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Modeling of Statcom

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Abstract

Statcom is a power electronic device connected in shunt across the load to solve power quality problems, reduce fluctuations in bus voltage, reduce unbalance of three phase voltages and reduce flicker. Modeling of Statcom specifically to simulate for solving power quality problems presents various problems due to various types of control strategies. Modeling of statcom for hysteresis control strategy is presented.

Index Terms— Point of Common Connection, hysteresis control, modeling,

Introduction

Statcom is based on Voltage Source Inverter that can be connected to the grid. It can be controlled in such a way that it can supply a particular desired value of reactive power or it can supply an amount of reactive power that is needed to keep the bus voltage at the point of common connection (PCC) constant. The first application of supplying reactive power of required amount can be called constant reactive power mode. The later method is called constant voltage method. Both have their own area of applications

The first method gives rise to improved power factor to the desired extent and also harmonics can be suppressed to a large extent. The second method guards against voltage sags or swells and also mitigates the flicker. These effects depend on the control strategy and also on the way feedback is taken.

Statcom has a voltage source inverter which takes DC voltage from a capacitor which is maintained at a relatively constant voltage. The three phase inverted voltage is connected to the grid by means of a reactor in each phase. If the voltage output of the inverter is exactly equal to that of the bus voltage, the voltage across the reactance is equal to zero. However when the voltage output of the inverter is greater than that of the bus the difference in the two voltages is dropped across the reactance. The current flow in the reactor lags by 90^0 with respect to the drop across the reactor this current flow from the inverter in to the system and causes reactive power to be injected in to the system. On the contrary if the inverted output voltage is less than that of the bus at PCC it draws reactive power from the system. The coupling between bus voltage and reactive power injection is well known to power system engineers. So the reactive power injection causes bus voltage to increase and reactive power drawal causes bus voltage to drop. This effect can be utilized by taking actual bus voltage as feedback and subtracting it from the voltage reference value and using the error as a guide to inject or draw reactive power which goes a long way in improving the bus voltage. The control strategy applied here determines whether the statcom will be effective in controlling voltage sags and swells or in mitigating flicker in the presence of highly non linear fluctuating loads like an arc furnace are present.

Control strategies adapted in control of statcom

The control strategies adopted are Phase angle control, Constant DC link voltage, Direct current control based on PQ theory. In the first method reactive power has to be measured based on the three phase voltages and phase currents. Actual value of reactive power so obtained is subtracted from the reactive power reference value. The error is fed to a PI controller giving rise to reference phase angle. Now the firing pulses are shifted so as to cause the inverted voltage to be shifted slightly in phase with respect to the system voltage at PCC. This causes active power to flow in to the DC link capacitor and charge it to a higher voltage and produce higher inverter voltage and hence the injection of reactive power to be increased. Now the actual reactive power equals the reference and no error will be produced causing no further shift in phase angle. Thus phase angle control is used to supply a desired value of reactive power to the system.

In the constant DC link voltage method the capacitor voltage is kept constant by means of a control loop. Also reactive power is measured and compared with reference and the error is fed to a PI controller. V_d is calculated from the three phase voltages which in turn is subtracted from V_{dref} and fed to a PI controller. A fixed amplitude sine wave is produced which is modulated by the control signal obtained from reactive power error this modulated signal is used to control the sinusoidal pulse width modulation generator. This way the output voltage of the inverter is made to inject reactive power of required magnitude.

In the third method the three phase voltages and the three phase currents are transformed to Alpha, Beta, Zero coordinates and the current references are calculated in the Alpha, Beta coordinates. These three reference currents are compared with the actual currents and the hysteresis current control method is used to inject suitable values of current in to the system. This is known as direct current control method using PQ theory.

MATHEMATICAL MODELING OF STATCOM

The Mathematical modeling of statcom is based on the following equations, where 'e' represents the voltage of the statcom and 'v' represents the bus voltage at the point of common connection and 'i' represents the current drawn by the statcom. The difference in bus voltage and statcom voltage is dropped across the coupling inductor whose inductance is 'L' and resistance is 'R'.

