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Design of STATCOM for unbalanced Voltage Systems with Adaptive multilevel converter (AMC)

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Abstract:

Adaptive multilevel converter (AMC) for shunt static compensator (STATCOM) connected with unbalanced voltage systems are proposed in this paper. The AMC is designed with the current control algorithm with time-discrete system and PWM control of phase-shifted carrier modulation technique. The proposed converter is having better compensation of the reactive power and harmonics. The AMC is designed with reduced number of switches and an approach to find fault switch. An 11 level AMC is proposed with STATCOM integrated with unbalanced voltage system. The dynamic performance of the STATCOM under transient conditions is validated by MATLAB/SPS (SimPowerSystem) Tool.

Index Terms:

Adaptive multilevel converter (AMC), Fault Detection, DC voltage balancing, STATCOM, and PWM control.

I.INTRODUCTION:

Nowadays, multilevel converters are used like the power stages in STATCOMs [1], due to their advantages over other converter topologies. The voltage stresses can be reduced when the numbers of levels increases, the power switches are driven with a low commutation frequency and multilevel converters can synthesize a voltage waveform with a very low harmonic content [2]. Compared with diode clamped multilevel converters or flying capacitor multilevel converters, the cascaded multilevel converters can be directly connected to a medium-voltage network without a bulky step up transformer, resulting in cost and weight reductions [3]. However, they have some restrictions when the fast compensation of large, fluctuating unbalanced loads, such as electric traction systems [4], is required. THE static synchronous compensator (STATCOM) has been well accepted as a power system controller for improving voltage regulation and reactive compensation. There are several compelling reasons to consider a multilevel converter topology for the STATCOM. These well known reasons include the following:

1)Lower harmonic injection into the power system;

2)Decreased stress on the electronic components due to decreased voltages; and

3)Lower switching losses.

Various multilevel converters also readily lend themselves to a variety of PWM strategies to improve efficiency and control. This converter uses several full bridges in series to synthesize staircase waveforms. Because every full bridge can have three output voltages with different switching combinations, the number of output voltage levels is 2n + 1 where n is the number of full bridges in every phase. The converter cells are identical and therefore modular. Adaptive multilevel converters [5] (AMC) have recently been proposed as an alternative to conventional multilevel converters in medium voltage applications. They provide a viable approach to constructing a reliable and cost effective STATCOM, with an increased number of levels capable of eliminating the coupling transformer and replacing it with cheap reactors to allow a power exchange with the power system.

In addition, it can operate continuously under unbalanced conditions, it is capable of surviving symmetrical and asymmetrical faults without increasing the risk of system collapse and it has fault management capability. The focus of this paper is to realize a transformerless STATCOM, based on an AMC for the compensation of a nonlinear unbalanced load in a medium-voltage level. For this purpose, a control strategy based on the instantaneous power theory is developed for extracting the compensating current signals.

Then, a new real-time current control technique is introduced for the AMC, based on the predictive control method. An appropriate switching modulation technique is applied to the AMC, keeping the stored energy in all of the legs balanced, even if the converter currents are unbalanced and the network voltages are slightly distorted. Analytical formulas are derived to demonstrate the accurate mechanism of the DC-link voltage balancing. Simulations are conducted to prove the effectiveness of the proposed controller and the topology of the AMC based STATCOM.

The organization of the paper is as follows: section II describes the Power Circuit description, control method for Adaptive Modular Converter, balancing of DC-bus voltage is observed in Section IV, Simulation Results are observed in Section V, and finally Section VI concludes the paper. The basic circuit structure of a four-wire STATCOM based on a MMC is depicted in Figure. 1. Unlike conventional multilevel converters such as diode clamped or flying capacitor multilevel converters, there is no common DC-link capacitor in the configuration of the proposed STATCOM topology.

The MMC is comprised of two polarized star-connected half-bridge cascaded converters (HBCC), which are connected to the network in parallel. While one HBCC has a negative common link (NLHBCC), the other has a positive common link (PL-HBCC), and the negative and positive links are floating points. Each leg of both of the HBCCs consists of a number of series-connected half-bridge modules (HBM), and the legs are connected in a star structure.

