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POWER QUALITY ENHANCEMENT BY USING CASCADED MULTILEVEL INVERTER BASED SAPF WITH PI CONTROLLER

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Abstract: Modern power systems necessitate the development of active power filters that reduce harmonic currents and voltages in order to meets the standards of utility grid power quality. For the purpose of compensating reactive power and reducing (THD) total harmonic distortion in source current under balanced and unbalanced nonlinear loads, this article presents a 3-phase 5-level cascaded H-bridge (MLI) based Multi-Level Inverter in (SAPF) Shunt Active Power Filter. The recommended SAPF extracts harmonic currents from sources utilizing the instantaneous active reactive power theory (p-q). The proposed system results are implemented in the MATLAB/SIMULINL software.

Key words: Power Quality, Shunt Active Power Filter Cascaded H-bridge Multilevel Inverter, PI controller

I.INTRODUCTION

There are nonlinear electric appliances that rely on switching power in every utility in the globe. There is a risk of power quality difficulties when non-linear loads like arc furnaces, computers, and variable frequency drives (VFDs) are present [2]. Power losses, overheating of devices, insulation failures, and communication system interference can all be caused by harmonic distortion in low-voltage distribution systems.A lack of power quality is a concern for both the utility and its customers as a result. When the IEEE-SA addressed the harmonics limitation standard in 1992 with IEEE Std 519-1992 [5], they updated it in 2014 with IEEE Std 519–2014 [10].An acceptable maximum THD level of 5% has been established under this standard. Because of this, power filters are employed to meet the 5% limit. Power filters are often employed to reduce harmonic distortion, according to the research. Power quality can be improved by connecting passive filters to the distribution network. Passive filter design might be difficult for industrial nonlinear loads connected to rigid power sources. As a result, passive filters have a number of drawbacks intrinsic to their design, such as their huge size, resonance with load impedance or utility impedance, instability, and flexibility.As an alternative to passive filters, voltage source inverter-based APFs have also been proposed as a solution. For power quality difficulties, an APF is a good option because of its greater filtering precision, fast dynamic response, and flexibility. Current harmonic and reactive power detection methods, as well as the compensation control algorithm, have a significant impact on the shunt active power filter's ability to mitigate harmonics. The instantaneous reactive power theory (P-Q theory) is commonly used in reference compensation current control.This idea was initially generalised in 1983 by Akagi et al. [10]. For the extraction of fundamental and harmonic components, many studies have proposed strategies including estimating the reference compensation current and regulating the voltage of the DC-link capacitor. The authors were able to anticipate the reference compensation currents required for nonlinear loads connected at the point of common coupling using a new version of the P-Q theory, in order to compensate for harmonic currents pulled by such loads (PCC).Under unbalanced voltage conditions, Gary W. et al. [12] have proposed a strategy for reducing harmonic current. Researchers found that an active power filter coupled to the feeder's end bus reduced harmonic expansion throughout the feeder, according to the findings. In [14], a sliding discrete Fourier transform of positive-sequence components is used to derive the reference compensation current. Mehrasa [16] developed a Direct Lyapunov control technique to reduce harmonic currents and manage reactive power. Kanjiya [17] states that trials on the proposed shunt active power filter were managed by a single-step noniteratively optimised algorithm in real-time experiments.Controlling harmonic currents in both stable and dynamic load conditions proved to be possible with the proposed approach.

A single semiconductor switch's limited voltage handling capacity and the sluggish switching speed of large current devices mean that active power filters based on two-level inverters frequently cannot handle these situations. For high voltage and high current demands, multi-level inverters were recommended. Cascade H-bridge, diode-clamped, and flying-capacitor are three forms of multi-level converters [18]. Cascade multi-level converters have a number of advantages over diode-clamped and flying-capacitor converters, including: There are no transformers or dynamic voltage balancing circuits required when using semiconductor switches for high voltage and power output. A larger number of output levels is critical for reducing harmonic content in the voltage and current generated by the output device(s). A multilevel inverter can create high power by using a series of power semiconductor switches with numerous lower DC voltage sources and synthesising a staircase voltage waveform for the power conversion. Each power semiconductor switch requires a triggering signal to control the switching frequency in order to provide a low distortion output voltage that is almost sinusoidal. Using a five-level cascaded H-bridge inverter linked directly to the power source, a three-phase shunt active filter may reduce harmonics. MATLAB/Simulink is used to carry out the method.

