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Design and Simulation of Static Synchronous Compensator for PQ Improvement Using Active Disturbances Rejection Controller (ADRC)

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ABSTRACT:

In this paper, a novel control approach of the PI controller used for individual DC voltage balancing control of series connected H-bridge converter-based STATic synchronous COMpensator (STATCOM) is presented. An Active Disturbances Rejection Controller (ADRC) of designed with phase shift sinusoidal pulse width modulation, using two control loops (DC voltage control loop and phase angle shift control loop) to ensure DC voltage balance. A passivity based control technique has been proposed for DC voltage controlling. The simulation results verify that the proposed method has good effects of balancing individual DC voltage for Power Quality improvement.

Key words: ***ADRC controller, STATCOM, DC voltage control, multilevel inverter.***

INTRODUCTION

Multilevel converters have received more and more attention because of their capability of high voltage operation, high efficiency, and low electromagnetic interference. especially, multilevel converters have been used for STATCOM widely as it can improve the power rating of the compensator to make it suitable for medium or high-voltage high power applications[1-2]. There are many types of multilevel converters used for constructing STATCOMs such as diode-clamp converter, flying capacitor based converter, and cascaded H-bridge converter. Cascaded H-bridge topologies are more popular because of its many advantages:

(1) It can generate almost sinusoidal waveform voltage from several separate dc sources to reduce harmonics.

(2) It cans response faster because of eliminating the need of a transformer to provide the requisite voltage levels.

(3) Modularized circuit layout and packing is very easy due to the simplicity of structure [3-4].

Fig. 1 shows the block diagram of a cascaded H-bridge multilevel converter based STATCOM. The converter used in STATCOM acts as an inverter, and each H-bridge cell can generate three different voltage outputs by connecting dc voltage to ac side through different states of the four switches.

The control of the phase angle between line voltage and voltage source converter (VSC) voltage leads STATCOM to absorb or supply reactive power. For cascaded H-bridge converters based STATCOM, it is important to ensure that the power drawn from each DC side is equal. Thus, each H-bridge cell in the inverter is equally utilized. However, due to inverter devices are not ideal and have different tolerance

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errors, each dc capacitor voltage may not be exactly balancing.

It is a main disadvantage for cascaded H-bridge converters used for STATCOM, so it is necessary using an additional control strategy to balance the DC voltages [5-7]. Several literatures have discussed how to balance the DC voltage of the cascaded H-bridge multilevel converter. In [6] shifting a small phase angle of the output voltage for every H-bridge cells is presented. In [5] [6] a switching pattern swapping scheme is presented. However, a low-frequency switching modulation--looking-up table method was used in it due to the limitations of high power electronic switches. In [1], it combines individual balancing control with clustered balancing control to regulate DC voltage. However, it is not easy to assign appropriate values to gain parameters. Like in [1], in [8], additional control loop is used to regulate the active power absorbed by each cell.

Generally, phase angle shift control scheme is one of the most simple methods and easy to realize. This paper proposed a novel design approach about the PI controller of the two control loops (traditional DC voltage control loop and a small phase angle shift control loop), by means phase shift SPWM technique, it can realize DC voltage well balance.