II.POWER CIRCUIT DESCRIPTION

Main circuit structure

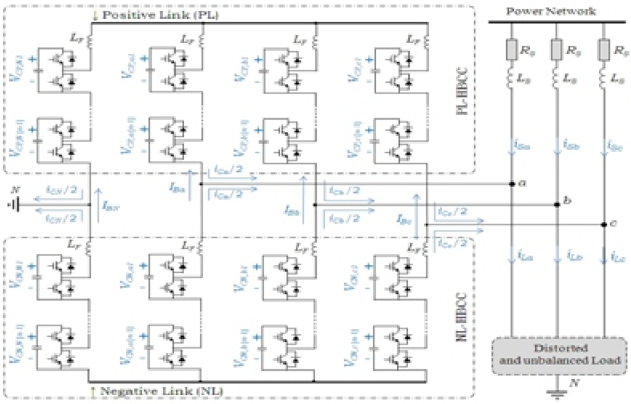

Figure 1: Circuit structure of the AMC based STATCOM and the way of its connection to the network.

Thus, each HBCC can be directly connected to a medium-voltage network without a coupling transformer. In four-wire load compensation, both of the star-connected HBCCs have four similar legs. To compensate a three-wire unbalanced load, the converter can also be composed of two three-leg polarized HBCCs. Both the NL-HBCC and the PLHBCC have the same power rating as well as the same current contribution to the STATCOM.

In fact, each HBCC can be independently applied to the network as a STATCOM, when the required compensating currents are balanced. Under unbalanced conditions, the flow of the negative-sequence currents on the output side of the AMC causes circulating current flow among the HBCC legs of the converter. The most important effect of the circulating current is the energy transfer between the legs. Therefore, it is imperative that both the PL-HBCC and the NL-HBCC in the shape of one AMC are applied to the network as a STATCOM, when the required compensating currents are unbalanced. In this condition, the stored energy of all of the legs of the AMC can be balanced, by applying an appropriate modulation scheme.

Half-bridge cascaded converters:

An n-level HBCC is defined by the available (n - 1) identical HBMs cascaded in each leg of that HBCC. All of the n-level legs are connected to the network using an inductive filter (L_F). In addition, all of the HBMs have the same semiconductor ratings as well as identical DC-link capacitances. Therefore, each HBM can be assumed to be an identical two-terminal device.

Voltage regulation of the DC-link capacitors is achieved without any additional connections or energy transfer circuits to the associated HBM. Each HBM is capable of producing either V_CM (the DC-link capacitor voltage of the module) or 0 volt at any given instance. Thus, the resultant voltage of a (n-1) cascaded HBM varies between [0, V_DCM], where V_DCM = (n - 1)V_CM. The voltage across a cascaded HBM, in all of the legs of each HBCC, includes a DC component and an AC component, as shown in Figure. 2.

The value of the AC voltage component must be the same for the corresponding legs of the NL-HBCC and the PL-HBCC, while the value of the DC voltage component must be in the inverted form for them. As a result, irrespective of the voltages on the filter inductors, the average voltage between the positive-link and the negative-link (V_PL-V_NL) is always VDCM. Thus, the average voltage between the positive-link and the neutral point (N) is V_PL = +V_DCM/2, while the average voltage between negative-link and N is V_NL = - V_DCM/2. Although the voltage on a leg has a DC component, there exists no DC component on the line-to-line voltage or the line-to-neutral voltage in both HBCCs.

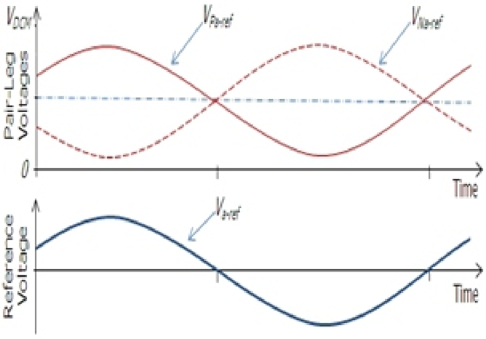

Figure 2: Reference voltages of the NL-HBCC leg and the PL-HBCC leg against the pair-leg reference voltage, all for phase a.