II.EXISITNG SYSTEM

The figure.1 indicates the configuration of the basic 3-phase (SAPF) shunt active power filter. The scheme contains source, nonlinear loads and shunt active filter. The SAPF consists 3 components i.e., DC link capacitor, voltage source inverter and passive filter. Because of usage of nonlinear load it may be chance to produces harmonic currents in the source these are compensated by shunt active filter. The main drawback is using only three level inverter in ASPF the THD is high.

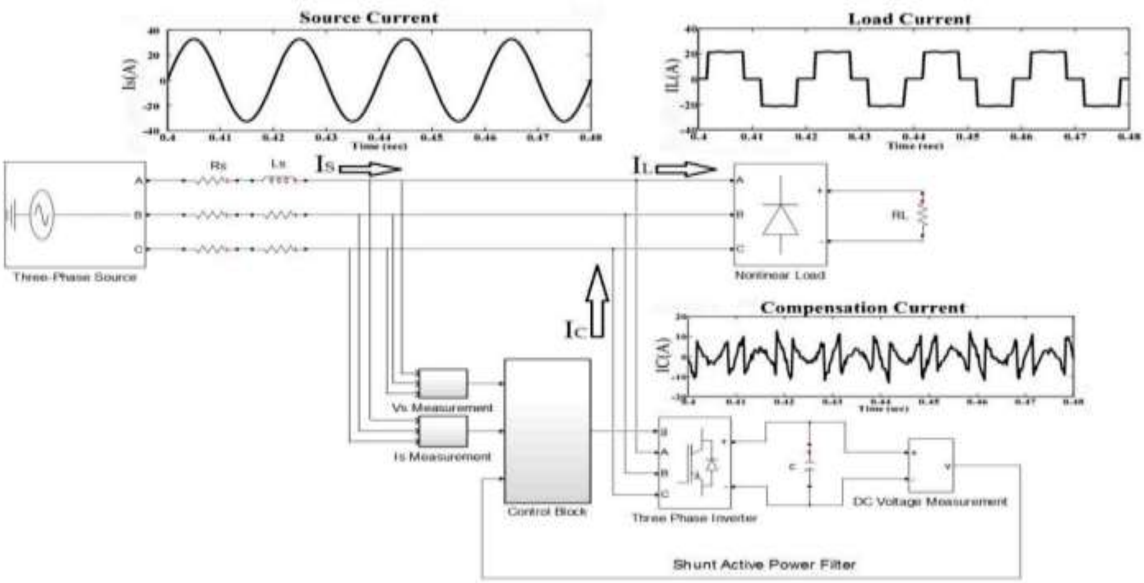

Fig 1 Configuration of active power filter using a three-phase three-wire system.

III.PROPOSED SYSTEM

Currently the multilevel inverters are used in high power applications. The high ac output voltages of a cascade multilevel inverter are achieved through the series-connection of several H-bridge VSCs. Each of the m-level cascade multi-level inverters has a different dc source for each of the (m-1)/2 single-phase complete bridges. As in the inverter no. of levels increases, it is able to produce a nearly sinusoidal waveform voltage. Figure 2 depicts a multilayer inverter with five levels of cascade. Two 1-phase complete bridges are associated in sequence on each leg. If S is the no. of DC sources, then the no. of o/p voltage levels is (2S+1) in this arrangement. Phase voltage has five levels with S=2 and a maximum magnitude of 5Vdc.

In Figure.2. I_L represents current at the load, I_s represents current of the source, I_c represents injected current by SAPF.

$$I_s = I_L + I_C \qquad (1)$$

At PCC, the SAPF supports as a current controlled source that injecting opposite but identical quadrature and harmonic components of load currents. The active filter and non-linear load are viewed as an ideal resistor by the system. It is possible to utilize an active Shunt Power filter in conjunction with a pulse width modulation VSI as a current supervisor device. The use of multiple inverters in high power energy conversion is a recent development in research. An inverter with many levels can reduces the harmonics in the o/p voltage and electromagnetic interference, allowing the circuit to run more efficiently. Multiple inverters have a lower ripple current due to their stepped output voltage. Each H-bridge module has its own capacitor. To make up for the switching and capacitor losses, the APF uses a little amount of power from the source, and the voltages on the capacitors are measured, compared to a reference, and then sent to the PI controller, which generates the APF's loss component. The 5-level multilevel inverter output voltage waveform is better than that of a conventional three-level inverter.

