.STATCOM network connection.

Three types of loads are connected through transformer in bus B3 for load variation purpose. The load and STATCOM currents are directed in the three bus system.

3. CIRCUIT DESCRIPTION

Two important circuits are mainly discussed in STATCOM. They are,

1. Power Circuit
2. Control Circuit

3.1 .Power circuit

The power circuit configuration is nothing but connection of a cascaded multilevel converter in the system. In reactive power compensation, seven level cascaded-multilevel converter with separated DC capacitors are constructed with a number of identical three H-bridge converters. The cascaded converter method is very simple and less components. The CMC based STATCOM improves the dynamic responses of the power system network.

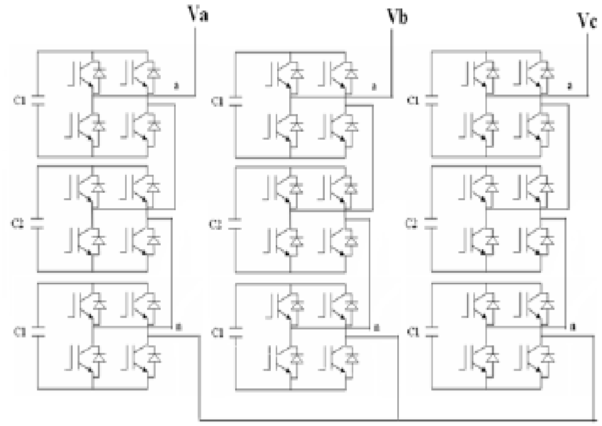


Figure 2.Seven Level Cascaded Multilevel Converter(CMC).

3.2. Control Circuit

The control circuit is capable of independently controlling the direct axis component i_{td} and the quadrature axis component i_{tq} of the VSC/CMC current with minimal coupling between them. The controllers generate the desired values of dq components of the VSC/CMC terminals.

The PWM pattern generator uses these signals to generate the gating pulses for converter as shown in fig.3 [7].

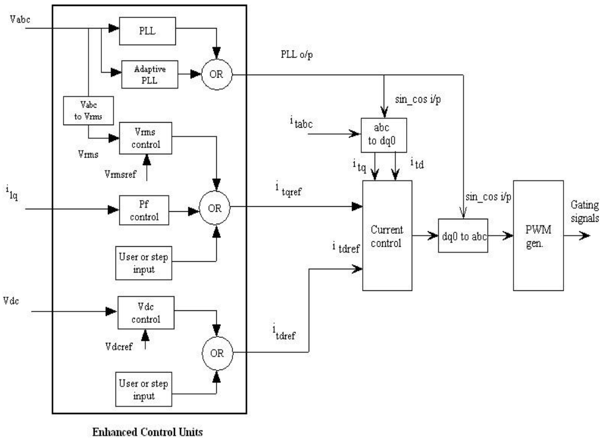


Figure 3.Block Diagram of STATCOM Control.

Control scheme has some units as follows,

1.Step input control
2. RMS voltage control
3. Power factor control
4. DC voltage control
5.Cascaded control

The Three-Phase V-I Measurement unit is used to measure the voltages and currents in a circuit. It can be measured the voltages and currents in per unit (p.u.).The per unit values of main system bus are given to abc to dqo converter. RMS value is taken from system bus and i_{lq} value is known from load current for power factor reference value. Reference current of quadrature axis is selected from maximum variation of any one of RMS value or i_{lq} value.

In RMS voltage control mode, the RMS voltage control unit, shown in fig.4., generates i_{tqref} by first comparing the measured RMS voltage on the bus B2 with a user supplied reference and then feeding the error signal into a PI controller. The output of the PI controller is limited to avoid overload. Controlling the bus B2 voltage through i_{td} control is feasible because the bus B2 voltage is related to i_{tq} by,

$$V_{rms} = E_s - i_{lq} X_t - i_{tq} X_t \qquad (1)$$

Where V_{rms} is the bus B2 voltage , E_s is the Thevenin voltage of the bus B2 , and X_s is the Thevenin system inductance. Since this controller generates the current reference only, the current controller for i_{tq} must be enabled when the bus B2 voltage-control scheme is in operation.