The instantaneous voltage on any two terminals of an HBCC is dictated by the difference between the cascaded HBM voltages of each of the legs connected to those terminals. Therefore, regardless of the filter inductor voltages, the line-to-line voltages of an HBCC can be adjusted within [-V_DCM; +V_DCM] .To enable compensation of the inductive loads, a value of VDCM must be chosen that is greater than the peak-to-peak amplitude of the line voltage [6]. In addition, both the NL-HBCC leg and the PL-HBCC leg connected to the same phase are controlled so that they constantly supply half of the AMC current per phase.

Balancing currents:

Under unbalanced conditions, the flow of the negative sequence currents on the output side of the MMC causes the DC currents to flow along the HBCC legs of the converter. In this condition, the energy stored in the HBM capacitors of the leg supplying active power wants to be reduced, while it wants to be increased in the leg consuming active power.

The energy stored in both of the legs connected to one phase (pair-leg) is equal, because each leg provides half of the output current in the corresponding phase. Nonetheless, the energy stored in the four pair-legs of the MMC may have different values, in the unbalanced condition. As a result, the direct balancing currents (I_B), flow from the over-charged pair-legs towards the undercharged pair-legs. Under such circumstances, the leg currents of the pair-leg connected to phase x are equal to:

$$\begin{bmatrix} i_{Nx} \\ i_{Px} \end{bmatrix} = \begin{bmatrix} \frac{i_{Cx}}{2} + I_{Bx} \\ \frac{i_{Cx}}{2} - I_{Bx} \end{bmatrix} \; (x = a, b\; or\; c) \qquad \text{- (1)}$$

where, i_Nx, i_Px, i_Cx and I_Bx are the NL-HBCC leg current, the PL-HBCC leg current, the STATCOM output current and the pair-leg balancing current, respectively, for phase x. In addition, in a four-leg MMC, the current of the NL-HBCC leg and the PL-HBCC leg connected to the neutral can be obtained as follows:

$$\begin{bmatrix} i_{NN} \\ i_{PN} \end{bmatrix} = - \begin{bmatrix} I_{Na} + I_{Nb} + I_{Nc} \\ I_{Pa} + I_{Pb} + I_{Pc} \end{bmatrix} \qquad \text{- (2)}$$

The balancing current magnitude in a pair-leg, IBx depends on the value of the active power interchanged between the network and that pair-leg. Applying Kirchhoff's current law (KCL) for each of the HBCCs leads to:

$$I_{Ba} + I_{Bb} + I_{Bc} + I_{BN} = 0 \qquad \text{- (3)}$$

This means that the sum of the total converter balancing currents will always be zero. In the presence of an appropriate modulation technique, the balancing current makes the stored energy at all of the legs remains balanced. In the steady state condition, the value of the balancing current through a pair-leg does not have an effect on the output current of the STATCOM in the corresponding phase.

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Meanwhile, any balancing current fluctuations are attenuated through the inductance L_F. Whenever an abrupt change occurs in the converter currents, the filter inductors damp the sudden rise in the balancing current I_Bx. The filter inductors, in all legs are identical and the inductance L_F is calculated according to the maximum permitted ripple on the output currents. The value of the required inductance can be calculated through the following equation:

$$L_F = \frac{V_{DCM}}{(n-1)\, f_C \Delta\, i_{C,max}} \qquad - (4)$$

Here $\Delta_{iC,max}$ is the maximum allowable ripple on the output current and f_c is the switching frequency of each HBM.

III.CONTROL STRATEGY:

The main challenges associated with AMC based STATCOM control are shaping the output phase currents, balancing the DC-link voltages of all of the HBMs, and keeping the DC-link voltages at the desired reference value. However, this can become difficult if the converter currents have zero or negative sequence components, or the series HBMs have slightly different characteristics. When implementing a medium voltage MMC, even the parasitic stray capacitances to the Earth can lead to unwanted scaling effects and unequal voltage distribution among the series connected HBMs.