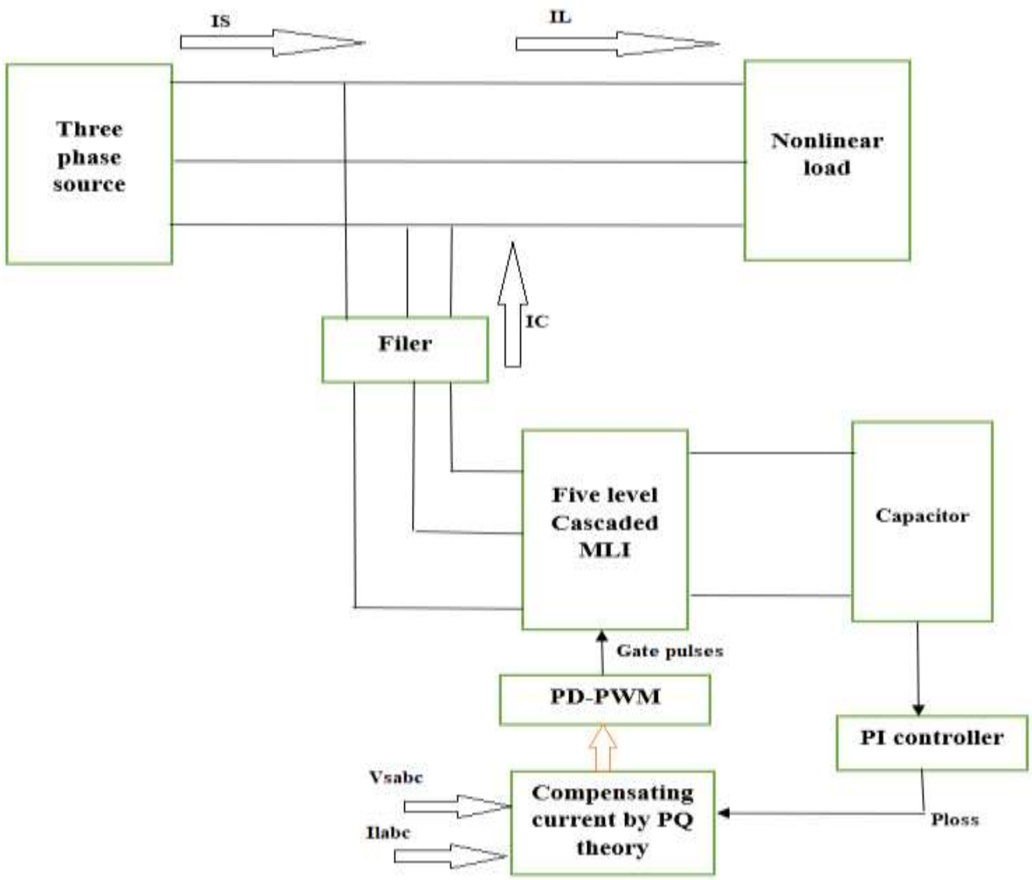

Figure 2. Proposed Five level Cascaded H-bridge Multilevel Inverter based SAPF.

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A)5-level inverter

Cascading two three-level full-bridge units produces a 1-phase Five-Level CMLI cell. The circuit arrangment is indicated in Fig. 3, DC sources of two are needed for each phase of a five-level CMLI.

-Vdc,-Vdc/2,0,Vdc/2, and Vdc are the five output voltages that can be found at the output of this inverter.