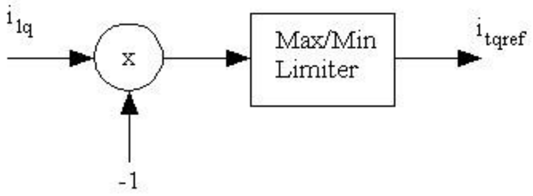


Figure 4. RMS voltage control.

In power factor control mode, the power factor control shown in fig .5 assigns i_{tqref} to be the negative of i_{lq} , the quadrature component of the measured load current, provided i_{lq} is within the VSC operating range. Otherwise, it is set of the VSC maximum current rating. Since this controller for i_{tq} must be enabled when the power factor correction scheme in this operation. It should be noted that RMS voltage-control mode and power factor control mode are mutually exclusive.

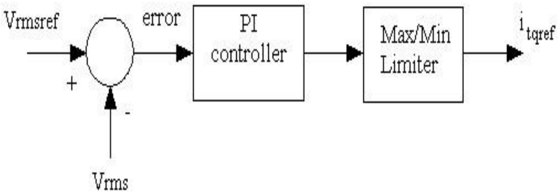


Figure 5. Power factor control.

The DC voltage-control scheme compares the dc voltage on the capacitor with a user-supplied reference and feeds the error signal into a proportional-Integral (PI) controller that computes i_{tdref} as shown in fig.6. The output of the PI controller is limited to avoid overloading the VSC/CMC. DC capacitor has been assumed as a DC source for STATCOM and also considered for lossless compensator.

Let us define the following error signal,

$$e = V_{dcref} - V_{dc} \qquad (2)$$

The controller is then given by,

$$i_{tdref} = K_p\, e + K_i \int e\, dt \qquad (3)$$

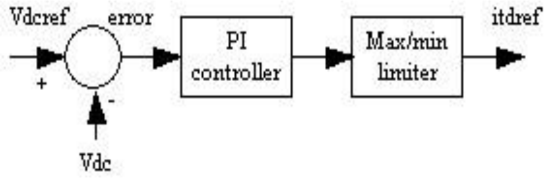


Figure 6. DC voltage control.

These dq reference currents are compared with actual dq current values of bus B2 as shown in fig.7. The error is minimised and its output is given for dqo to abc converter. These abc signals are used to generate pulses for VSC [8][9].

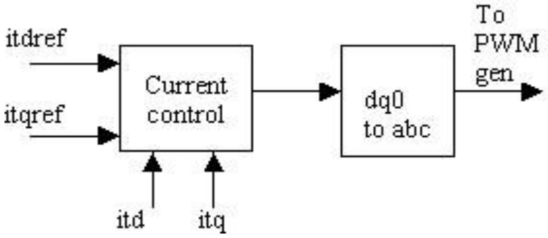


Figure 7. Current control.

The loads are added in bus B2 through rated transformer. Due to any fault in load side, the loads are disconnected immediately. The STATCOM functional block diagram is shown in Fig.8. This immediate load rejection makes heavy oscillation in entire system[10].

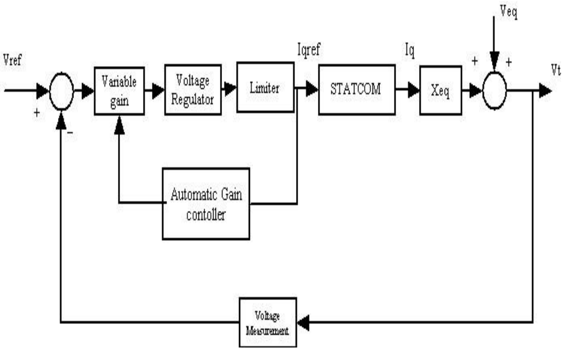


Figure 8. STATCOM functional diagram with Automatic Gain Controller.

The reactance Xeq is decreased by load addition, however increased by load rejection. The reactance Xeq in the total power system including STATCOM is increased by load rejection. So Xeq is compensated by gain increasing or tuning method in the STATCOM controller. Automatic gain controller is used to reduce the oscillation and improve the stability of STATCOM [10]. Due to elimination of oscillation, STATCOM gets effective dynamic response in the total system voltage.