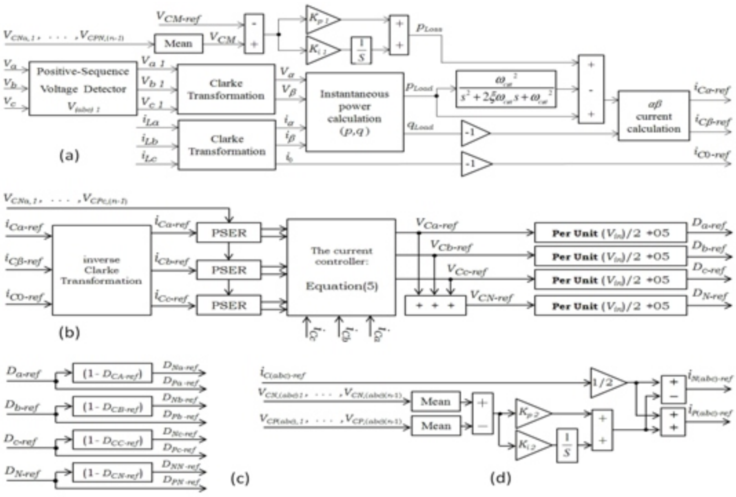

Figure 3: Proposed controller for the MMC based STATCOM: (a) derivation of the three-phase reference currents in αβ0 coordinates, (b) the current controller and reference duty cycle extraction, (c) duty cycle extraction to generate switching modulation signals for each HBM, (d) the Pair-leg Stored Energy Regulator (PSER) diagram.

A basic diagram of the proposed controller is shown in Figure. 3. The diagram consists of both a reference current extractor and a predictive current controller.

Reference signals calculation:

The general instantaneous power theory [7] introduces the reference currents for each phase of the MMC based STATCOM as described in Figure. 3(a). The objective of this compensation theory is to make the source currents completely sinusoidal and balanced, i.e. in phase with the fundamental positive sequence component of the source voltage. The reference current can be obtained for both unbalanced load conditions and unbalanced voltages conditions, simultaneously. By measuring the three-phase voltages of the point of common coupling (PCC), the reference voltages of the legs in each pair-leg can be calculated.

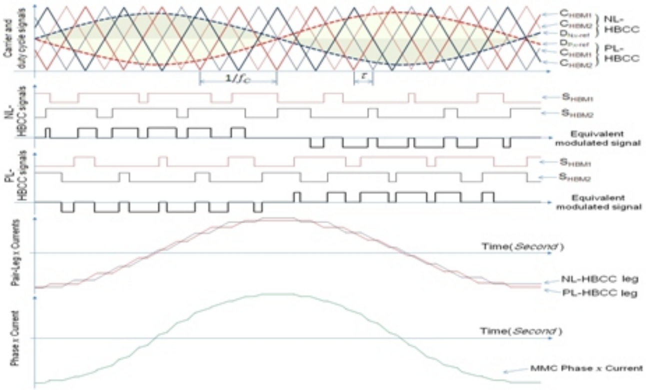

Figure 4: Illustration of applied phase-shifted PWM modulation technique to create switching signals for all HBM in a pair-leg, assuming each leg of the AMC includes two HBM.

HBM switching modulation signals among the various pulse programming methods, the carrier based pulse width modulation (PWM) methods are the preferred approaches in multilevel converters due to their fixed switching frequencies and their implementation simplicity. Phase-shifted PWM (PS-PWM) is the most commonly used modulation technique for cascaded multilevel converters, because it offers an even power distribution among all of the HBMs, and it is very easy to implement independent of the number of series HBMs [8]. This modulation shifts the phase of each carrier signal in a proper angle to reduce the harmonic content of the passing current from each leg and to lower the output current ripple of the MMC (see Figure. 4).

Although the carrier signals used for each HBM have a similar shape, they are relatively shifted to each other as follows:

$$\tau = \frac{1}{2(n-1)f_C} \qquad - (5)$$

Where τthe time interval between two adjacent carriers signals and f_C is is the frequency of each carrier signal (actually the switching frequency of each HBM). While each HBM in a leg has an independent carrier signal, the reference signal is shared by all of the HBMs in a series. The switching pattern for each HBM is obtained by comparing the reference duty cycle signal with the carrier signal related to that HBM. To reduce the output current ripple of the AMC, the carrier signals for the NL-HBCC legs are shifted by 180deg in comparison with those of the PL-HBCC legs, as shown in Figure 4. Therefore, the output current ripple of the AMC can reciprocally be canceled up to 50% in comparison with the ripples of each HBCC.

