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Three phases cascaded five level shunt active filters with fuzzy logic control for Power quality improvement

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Abstract— SAF can provide fast and efficient reactive power support to maintain power system voltage stability. In the literature, various SAF control methods have been discussed including many applications of fuzzy logic controllers. However, these previous works obtain via a trial-and-error approach or extensive studies with a tradeoff of performance and applicability. Hence, control parameters for the optimal performance at a given operating point may not be effective at a different operating point. This project proposes a new control model based on adaptive fuzzy logic control, which can self-adjust the control gains during a disturbance such that the performance always matches a desired response, regardless of the change of operating condition. Since the adjustment is autonomous, this gives the plug-and-play capability for SAF operation. In the simulation test, the adaptive fuzzy logic control shows consistent excellence under various operating conditions, such as different initial control gains, different load levels, and change of transmission network, consecutive disturbances, and a severe disturbance. Here in SAF three phase five levels cascaded multilevel inverter is used as a voltage source converter. This project is implemented in Matlab simulation.

Keywords- Multilevel Inverter, Synchronous Reference Frame Theory, dc link voltage control, Shunt Active Filter, Fuzzy logic control.

I. INTRODUCTION

There has been a continuous rise of nonlinear loads over the years due to intensive use of power electronic control in industry as well as by domestic consumers of electrical energy. The utility supplying these nonlinear loads has to supply large vars. Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous var control with fast dynamic response and on-line elimination of harmonics. To satisfy these criterion, the traditional methods of var compensation using switched capacitor and thyristor controlled inductor coupled with passive filters are increasingly replaced by active power filters (APFs) and hybrid APFs. The hybrid APFs improve the characteristics of passive filters with smaller rated APFs. The majority of the reported APFs and hybrid APFs use a var calculator to calculate the reactive current drawn by the load and accordingly a reference current is generated. The compensator current is made to follow the reference current for the required compensation. This method exhibits good current profile and fast dynamic response; however the generation of reference current is a complicated process. In the proposed indirect current controlled APF, the reference current is generated from the DC link capacitor voltage directly, without calculating the reactive current drawn by the load. As the reference current in the proposed APF is generated from the DC link capacitor voltage, without calculating the reactive current drawn by the load, the compensation process is straight forward and simple as compared to the control techniques of conventional APFs. For higher rated nonlinear loads; multilevel inverters (MLIs) can be used. To control the output voltage and reduce undesired harmonics of MLIs, sinusoidal PWM, selective harmonic elimination or programmed PWM and space vector modulation techniques have been conventionally used in MLIs. The major complexity associated with such methods is to solve the nonlinear transcendental equations characterizing the harmonics using iterative techniques such as Newton–Raphson method. However, this is not suitable in cases involving a large number of switching angles if good initial guess is not available. Another approach based on mathematical theory of resultant, wherein transcendental equations that describe the selective harmonic elimination problem are converted into an equivalent set of polynomial equations and then mathematical theory of resultant is utilized to find all possible sets of solutions for the equivalent problem has also been reported. However, as the number of harmonics to be eliminated increases (up to five harmonics), the degrees of the polynomials in the equations become so large that solving them becomes very difficult. The evolutionary algorithm can be applied for computing the optimal switching angles of the MLI with the objective of optimizing the individual harmonics to allowable limits. In this paper the compensation algorithms used to extract the three-phase reference currents are based on the synchronous reference frame (SRF) method. Although the SRF method is based on the balanced three phase loads, it can also be used for single-phase loads, allowing independent control of all three phases. The flexibility to choose the SRF-based controller strategy will determine if the negative, zero or both sequence current components will be compensated. The SRF-based algorithms will be evaluated under unbalanced load conditions and will be applied to APF topologies. Mathematical analyses of the SRF-based algorithms are presented and simulation results are performed to validate the theoretical development and confirm the performance of the shunt APFs.