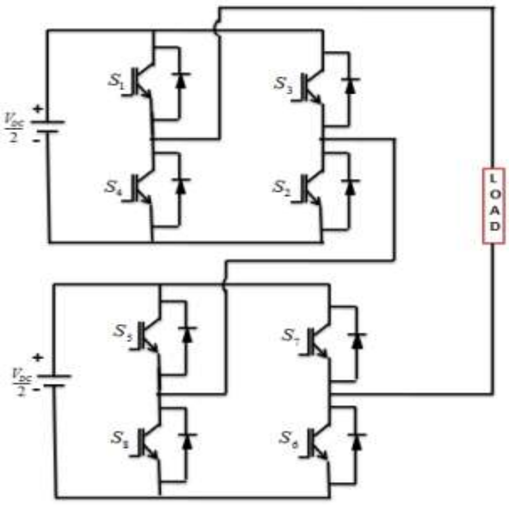

Fig .3 Single-Phase Five-Level CMLI Construction

B) SAPF CMLI Switching Pulses Generation

To increase output voltage, LSPWM is often used in Cascaded H-Bridge inverters since it is easy to implement and effective. Using this method, an inverter's H-bridge cells are distributed with a constant amount of power. When using LSPWM's N-level inverter, you'll need N carrier signals. PD, POD, and APO are three subclassifications of LSPWM technique Phase Disposition (PD), POD, and Alternate Phase Opposition Disposition (APO) (APOD). In comparison to other modulation techniques, PD kind of Level Shift-PWM is more dependable and suppresses harmonics to a considerably smaller amount. As a result, PDPWM has been introduced for SAPF's 5-level CMLI VSIs. After calculating the reference recompensing currents, these signals are equated to the corresponding real currents to see if they match. To get the gate signals needed for CMLI, the errors obtained this way are compared to triangular carriers.

C) Active reactive power (PQ) Theory

The PQ method is frequently used to compute the reference currents required for compensation. Figure 4 depicts the PQ theory procedure for calculating reference currents. Clarke's transformation is used to sense and convert voltages and currents on the source and load sides into a —0 reference frame.

Clarke transforms the a-b-c stationary reference synchronizes to the $\alpha\beta 0$ rotational synchronizes, which is the basis of instantaneous PQ theory Expressions for converting voltage and current values from the sources to $\alpha\beta 0$ components can be found below.

$$\begin{bmatrix} v_o \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3)$$

where Va, Vb, and Vc represents the a-b-c coordinates' 3-phase voltages, ia, ib, and ic represent the a-b-c coordinates' three-phase currents, v0, vα, and vβ represent the $0\alpha\beta$ coordinates' three-phase voltages, and i0, Iα and Iβ represent the $0\alpha\beta$ coordinates' three-phase currents. There is no zero-sequence component in this study's 3-phase three-wire system. The active and reactive powers, P and Q, can be signified in abc coordinate.

$$S = P + JQ = v_{\alpha\beta} i^*_{\alpha\beta} = (v_\alpha - jv_\beta)(i_\alpha + ji_\beta) =$$

$$(v_\alpha i_\alpha + v_\beta i) + j(v_\alpha i_\beta + v_\beta i_\alpha) \quad (4)$$

where, P denotes the real power, S represents the complex power and Q signifies reactive power. This allows us to create both the instantaneous active reactive power components (P&Q) as follows :

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

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As can be seen in Expressions (6) and (7), the instantaneous PQ components are broken down into their DC and AC components when nonlinear loads are present. AC (ep) represents the energy exchanged from a source to a load, as shown in Figure 3. q and eq indicate the fundamental and harmonic components of the instantaneous reactive power component (Q), The power transferred from a source to a load is represented by DC (p), which reflects the essential components of current and voltage in the instantaneous active power (P), which are responsible for the energy flow among the load and phases.

$$P = \bar{p} + \tilde{p} \quad (6)$$

$$Q = \bar{q} + \tilde{q} \quad (7)$$

The active power's AC component (ep) and entire reactive power (Q) are necessary to generate harmonic reference current.

$$\tilde{p} = P - \bar{p} + \bar{p}loss \quad (8)$$

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \cdot \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{P} \\ Q \end{bmatrix} \quad (9)$$

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (10)$$

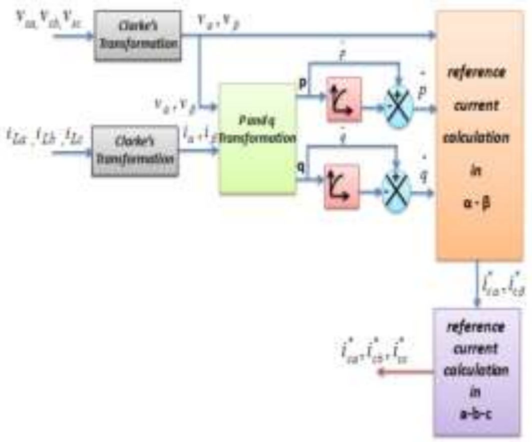

Fig. 4 P-Q theory is used to derive reference currents.