Cascaded PI controller is designed as shown in fig.9 The RMS value of system voltage is compared with reference value and minimize the error through one of the PI controllers. Similarly capacitor voltage is taken and compared with its reference value and its error is minimized through PI controller. Finally these outputs are given as references of q and d axis currents of controller. Actual values of d and q currents of converters compare with reference values and get error minimized through PI controller. The PI controllers are cascaded for VSC based STATCOM.

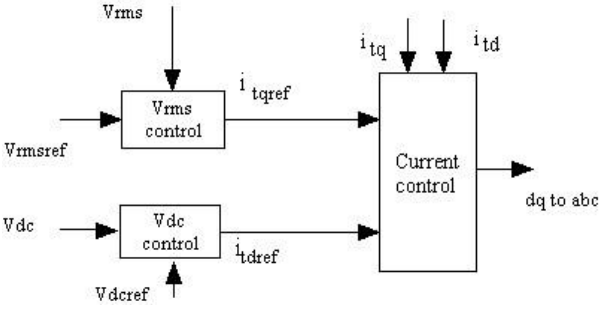


Figure.9. Cascaded PI control.

$$V_{td} = V_{sd} + \omega L i_{tq} - K_p\, e - K_i \int e\, dt \qquad (4)$$

$$V_{tq} = V_{sq} - \omega L i_{td} - K_p\, e - K_i \int e\, dt \qquad (5)$$

From these equations, required voltage in STATCOM terminal is generated by the feedforward method. Vsq is not considered due to avoid phase angle variation between source voltage and CMC output voltage. The output predicted voltage signals of Vtd and Vtq are taken for conversion of three phase signals. These signals are used to generate gating signals to CMC.

4. SIMULATION OUTPUT

The STATCOM is connected to the bus B2 for 230KV, 50Hz through 20/230KV, 100MVA coupling transformer as shown in fig.1. On this power system network , the +/-100 MVAR STATCOM can compensate reactive power and maintain effective voltage profile. The reactive power generation or absorption by generating converter voltage which is in phase with the source voltage in bus B2 [11].When the CMC output voltage is lower than the source voltage , the STATCOM will absorb reactive power, when capacitor voltage is higher, it will generate the reactive power and supply the reactive power to bus B2.

4.1. Dynamic representation for load variation.

The Load current and dq axis current variation is clearly shown through Fig.10 Due to fast stable operation of STATCOM, dq currents of source terminal get effective responses as shown in Fig.11. As shown in fig.8,the system reactance, X_{eq}, is a part of the feedback loop and it is crucial to note that X_{eq} varies as loads are added or rejected from the power system . Therefore the overall closed loop gain and the stability margin of the STATCOM are affected by X_{eq}. If the impedance of the power system increases (weak system) , the amount of voltage is varied. The STATCOM reactive current is also varied and the overall system tends to instability. If the power system impedance decreases (strong system), the system is stable, although the response is slower than that of the weak system.

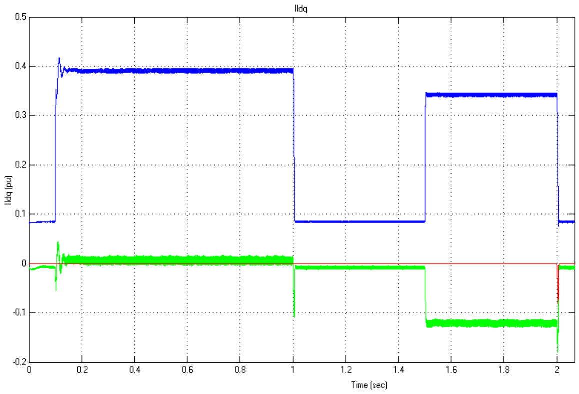


Figure 10. Load terminal dq0 Currents with Load variation.

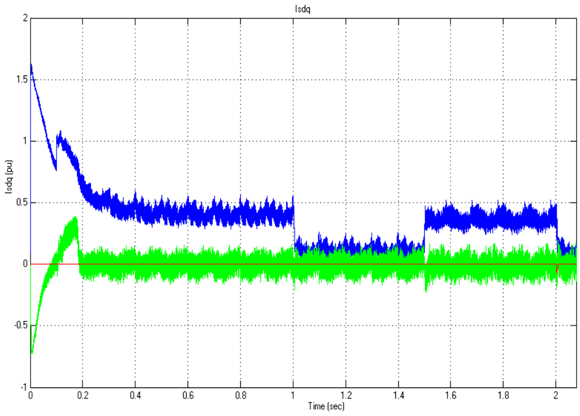


Figure 11. Source terminal dq0 Currents with Load variation.