IV.BALANCING OF DC-LINK VOLTAGE:

Self energy balancing inside the AMC:

The instantaneous power of both legs in a pair-leg connected to phase x of the network, can be calculated using (1) and (5). Over the network frequency (i.e. 50 Hz or 60Hz), the instantaneous power of each leg has a DC component along with an alternative component as follows:

$$\begin{bmatrix} P_{Nx} \\ P_{Px} \end{bmatrix} = \begin{bmatrix} \overline{P_{Nx}} \\ \overline{P_{Px}} \end{bmatrix} + \begin{bmatrix} \widetilde{P_{Nx}} \\ \widetilde{P_{Px}} \end{bmatrix} \qquad - (6)$$

The DC component of the instantaneous power is equal to (V_DCM I_BN)/2, which is the same for both legs connected to the neutral. As a result, the stored energy in both legs of each pair-leg is equal. On the other hand, the stored energy in all of the pair-legs becomes equal, due to the presence of the balancing currents, resulting in an energy balance among all of the pair-legs in the converter. In fact, all of the pair-legs are connected together in parallel. Therefore, the MMC theoretically has the ability of self energy balancing among all of the legs, even in unbalanced conditions. To regulate the total stored energy inside the converter, so that it is equal to a predetermined reference value, a DC voltage regulator unit is added to the reference output power of the STATCOM as shown in Figure 3(a). As a result, the mean value of all of the DC-link capacitor voltages is regulated toward a certain value by estimating the power losses through the DC voltage regulator unit. However, the energy stored in both legs connected to the same phase may be a little different, due to the non-ideal nature of the converter elements. This may be eliminated by using an appropriate local controller to adjust the current contribution of both legs connected to the same phase, as shown in Fig. 3(d). There are four pair-leg stored energy regulators (PSER) in the MMC, which regulate the stored energy of both legs in a pair-leg.

Capacitor voltage balancing in the cascaded HBM Each HBM has two complementary switches in series, providing either the DC-link voltage or zero for the AC output. When the AC output voltage of a HBM in the NL-HBCC is set to its DC-link voltage, the capacitor voltage of the HBM, decreases for a positive input current (i_Nx >0), and increases for a negative input current (i_Nx < 0). Conversely, in the PL-HBCC, the capacitor voltage increases for a positive input current (i_Px > 0) and decreases for a negative input current (i_Px < 0). When the output voltage of a HBM is set to zero, the capacitor voltage will not change in both of the HBCCs. These switching effects can be used for capacitor voltage balancing among all of the series HBMs in a leg. For this purpose, the measured capacitor voltages of the legs are sorted in ascending order during each of the switching periods. The sign of the leg current and the number of the HBM that are permanently set to its DC-link voltage determine which HBM should be selected [9].

V.SIMULATION RESULTS:

The simulation circuit of the electrical distribution system feeding to an unbalanced is shown in Figure. 5. The STATCOM has been shown to be an efficient controller to mitigate arc furnace flicker. The electrical network consists of a 115-kV generator and impedance that is equivalent to that of a large network at the point of common coupling (PCC). The STATCOM is connected to the system through a Y-Delta transformer. The system was simulated using MATLAB/SimPowerSystem Tool. The electrical arc furnace load is non-sinusoidal, unbalanced, and randomly fluctuating.

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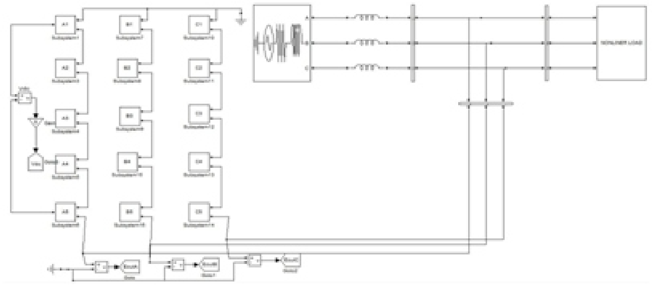

Figure 5: simulation circuit STATCOM interconnected with Power System.