II. SHUNT ACTIVE POWER FILTER

Shunt active filters are by far the most widely accept and dominant filter of choice in most industrial processes. Figure 1 show the system configuration of the shunt design. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The objective of the shunt active filter is to supply opposing harmonic current to the nonlinear load effectively resulting in a net harmonic current. This means that the supply signals remain purely fundamental. Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel to the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined together to withstand higher currents. The APF consists of a DC-bus capacitor (*C f*), power electronic devices and a coupling inductors (*L f*). Shunt APF acts as a current source for compensating the harmonic currents due to nonlinear loads. This is achieved by “shaFuzzy logicng” the compensation current waveform (if), using the Current Controlled- VSI. The required compensating currents are obtained by measuring the load current (*iL*) and subtracting it from a sinusoidal reference

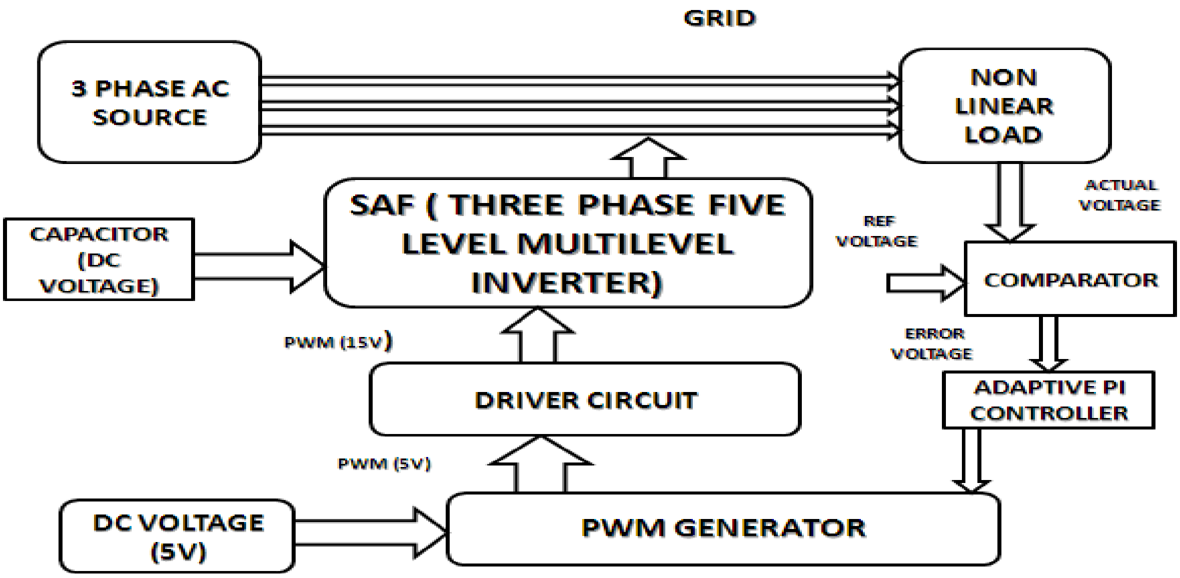

Fig. 1. Block diagram of the SAF system.

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The aim of shunt APF is to obtain a sinusoidal source current (is) using the relationship:
$is = iL - i f$.
Current component (iL , f) and the current harmonics (iL,h) according to
iL = iL,f + iL,h ……..(1)
Then the compensation current injected by the shunt APF should be
if = iL,h ………………(2)
The resulting source current is
is = iL –if = iL,f ..…….(3)

From the above equation (3) the source current contains only the fundamental component of the nonlinear load current and thus free from harmonics. When the shunt APF performs harmonic filtering, the ideal source current for a nonlinear load connected. In this way the shunt APF completely cancels the current harmonics from the nonlinear load, thus results in a harmonic free source current. The shunt APF can be considered as a varying shunt impedance from the nonlinear load current point of view. For the harmonic frequencies the impedance is zero, or at least small, and infinite in terms of the fundamental frequency. Due to this effect there is a considerable in voltage harmonics, because the harmonic currents flowing through the source impedance are reduced. The current carried by the Shunt APFs is the sum of the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. Reactive power compensation is also possible through the Shunt APF. Moreover for higher power rating applications, it is also possible to connect several shunt APFs in parallel to meet the requirement for higher currents.