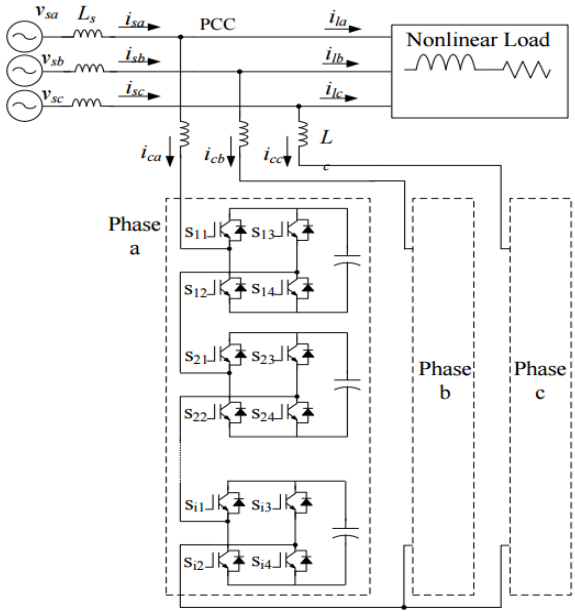

Fig 1: Schematic of a cascaded-multilevel converter based STATCOM system

STATCOM

Focus on the STATCOM operation and performance under abnormal network conditions.As probably the most severe cause of malfunctioning of grid-connected equipment is unbalanced voltage sags, this is the usual source of abnormal situations considered in these studies. Voltage sags typically tend to deteriorate the performance of the power converters and electrical machines connected to the ac network. In particular, a reduction of the power quality is noticed in this equipment, which is caused by a ripple in the output power and an increase in the current harmonic distortion.The following features followed by STATCOM:This device is connected to the line as a shunt mode.This device is based on voltage source inverter (VSI).In this device there are no chances of resonance phenomenon.Using this device the reactive power supported to the system or bus i.e. enhances voltage profile of the system.

Dynamic model of STATCOM

Fig. 2 shows the equivalent circuit of the STATCOM system where Vs is the source voltage, Vc is the generated voltage of the STATCOM and ic is the current drawn by the STATCOM, Lc and Rare reactance and resistance of source and filter reactor.

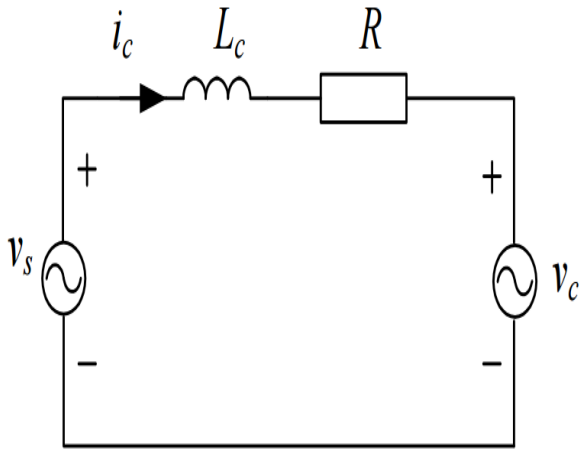

Fig 2: Equivalent circuit of the STATCOM

According to equivalent circuit shown in Fig. 2

$$L\frac{dI_c}{dt}+RI_c=V_s-V_c$$

In d-q synchronous reference frame, the mathematical expression of the STATCOM is shown as follows:

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$$L\frac{d}{dt}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + R\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} - \begin{bmatrix} v_{cd} \\ v_{cq} \end{bmatrix} + \omega L\begin{bmatrix} i_{cq} \\ -i_{cd} \end{bmatrix}$$

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \sqrt{3}U_s\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

Fig. 1 shows the circuit configuration of the star-configured STATCOM cascading H-bridge pulse width modulation (PWM) converters in each phase and it can be expanded easily according to the requirement. By controlling the current of STATCOM directly, it can absorb or provide the required reactive current to achieve the purpose of dynamic reactive current compensation. Finally, the power quality of the grid is improved and the grid offers the active current only.

For selecting insulated-gate bipolar transistor (IGBT), considering the complexities of practical industrial fields, there might be the problems of the spike current and over load. Consequently, in order to ensure the stability and reliability of H-bridge cascaded STATCOM, and also improve the over load capability, the current rating of the selected IGBT should be reserved enough safety margin.

The modulation technology adopts the carrier phase-shifted sinusoidal PWM (abbreviated as CPS-SPWM).

CONTROL STRATEGY

The decoupled currents can be written as

$$\frac{d}{dt}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} -R/L & 0 \\ 0 & -R/L \end{bmatrix}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} v_{sd} - v_{cd} + \omega L i_{cq} \\ v_{sq} - v_{cd} - \omega L i_{cd} \end{bmatrix}$$