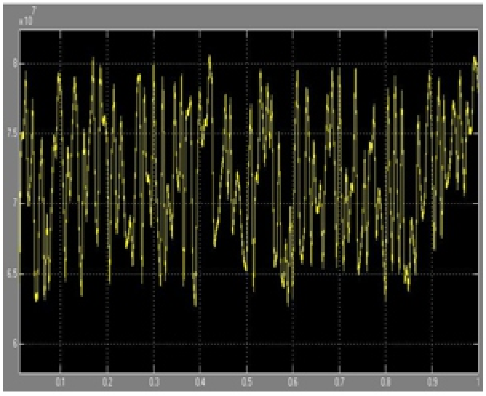

Figure 6: Active power drawn by the arc furnace load.

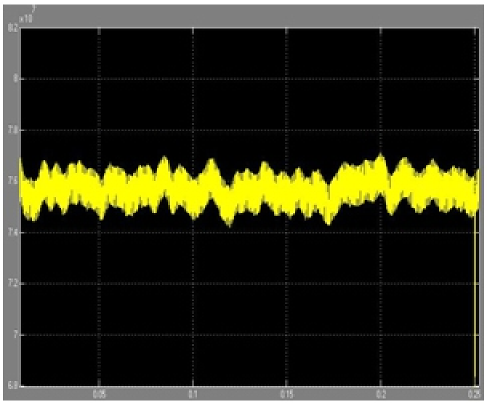

Figure 7: Line active power.

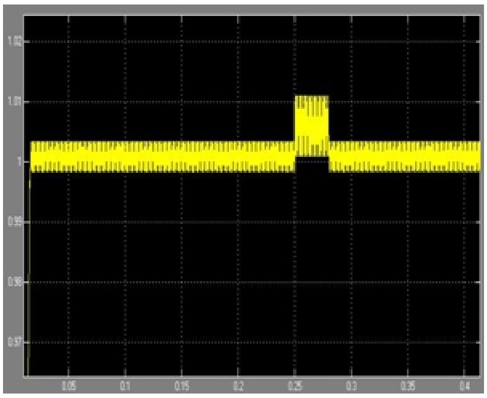

Figure 8: STATCOM voltage before, during, and after fault.

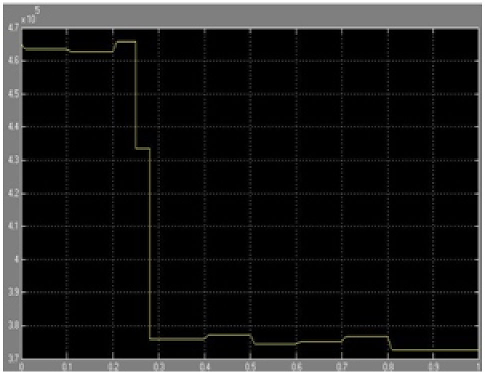

Figure 9: DC voltage before, during, and after fault.

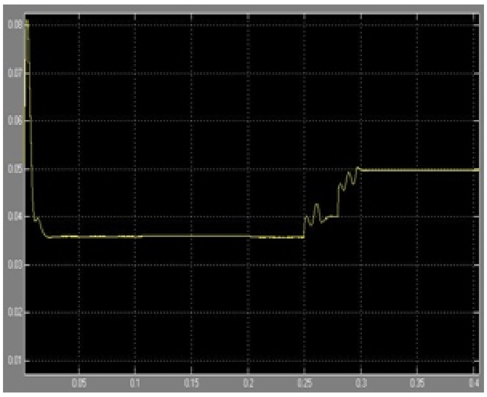

Figure 10: Modulation gain k before, during, and after fault.