III. SRF CURRENT CONTROL ALGORITHM

The SRF-based algorithms will generate the compensation reference currents (*ica* , *icb* , *icc*) for all topologies and, specifically, the neutral reference current (*icn*) when the F-L APF topology is used. The SRF-based algorithms can be used to perform load unbalance compensation or to independently compensate each of the three phases. When the load unbalance compensation is implemented the source currents become balanced and sinusoidal. However, when the phases are individually controlled the source currents will be sinusoidal but unbalanced. As the SRF algorithm is based on balanced three-phase loads, some modification must be done to apply it to a three-phase system, where each phase is treated as a single-phase system.

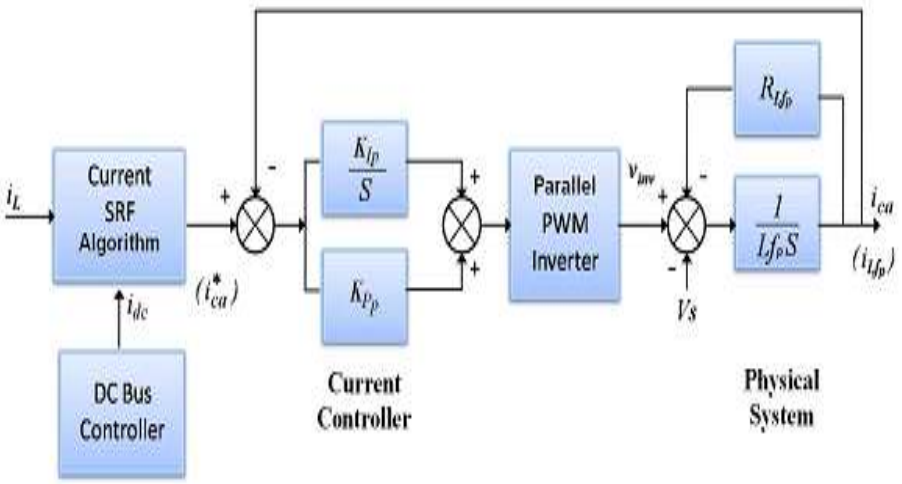


Fig. 2. SRF current control block diagram.

IV. PROPOSED SHUNT ACTIVE FILTER

The proposed SRF controlled shunt APF is shown in Fig.3. It has a three phase three level cascaded type multilevel inverter and it has two control loops, the voltage control loop and the current control loop. The voltage control loop regulates the value of the DC link capacitor voltage (Vc). The sensed DC link capacitor voltage is sent to a low pass filter (LPF) to remove the ripples present in it. The voltage thus obtained is compared with a reference DC voltage (Vdc, ref) and the error is fed to a FUZZY LOGIC controller. The output of the FUZZY LOGIC controller is the amplitude (k) of the current, which is used to derive the reference current. The derived reference current is compared with the source current in the current control loop for generating gate signals for the switches of the voltage source inverter (VSI) of the APF. SRF control has been used in the current control loop of the proposed APF. The VSI is controlled to produce a fundamental terminal voltage in-phase with the AC system voltage. When the fundamental inverter terminal voltage is more than the RMS value of AC system voltage Vs, a leading current is drawn from the AC system and when the inverter terminal voltage is less than Vs, a lagging current is drawn from the AC system.