Introducing two intermediate variables, x1, x2

$$x_1 = v_{sd} - v_{cd} + \omega L i_{cq}$$

$$x_2 = -v_{cq} - \omega L i_{cd}$$

$$\frac{d}{dt}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} -R/L & 0 \\ 0 & -R/L \end{bmatrix}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Variables x1, x2 can be obtained

$$x_1 = k_p(i_{cd}^* - i_{cd}) + k_i\int(i_{cd}^* - i_{cd})dt$$

$$x_2 = k_p(i_{cq}^* - i_{cq}) + k_i\int(i_{cq}^* - i_{cq})dt$$

Icq* is the reference of the reactive current, and it can be got through reactive current detection. The reference of the active current,icd*, is derived from aPI controller as follows:

$$i_{cd}^* = (k_p + k_i/s)(v_{dc}^* - 2\sum v_{dci}/(n-1))$$

Where n is the number of level. The d-axis and q-axis reference voltage equations of the STATCOM in Fig. 3 are

$$\begin{bmatrix} v_{cd}^* \\ v_{cq}^* \end{bmatrix} = \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} - \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \omega L\begin{bmatrix} i_{cq} \\ -i_{cd} \end{bmatrix}$$

The modulation index and phase angle of STATCOM output voltage are given by:

$$MI = \sqrt{(v_{cd}^*)^2 + (v_{cq}^*)^2}\,/\,kn\overline{v}_{dc}$$

$$\delta = \tan^{-1}(v_{cq}^*/v_{cd}^*)$$

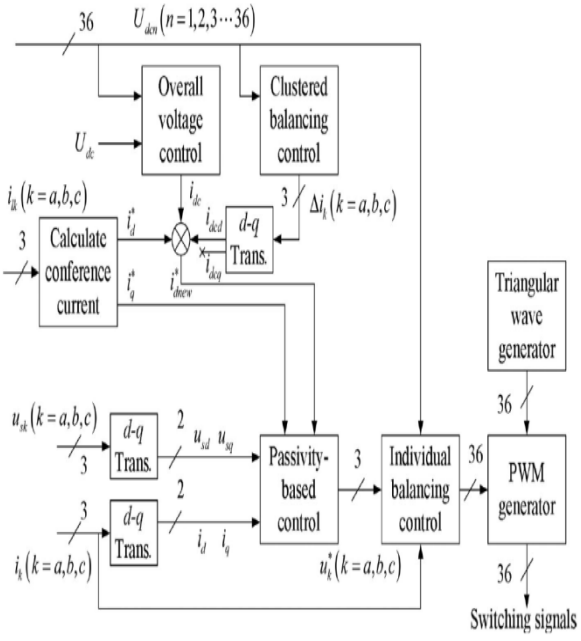

Fig 3: Control block diagram

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Generally, the dc capacitor voltage of H-bridge cascaded STATCOM is maintained at the given value through absorbing the active current from the grid that can be achieved by controlling the d-axis active current.

This d-axis active current i*dc = idc + idcd can be added to the d-axis reference current. The newfound d-axis reference current is i*dnew = i*d + i*dc. Now, the three expected stable equilibrium points of the system can be revised two: x*1 = i*dnew and x*2 = i*q Error system is established as follows:

$xe = x – x^* = [id –i^*dnewiq–i^*q]^T$

Where x* is the expected stable equilibrium point of the system.

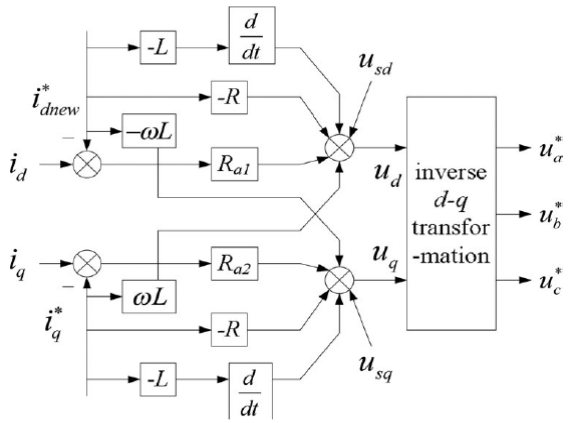

Fig 4: impedance controlling technique

As the first-level control of the dc capacitor voltage balancing, the aim of the overall voltage control is to keep the dc mean voltage of all converter cells equalling to the dc capacitor reference voltage. The common approach is to adopt the conventional PI controller which is simple to implement. However, the output voltage and current of H-bridge cascaded STATCOM are the power frequency sinusoidal variables and the output power is the double power frequency sinusoidal variable, it will make the dc capacitor also has the double power frequency ripple voltage.