The reactive power injection is done through the linkage reactance which may be the actual reactance of a reactor connected between the PCC and the statcom or the leakage reactance of the coupling transformer used to step down the grid voltage to a suitable voltage. When the statcom voltage is less than the system voltage the statcom draws reactive power or else when the statcom voltage is higher it injects reactive power. The current through the statcom is decided by the difference in voltages which actually acts across the linkage reactance and produces a current and hence the reactive power is decided by the difference in voltage and reactance value.

$$e_a - v_a = L\frac{d}{dt}i_a + Ri_a$$

$$e_b - v_b = L\frac{d}{dt}i_b + Ri_b$$

$$e_c - v_c = L\frac{d}{dt}i_c + Ri_c$$

The above equations can be put in the standard form of

$$\dot{x} = A\,x + \mathrm{B}\,u$$

Where X = $\begin{bmatrix} ia \\ ib \\ ic \\ Vdc \end{bmatrix}$ and u=$\begin{bmatrix} ea \\ eb \\ ec \end{bmatrix}$

and A=$\begin{bmatrix} -\frac{R}{L} & 0 & 0 & -m\sin(\omega t+\alpha) \\ 0 & -\frac{R}{L} & 0 & -m\sin(\omega t+\alpha-120) \\ 0 & 0 & -\frac{R}{L} & -m\sin(\omega t+\alpha-240) \\ n\sin(\omega t+\alpha) & n\sin(\omega t+\alpha-120) & n\sin(\omega t+\alpha-240) & 0 \end{bmatrix}$

$$B=\begin{bmatrix} \frac{1}{L} & 0 & 0 \\ 0 & \frac{1}{L} & 0 \\ 0 & 0 & \frac{1}{L} \end{bmatrix}$$

The difference in voltages is either in phase or exactly 180^0 out of phase with the bus voltage at PCC. But the current is at 90^0 lagging with respect to the voltage reference and hence the current either leads the bus voltage by 90^0 or lags by 90^0 either way the power drawn or injected in to the bus is reactive in nature. This is the basis of working of statcom. It can be further explained by the following diagrams.

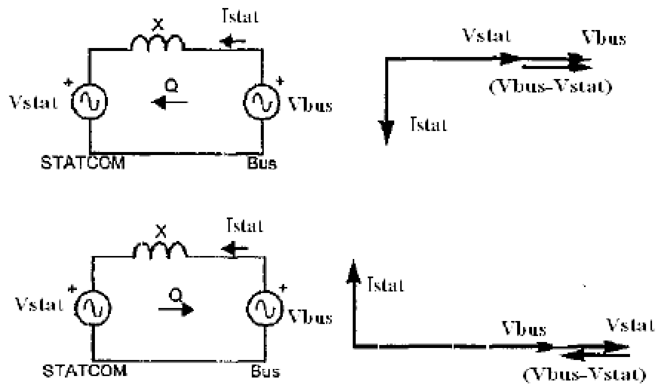

Fig.1. single phase equivalent circuit of statcom demonstrating drawal and injection of reactive power and corresponding vector diagrams.

HYSTERESIS CURRENT CONTROL STRATEGY

This method of current control is very suitable for the control of a Statcom. There are two control loops in this method. The two control loops are 1) DC link voltage control loop 2) Current control loop. The DC voltage signal is sampled at the rate of one sample per power cycle.

The DC link capacitor voltage can be controlled to the required value by setting the reference value for the DC link voltage. The sampled DC link voltage is compared with the reference value and the error so obtained is fed to PI controller the output of which is multiplied with a sine wave of unit magnitude and is used as reference current. At this stage three sine waves with phase angles shifted by 120 degrees from each other are used for three phase statcom.

Now the actual value of current is also obtained and from the reference current the hysteresis band is obtained by adding and subtracting 10% of the current reference value from it. The resulting reference current value with hysteresis band and the actual current are shown in the FIG.

This helps in maintaining the DC link voltage at the reference value and also to see to it that the value of current drawn by the statcom does not also exceed the rated current. The DC link voltage reference ultimately decides the statcom output voltage and hence the reactive power injected into the system.