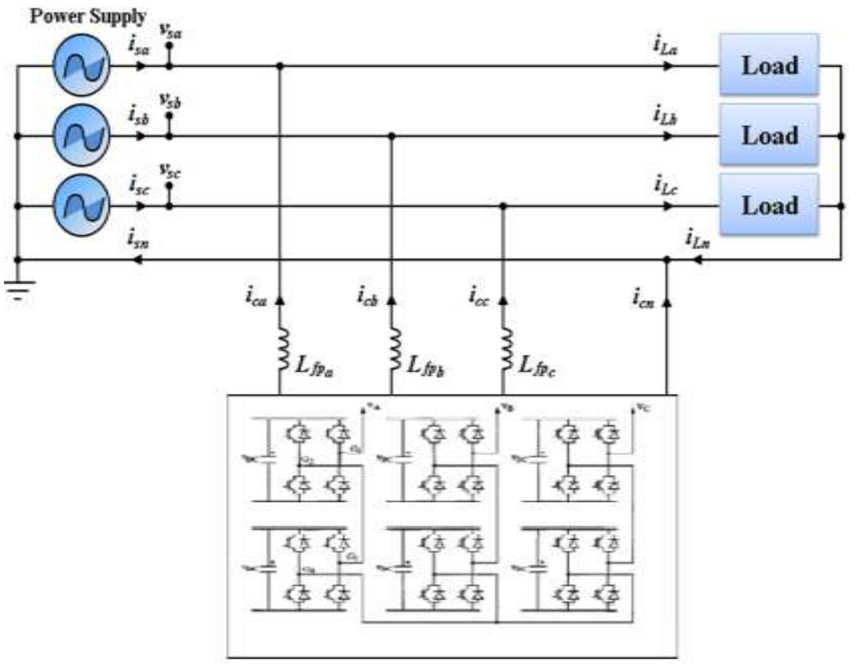


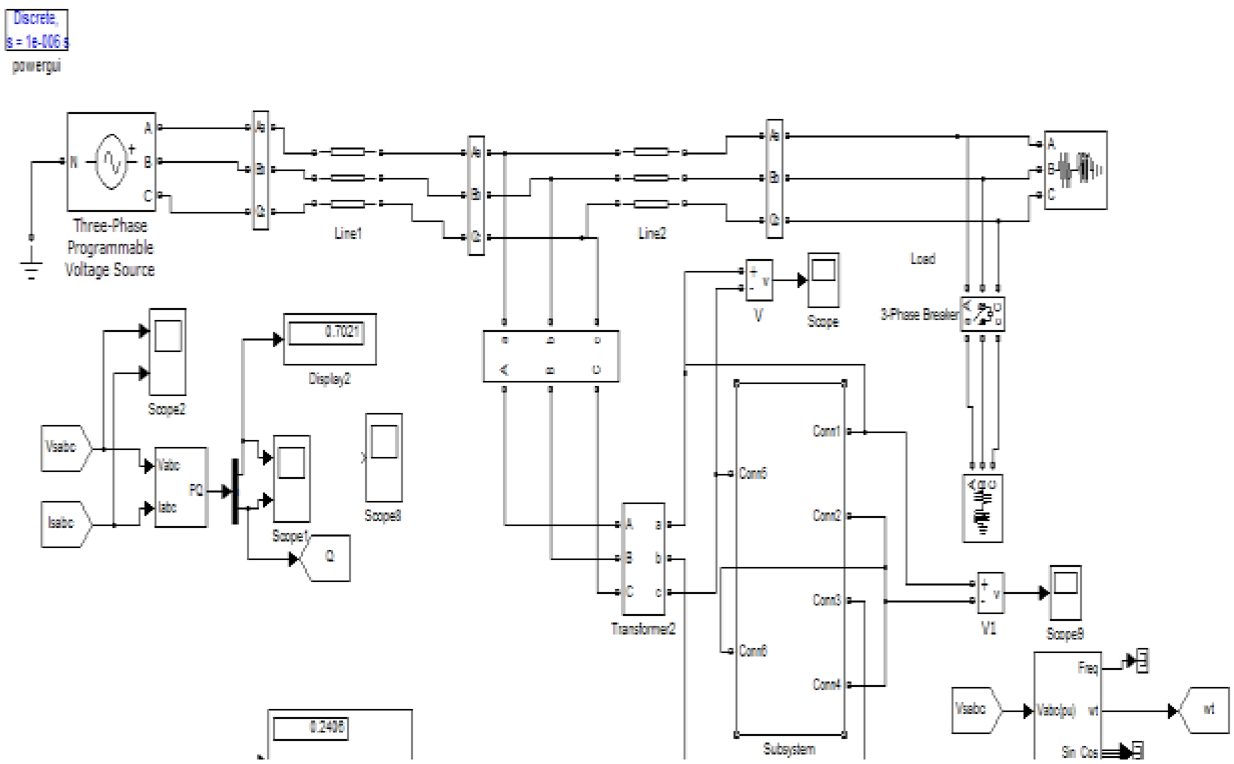
Fig.3 Proposed system circuit diagram

The magnitude of the inverter terminal voltage depends on the DC link capacitor voltage Vc. By controlling the gate signals of the switches, the inverter terminal voltage can be made to lag or lead the AC system voltage, so that real power flows into or out of the inverter circuit. By suitable operation of the switches, a voltage vcomp having a fundamental component Vcomp1 is generated at the output of the inverter. When Vcomp1 > Vs, leading current (with respect to Vs) will be drawn and the inverter supplies lagging vars to the system. The FUZZY logic controller is used to reduce the load voltage error and makes the system load voltage remains constant.