Therefore the power system strength affects the response time and stability of the STATCOM. If the voltage regulator is set to provide a fast response for a strong system, it may lead to instability for a weak power system . If the voltage regulator is set to provide a stable response for a weak power system, the response for a strong power system will be very slow and sluggish. Therefore the closed loop gain of the overall system is decreased.

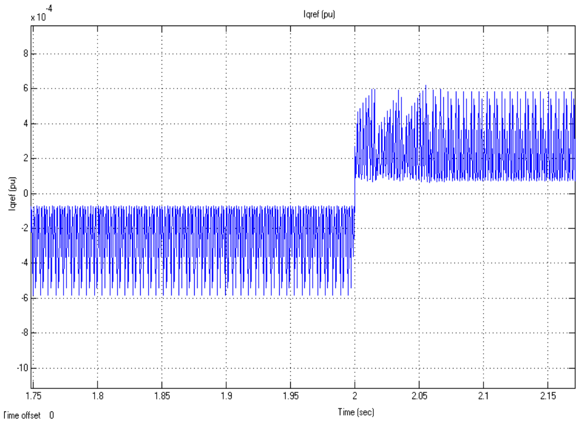


Figure 12. I_{qref} output for load rejection.

To demonstrate the effect of the power system strength on the STATCOM stability, an exact digital simulation, using the 6-pulse converter. The voltage regulator parameters are Kp = 0.004 and Ki =3.

The STATCOM is connected to bus B2 in the power system. It regulates the bus voltage to rated value. At t = 2 Sec, all loads are rejected and only system network with high impedance remains. As shown in Fig.12 reference output exhibits heavy oscillations. Although the STATCOM has a fast and stable response for the strong system, it exhibits oscillations for the weak power system.

4.2. Automatic Gain controller for load variation.

An Automatic Gain Controller (AGC) is used to vary the voltage regulator gain. The oscillation of the STATCOM is reduced in the case of a weak power system as shown in fig.8. The system detects the voltage regulator oscillations damping of oscillatons STATCOM is stable again. The voltage regulator gain gives a fast response for a strong system and improves the stability for a weak power system. The performance of the STATCOM is improved by AGC and source voltage of strong and weak power system is maintained for rated value without any oscillation as shown in fig.13.

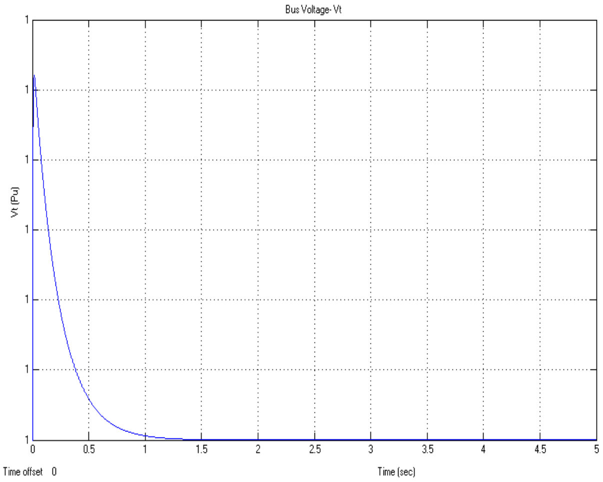
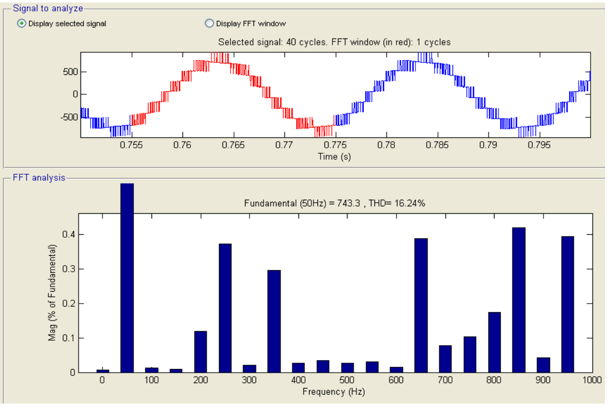


Figure 13. Source Voltage for load rejection with AGC.