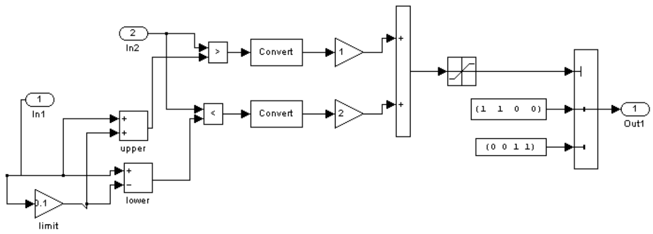

Fig.2.Simulink Diagram for implementing hysteresis current control strategy.

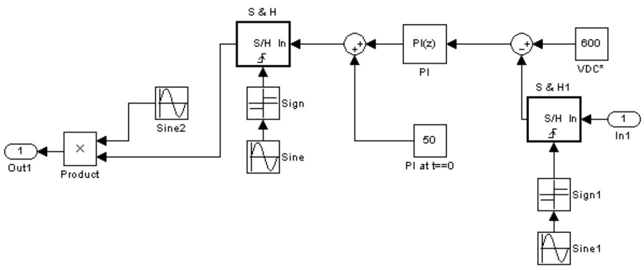

Fig 3. Simulink Diagram for DC link voltage control and generation of current reference.

STATCOM OPERATION

The statcom can be operated in one of two modes: Reactive power control mode and the voltage control mode. In reactive power control mode the actual reactive power injected in to the system is measured by sampling the three phase currents and the two bus voltages at the point of common coupling. The actual value of reactive power is compared with the set value of reactive power. The set value of reactive power may in turn be derived from the required power factor value. The error in this reactive power injection is fed to a PI controller whose output can be treated as the reference value for the DC link voltage. This actually completes the closed loop and maintains the desired power factor as may be required.

On the other hand if it is desired to maintain the system voltage constant at the point of common connection this voltage may be sampled at the rate of once per power cycle and can be compared with voltage reference which in turn is subtracted from the reference value and the corresponding error is obtained. This error is fed to a PI controller the output of which is treated as the reference value for the DC link voltage and thus completes the closed loop. This system acts in such a way as to inject only that much reactive power in to the system as may be required for keeping the bus voltage constant at the point of common connection constant. If the system is so designed that it has sufficiently good bandwidth this mode can control the voltage flicker as may be caused by such loads as arc furnaces, heavy induction motor loads etc and also voltage sags and swells which are menacing power quality problems.

A block diagram of the statcom implementing the hysteresis current control strategy is shown below

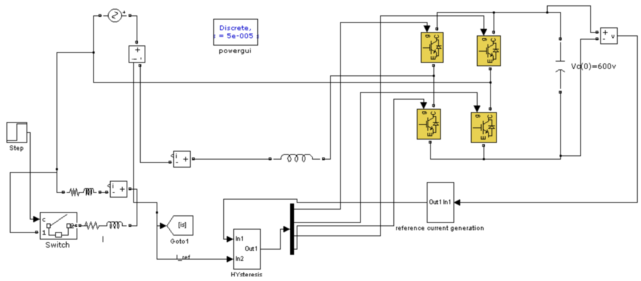

Fig.4.Single phase implementation of the statcom using hysteresis current control strategy

V Results

The wave forms showing current reference along with a band showing the derived upper and lower limits are depicted in fig. 5.The actual current drawn by the statcom can be regulated precisely to fall within this band and it can be made as close to the required value as desired.

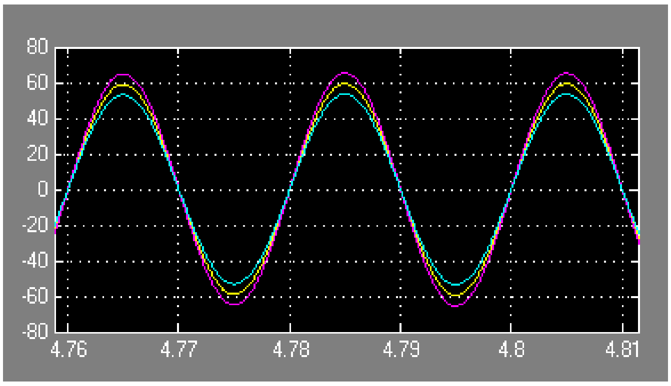

Fig.5. Sinusoidal current wave form showing the allowable upper and lower bands

The gate pulses generated are not of very high frequency as in the case of carrier based pulse width modulated method of generating gate pulses but of reasonably moderate frequency. The frequency is not constant either. Because of these features the switching losses are moderate as also the generation of higher order harmonics is also minimized. The nature of firing pulses is shown in fig.6.