The multilevel converter has drawn tremendous interest in the power industry. The general structure of the multilevel converter is to synthesize a sinusoidal voltage from several levels of voltages, multilevel voltage source converters are emerging as a new breed of power converter options for high power applications. These converter topologies can generate high-quality voltage waveforms with power semiconductor switches operating at a frequency near the fundamental. Multilevel topologies are able to generate better output quality, while operating at lower switching frequency. This implies lower switching dissipation and higher efficiency. Moreover, this topology utilizes switches with lower breakdown voltage; therefore, it can be used in higher power applications at lower cost. Compared to the multi pulse converter, multilevel converters are more flexible and have a wide application. They can be used as active power filters and to handle unbalanced loads. No phase shift transformer is required in this configuration, so a lower investment cost, plus a lower power loss, can be expected Compared to the multi pulse converter, multilevel converters has many advantages. They can be used as active power filters and to handle unbalanced loads. No phase shift transformer is required in this configuration, so a lower investment cost, plus a lower power loss, can be expected. The multilevel converter configuration can be further classified into three different configurations. Among the available multilevel converter topologies, the cascaded multilevel inverter constitutes a promising alternative, providing a modular design that can be extended to allow a transformer less connection. The cascaded H-bridge multilevel Inverter uses separate dc sources (SDCSs). The multilevel inverter using cascaded-inverter with SDCSs synthesizes a desired voltage from several independent sources of dc voltages, which may be obtained from batteries, fuel cells, or solar cells. In Cascaded multilevel inverter inverters are connected in series. A single-phase structure of an m-level cascaded inverter is illustrated in Figure 2.1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $–V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $–V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources.

Multilevel cascaded inverters have been proposed for such applications as static var generation, an interface with renewable energy sources, and for battery-based applications. Peng has demonstrated a prototype multilevel cascaded static var generator connected in parallel with the electrical system that could supply or draw reactive current from an electrical system. The inverter could be controlled to either regulate the power factor of the current drawn from the source or the bus voltage of the electrical system where the inverter was connected. Peng and Joos have also shown that a cascade inverter can be directly connected in series with the electrical system for static var compensation. Cascaded inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaic or fuel cells.