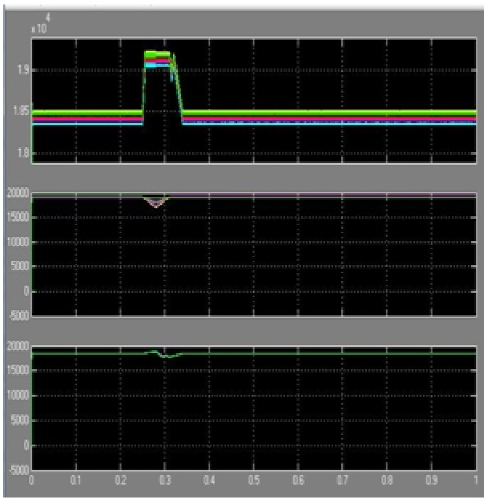

Figure 11: Individual module capacitor voltages before, during, and after fault.

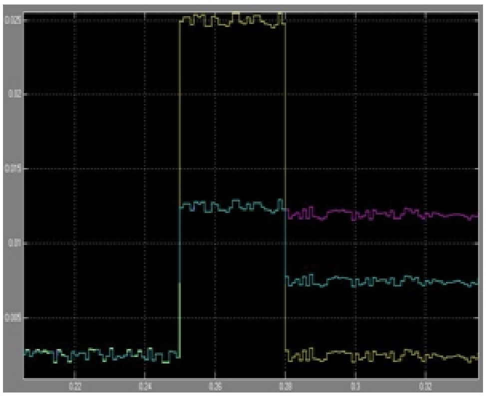

Figure 12: Percent harmonic content of the faulty phase before, during, and after fault.

CONCLUSION:

This paper presents a novel high-power STATCOM based on an Adaptive multilevel converter to compensate an unbalanced and distorted medium-voltage load. An appropriate predictive current controller which predicts in real time the module voltages, presents ac currents of the MMC based STATCOM that track their references with a small ripple. Considering the simulation studies, to compensate higher order harmonics, a smaller switching frequency for each switch is needed.

This will result in smaller switching power losses and an improvement in energy efficiency, as well as a reduction in the heat dissipation, dimensions and weight of the converter. The AMC based STATCOM is having advantages of adaptively and operation under unbalanced load conditions. The simulation results are validated for proposed AMC with STATCOM connected to Power System under various voltage levels.

REFERENCES:

[1] C. K. Lee, J.S K. Leung, S.Y R. Hui, H.S.H. Chung, “Circuit-level comparison of STATCOM technologies,” IEEE Transactions on Power Electronics, Vol. 18, No. 4, pp. 1084-1092, Jul. 2003.

[2] H. I. Eini, S. Farhangi, J. L. Schanen, M. K. Fard, “A fault-tolerant control strategy for cascaded h-bridge multilevel rectifiers,” Journal of Power Electronics, Vol. 10, No. 1, pp.34-42, Jan. 2010.

[3] R.E. Betz, T. Summerst, T. Furney, “Using a cascaded h-bridge STATCOM for rebalancing unbalanced voltages,” The 7th International Conference on Power Electronics, 2007.

[4] Pee-Chin Tan, R.E. Morrison, D.G. Holmes, “Voltage form factor control and reactive power compensation in a 25-kV electrified railway system using a shunt active filter based on voltage detection,” IEEE Transactions on Industry Applications, Vol. 39, No. 2, pp. 575 - 581, Mar./Apr. 2003.

[5] R. Marquardt, “Stromrichters chaltungen mitverteilten energiespeichern,” German Patent DE 10 103 031, Jan. 24, 2001.

[6] M. Tavakoli Bina, A.K.S Bhat, “Averaging technique for the modeling of STATCOM and active filters,” IEEE Transactions on Power Electronics, Vol. 23, No. 2, pp. 723 – 734, Mar. 2008.

[7] Akagi, Watanabe, Aredes, “Instantaneous power theory and applications to power conditioning,” The Institute of Electrical and Electronics Engineers Inc., 2007.

[8] R. Gupta, A. Ghosh, and A. Joshi, “Switching characterization of cascaded multilevel-inverter-controlled systems,” IEEE Transactions on Industrial Electronics, ol. 55, no. 3, pp. 1047–1058, Mar. 2008.

[9] S. Rohner, S. Bernet, M. Hiller, R. Sommer, “Modulation, losses and semiconductor requirements of modular multilevel converters,” IEEE Transactions on Industrial Electronics, IEEE Early Access, 2009.