D) Control of the DC Link Voltage by PI controller

The error among the DC capacitor's reference voltage & real voltage can be reduced using a PI controller in active filtering applications. In order for SAPF to generate correct reference compensating current signals, the capacitor voltage must be constant.

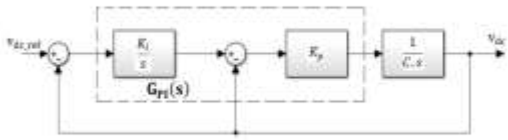

Fig 5 Closed-loop control of DC voltage.

IV.SIMULTION RESULTS

A)EXISTIG RESULTS

CASE 1: Under balanced nonlinear load

WITHOUT APF

Fig.5 MATLAB/SIMULINK diagram of three-phase system without SAPF

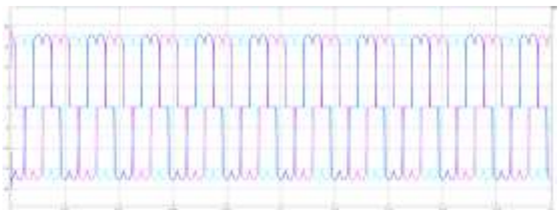

Fig. 6 Source currents without compensation

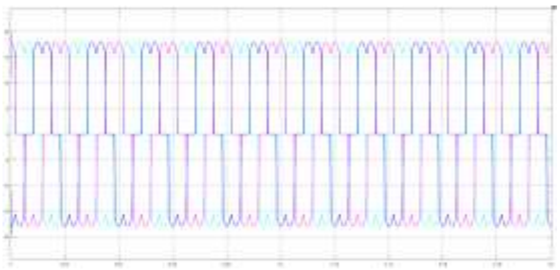

Fig .7 Load current

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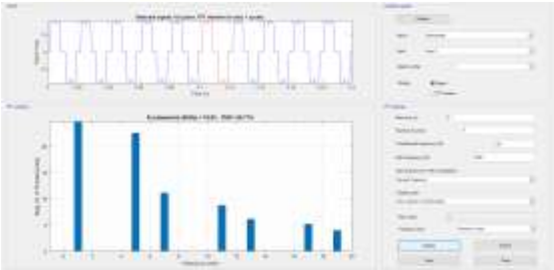