V. SIMULATION RESULTS



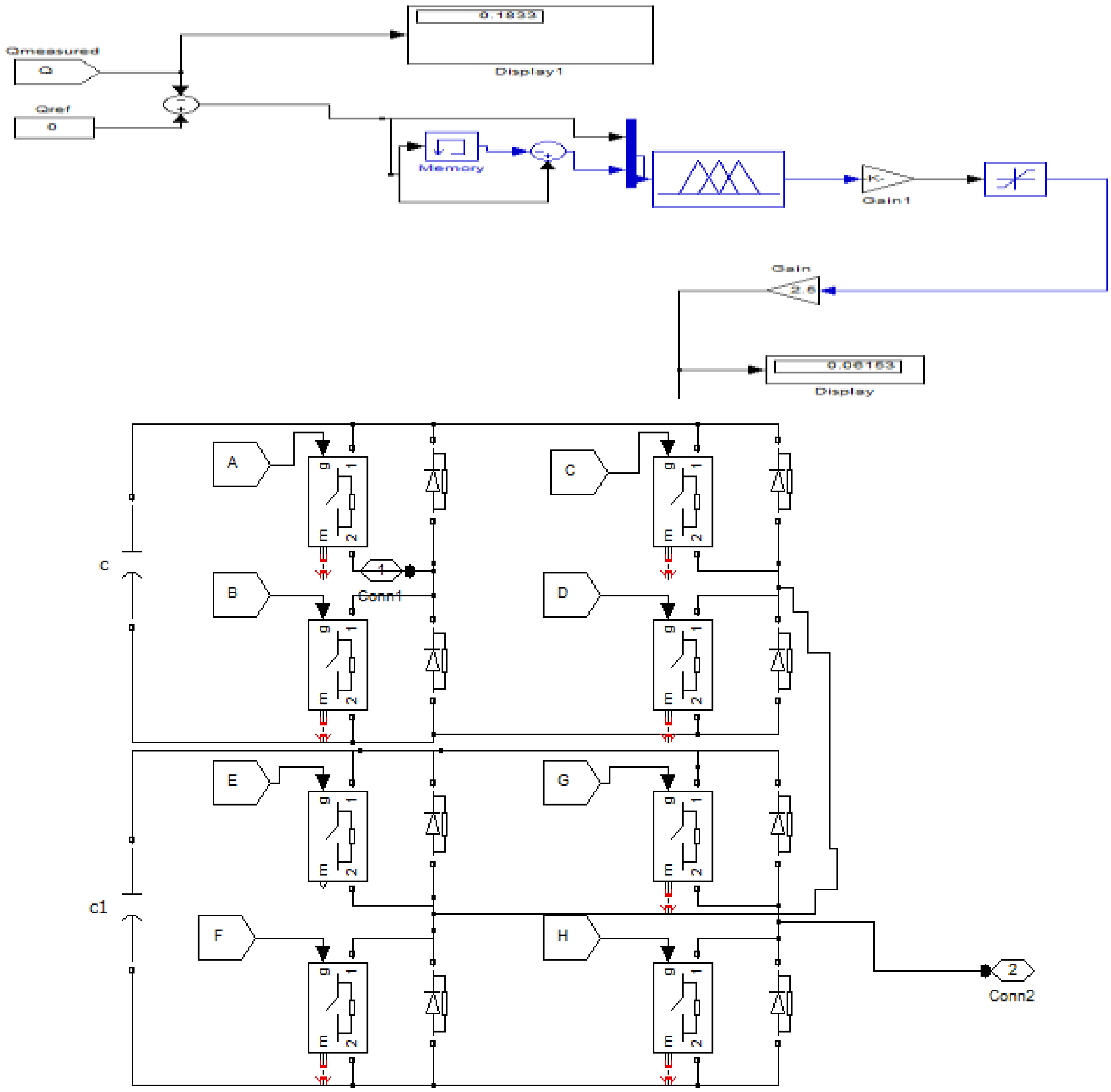


Fig.4 Proposed system Matlab Simulink

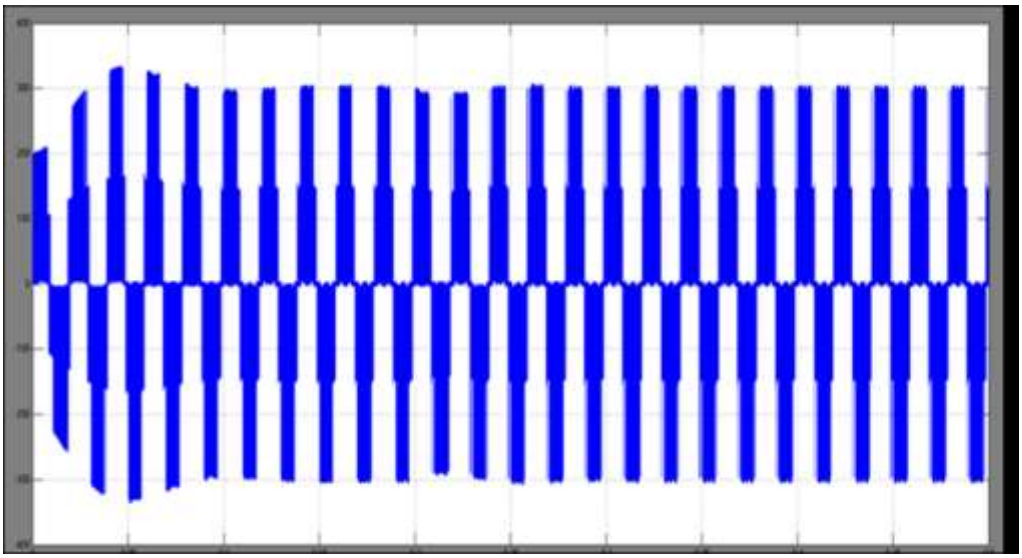


Fig. 5 Proposed system multilevel inverter output voltage

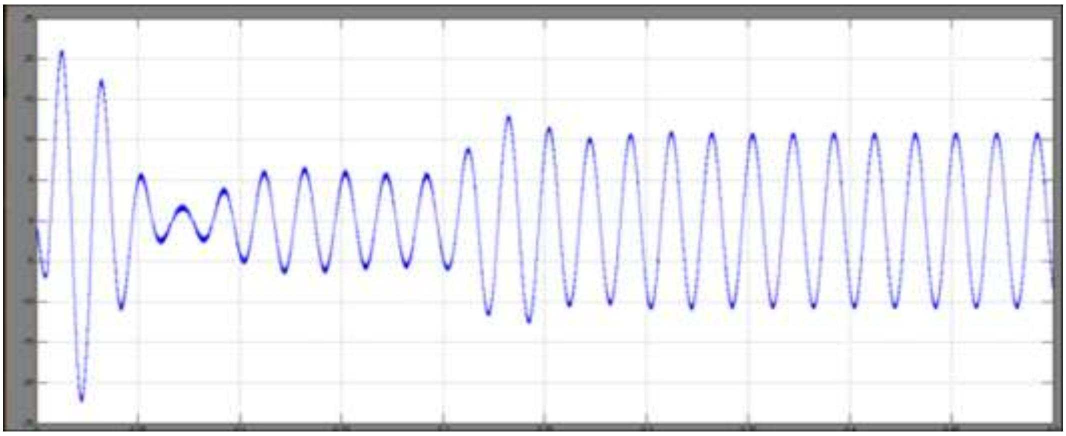


Fig.6 Proposed system load current

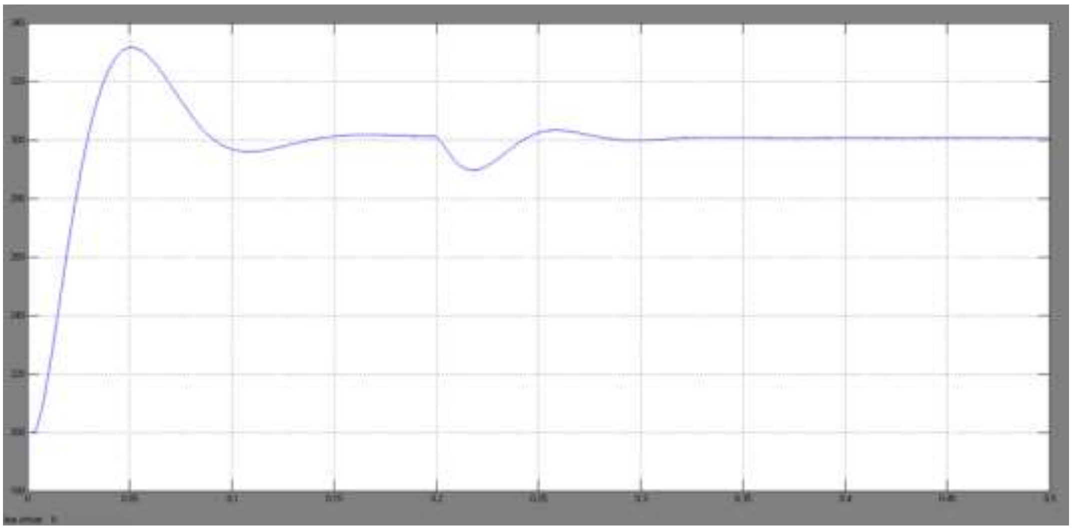


Fig.7 Constant DC link voltage using fuzzy logic control

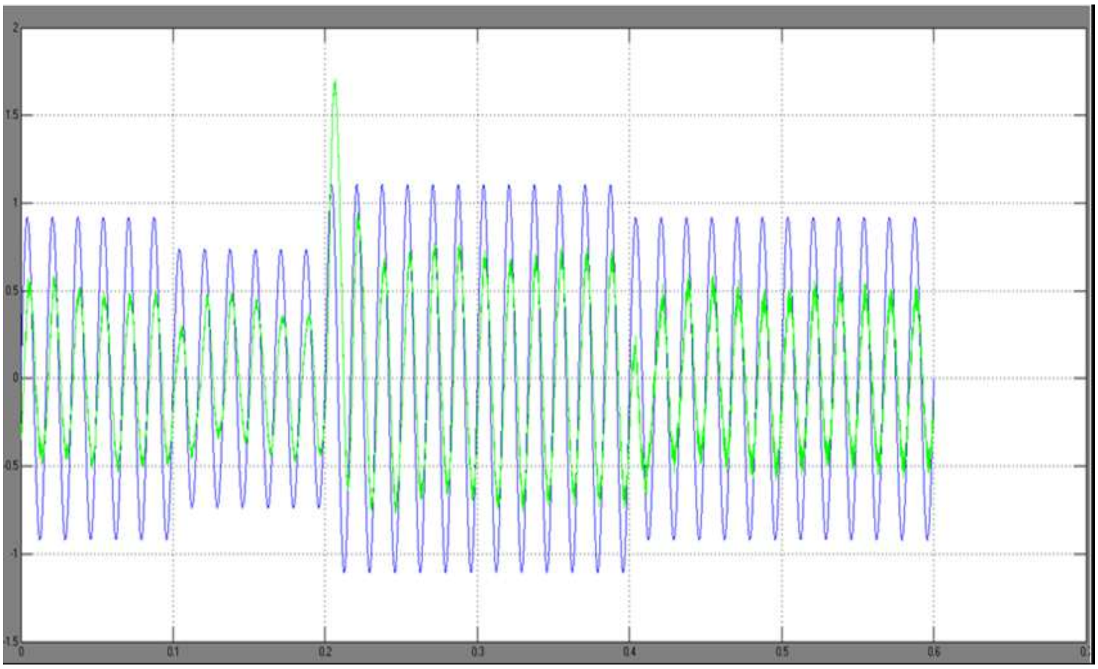