So, the reference current which is obtained in the process of the overall voltage control is not a standard dc variable and it also has the double power frequency alternating component and it will reduce the quality of STATCOM output current.

In general, when using PI controller, in order to ensure the stability and the dynamic performance of system, the bandwidth of voltage loop control is set to be 200–500 Hz and it is difficult to restrain the negative effect on the quality of STATCOM output current which is caused by the 100 Hz ripple voltage. Moreover, because of static error of PI controller, it will affect not only the first level control but also the second and the third one. Especially, during the start-up process of STATCOM, it will make the voltage reach the target value with a much larger overshoot.

As the overall dc voltage and the clustered dc voltage are controlled and maintained, the individual control becomes necessary because of the different cells have different losses. The aim of the individual balancing control as the third level control is to keep each of 12 dc voltages in the same cluster equalling to the dc mean voltage of the corresponding cluster. It plays an important role in balancing 12 dc mean capacitor voltages in each cluster. Due to the symmetry of structure and parameters among the three phases, a-phase cluster is taken as an example for the individual balancing control analysis.

The method can be illustrated as follows.

1) If the requirement is to reduce the duty cycle, it needs to shift down the normal modulation wave and shift up the opposite modulation wave.

2) If the requirement is to prolong the duty cycle, it needs to shift up the normal modulation wave and shift down the opposite modulation wave.

SIMULATION RESULTS

Two H-bridge cascaded STATCOMs are running simultaneously. One generates the set reactive current and the other generates the compensating current that prevents the reactive current from flowing into the grid. The paper is divided into two parts: the current loop control and the dc capacitor voltage balancing control. In current loop control, the measured simulation waveform is the current of a-phase cluster.

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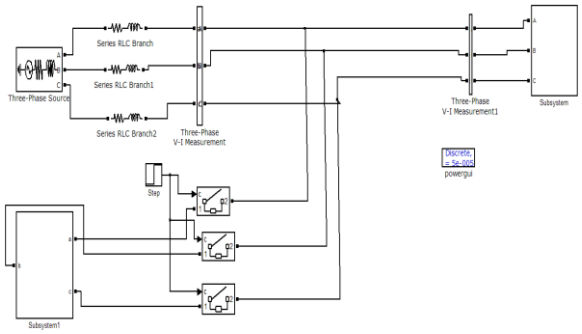