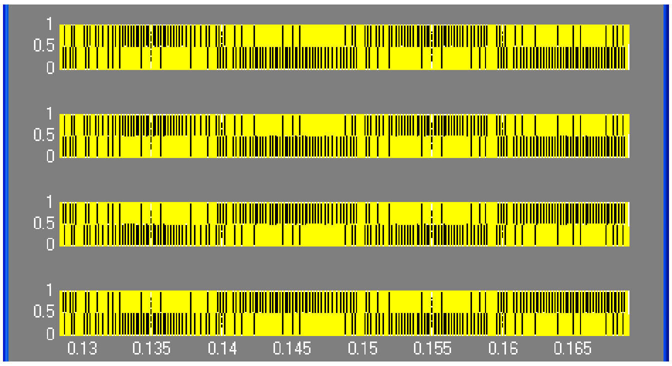

Fig.6. Gate pulses generated in case of hysteresis current control strategy.

The dynamics of voltage across dc link capacitor is important because the response of the system to changes in bus voltage or of reactive power requirement depends on this aspect. Response of the dc link voltage to step change in load is depicted in fig. 7 as shown below.

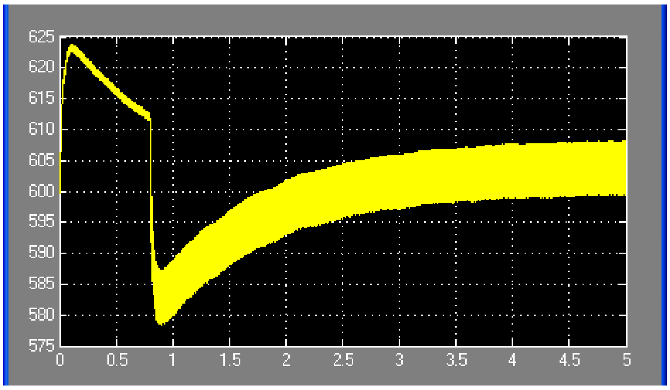

Fig. 7 showing settling of dc link capacitor voltage after a disturbance has occurred.

The wave form of the current drawn by the statcom is purely sinusoidal as may be seen from fig. 8 below. The glitches seen on the waveform are but inherent in the nature of this type of current control strategy. This could be reduced by keeping the upper and lower bands closer. But it can be seen that this leads to higher switching frequencies. It is important to keep this trade off in mind while deciding the range of these limits.

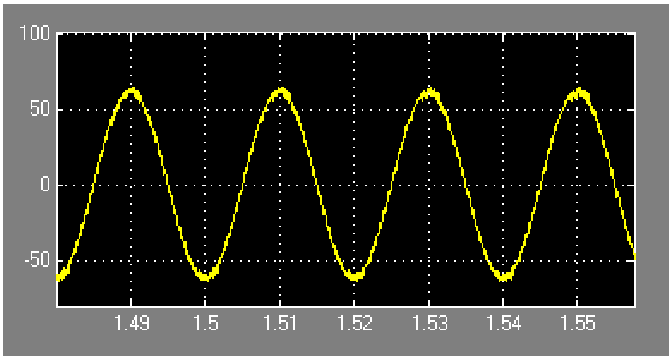

Fig. 8. Waveform of current drawn by the statcom.

VI CONCLUSIONS

It is shown that a statcom when applied properly in a power system can be used to improve power factor or mitigate power quality problems essentially of the nature of aperiodic voltage fluctuations. The method is simple and straight forward and can be easily implemented either in hardware or software.

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