Fig.8 Source voltage and current waveform

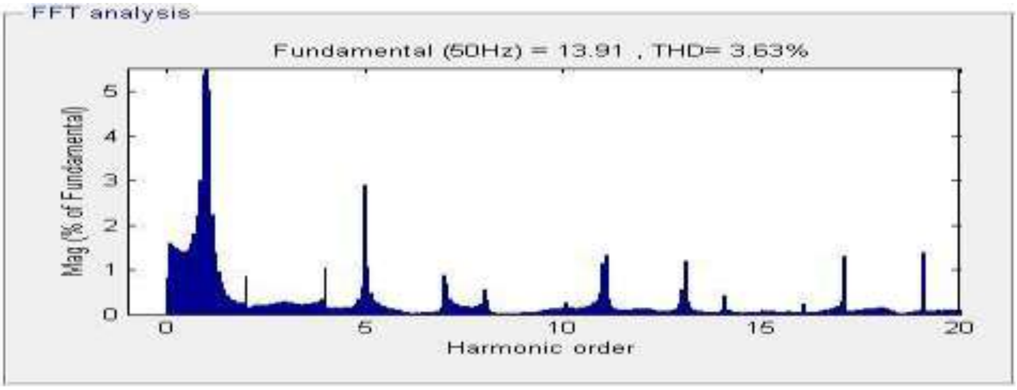


Fig.8 THD Result

VI. CONCLUSIONS

This paper presented compensation strategies, based on SRF and Fuzzy logic controller, which can be used in shunt APF topologies, when applied to three-phase systems, which allow harmonic current suppression, reactive and neutral current compensations to be conducted. The SRF-based controllers were used in three phase shunt APF topologies, and performed effectively. The algorithms allow the compensation of both load unbalances to generate sinusoidal and balanced source currents, and control each of the three phases independently. In this case the source currents will be sinusoidal but unbalanced and the THD result is 3.63%.

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