Fig 5: Simulation circuit of STATCOM interconnected to grid

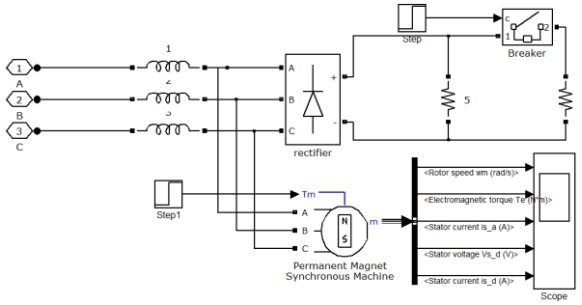

Fig 6: simulation circuit of Non-linear load along with PMSM motor

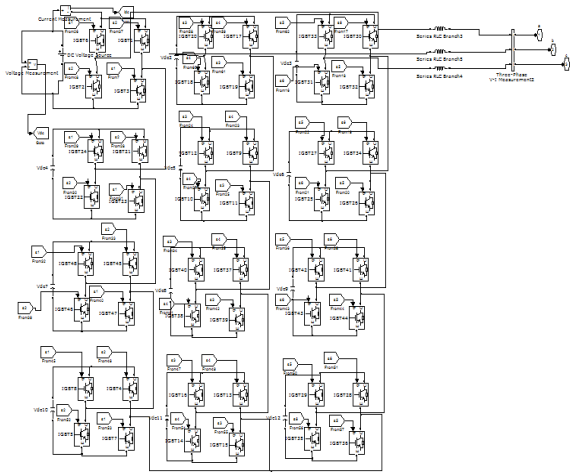

Fig 7: simulation circuit of H-bridge converter

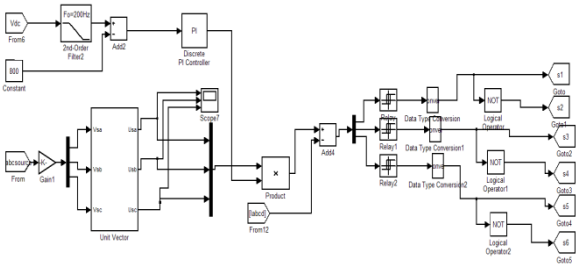

Fig 8: Simulation circuit of control strategy

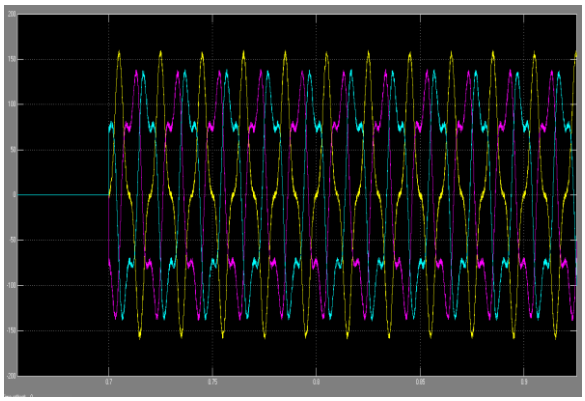

Fig 9: STATCOM current

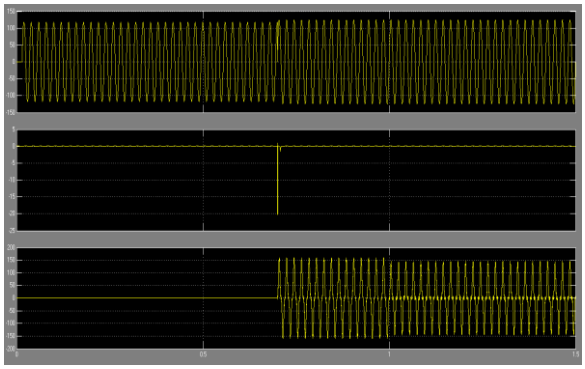

Fig 10: source current, load current and STATCOM current

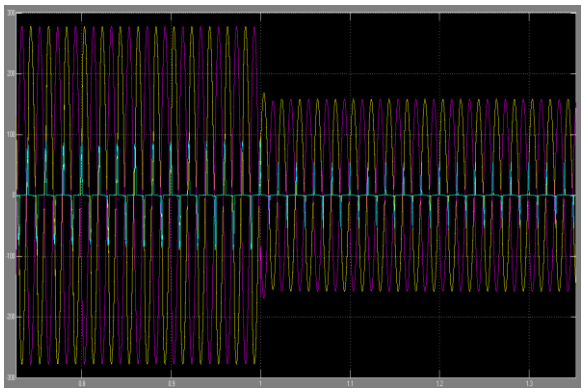

Fig 11: Load voltage

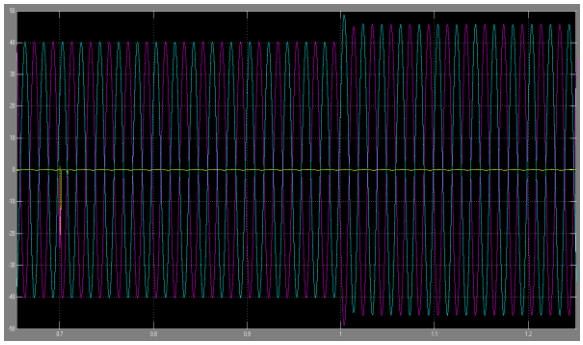

Fig 12: Load current

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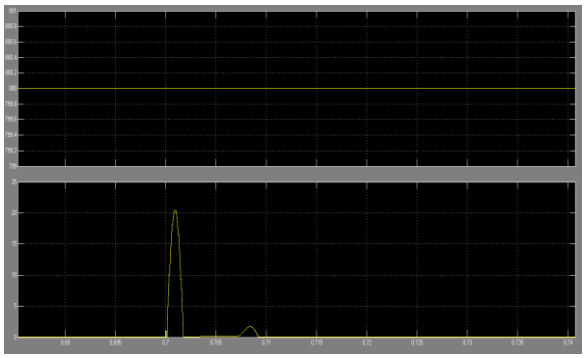