Fig.8 THD% of source current is 28.71%

WITH SAPF

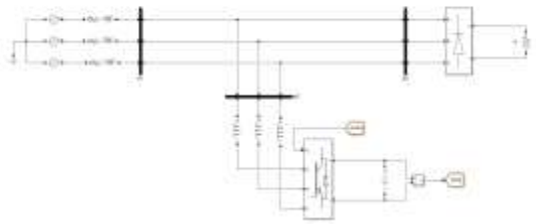

Fig.9 MATLAB/SIMULINK diagram of three-phase SAPF system design

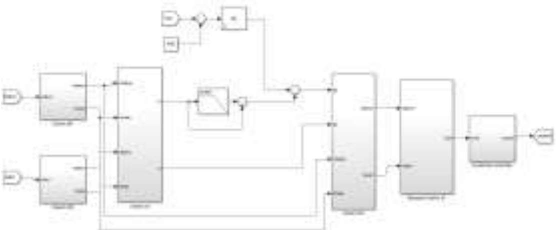

Fig.10 Control system

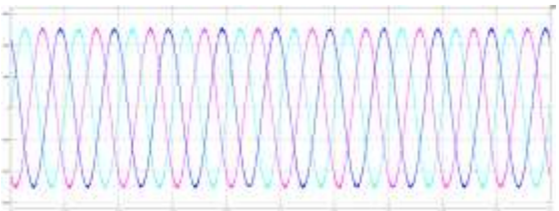

Fig.11 Source currents with compensation

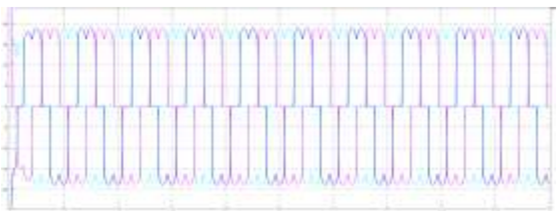

Fig.12 Load currents

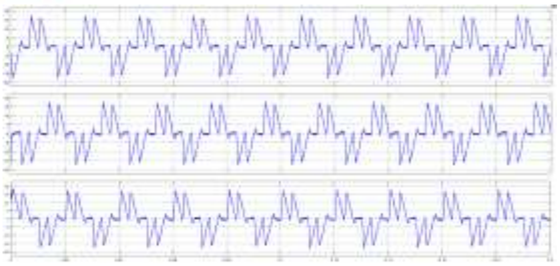

Fig.13 SAPF currents

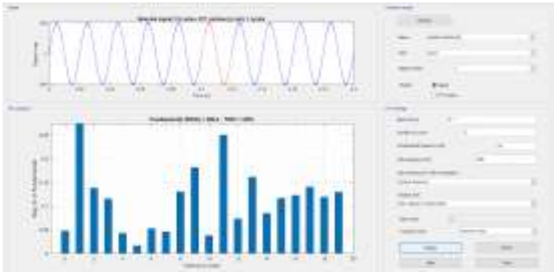

Fig .14 THD% of source current is 1.89%

CASE 2: Under unbalanced nonlinear load

WITHOUT SAPF

Fig.15 MATLAB/SIMULINK diagram of three-phase system without SAPF

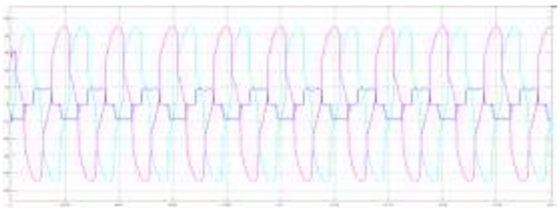

Fig.16 Source currents without compensation

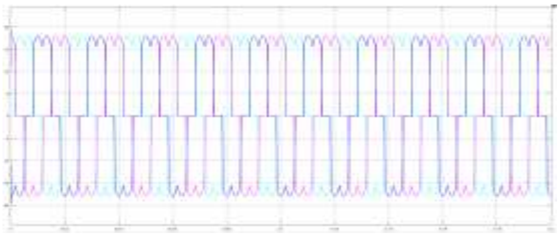

Fig.17 Load currents

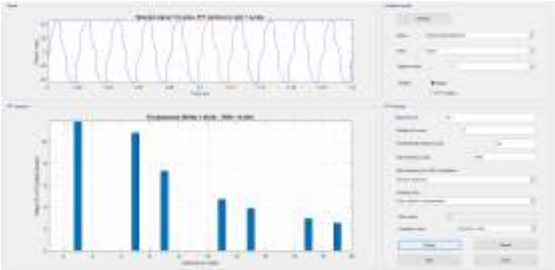

Fig.18 source current THD% is 15.40%