4.3. Cascaded controller.

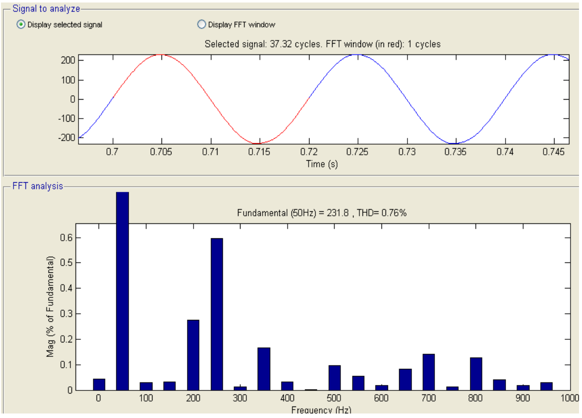
Cascaded controller based STATCOM is designed for seven level cascaded multilevel converter (CMC)[11]-[15]. This proposed controller reduced the THD values [16]. This result is given clearly in fig.14. THD value of voltage is 16.24% and current is 0.76% as shown in fig.15. THD values are minimized in the converter output voltage and current. Active and reactive power of source are shown in fig.16 and compensation is identified through reactive power variation. Power factor is improved as shown in fig.17. Three phase supply output is shown in fig.18.



Selected signal: 40 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 743.3 , THD= 16.24%

Figure14. THD of output Voltage of Cascaded Multilevel converter.



Selected signal: 37.32 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 231.8 , THD= 0.76%

Figure15. THD of output Current of Cascaded Multilevel Converter.

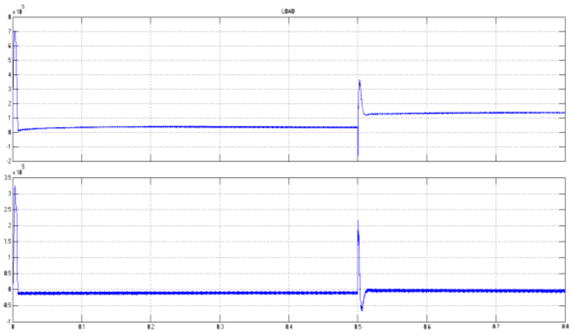


Figure16.Source Active and Reactive power.

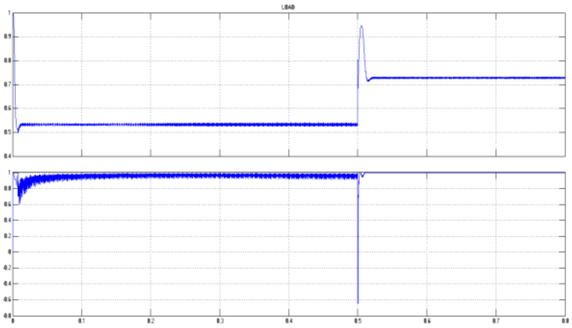


Figure17. Power factor in Load and Source Bus

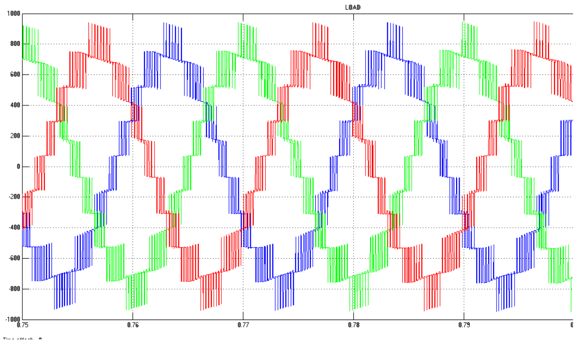


Figure 18.Three phase Supply Voltage of multilevel converter.

5.CONCLUSION

The cascaded controller is designed for seven level CMC based STATCOM. This control scheme regulates the capacitor voltage of the STATCOM and maintain rated supply voltage for any load variation with in the rated value. It has been shown that the CMC is able to reduce the THD values of output voltage and current effectively. The CMC based STATCOM ensures that compensate the reactive power and reduce the harmonics in output of STATCOM.

6. ACKNOWLEDGEMENTS

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