Fig 13: Dc link voltage and current

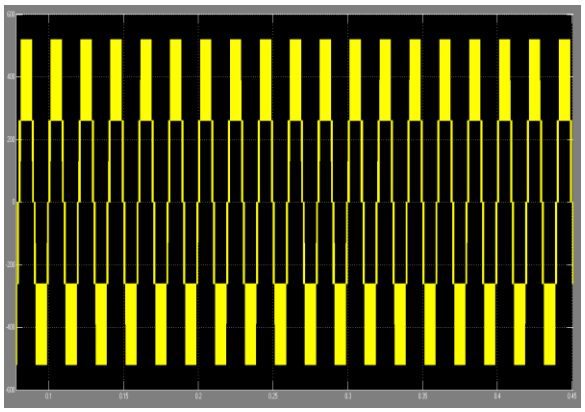

Fig 14: STATCOM voltage

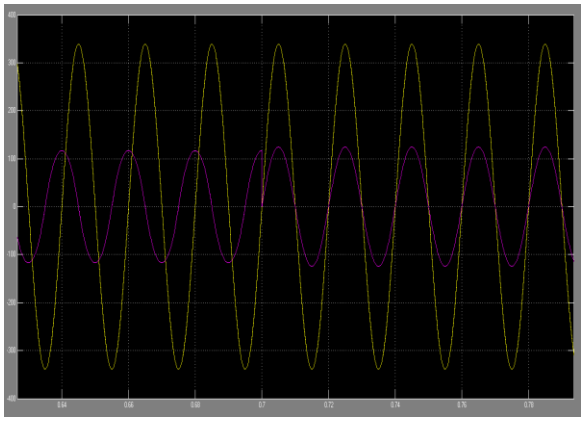

Fig 15: Source voltage and source current

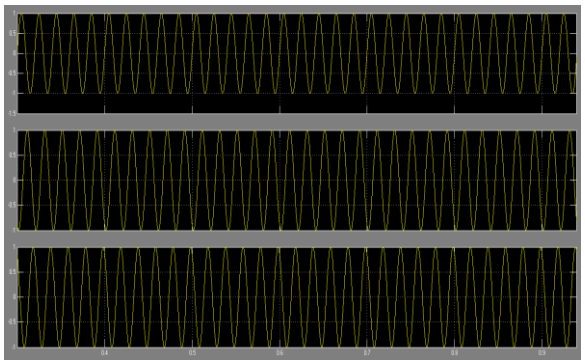

Fig 16: Synchronous reference frame voltage

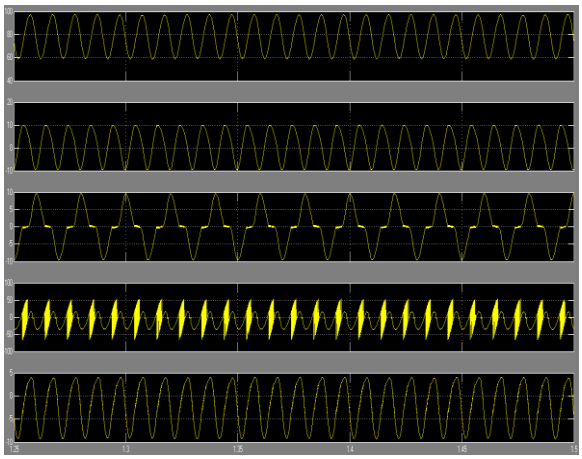

Fig 17: performance characteristics of PMSM motor

CONCLUSION

Paper finds its new application in H-bridge cascaded STATCOM for clustered balancing control. It realizes the excellent dynamic compensation for the outside disturbance. The previous method is the modulation strategy that is based on CPS-SPWM in this paper and it is very easy to be realized. The simulation results have confirmed that the proposedmethods are feasible and effective.

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