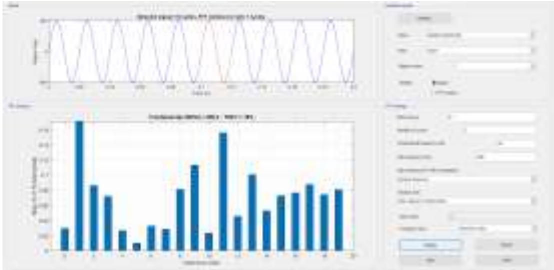

Fig.22 THD% of source current is 1.18%

WITH SAPF

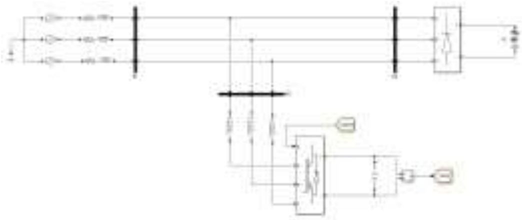

Fig.19 MATLAB/SIMULINK diagram of three-phase SAPF system design

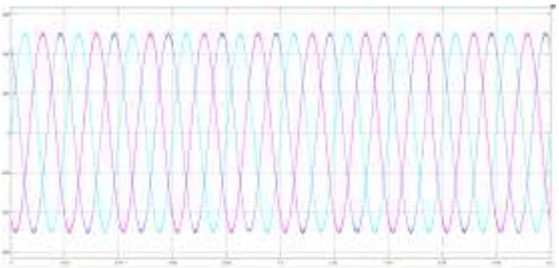

Fig.20 Source current with compensation

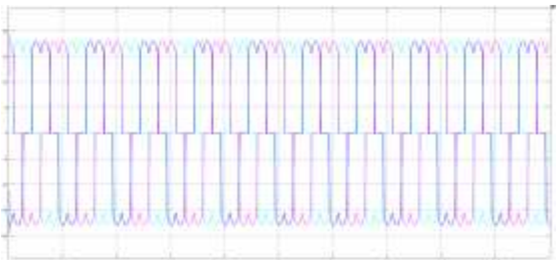

Fig.21 Load current

B)EXTENSION RESULTS

CASE 1: Under Balanced nonlinear load

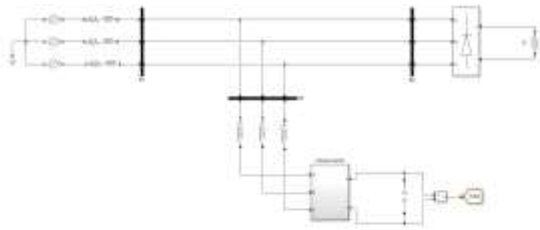

Fig.23 Simulink circuit of proposed SAPF with cascaded 5 level h bridge inverter

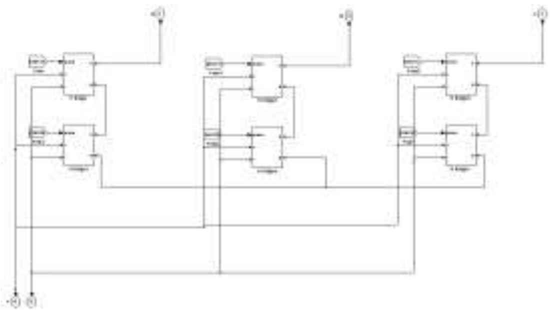

Fig.24 Subsystem of Cascaded-5 level H bridge inverter

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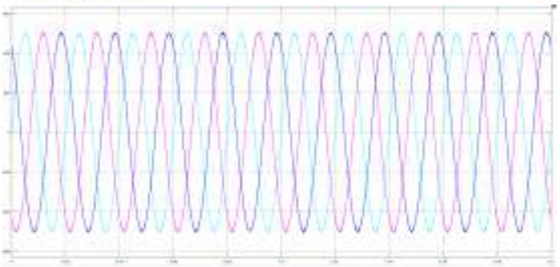

Fig.25 Source current with compensation

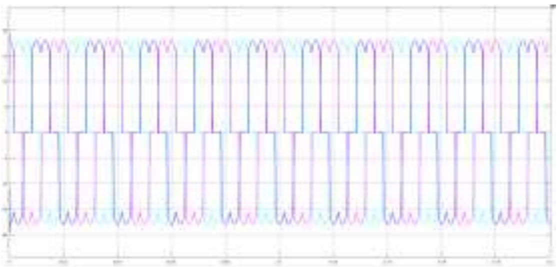

Fig.26 Load current

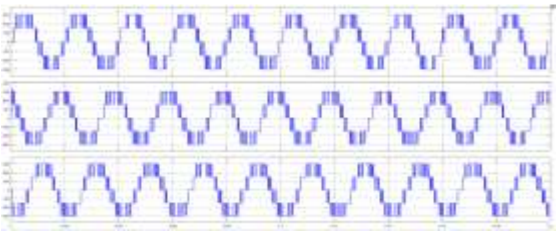

Fig.27 SAPF Voltage

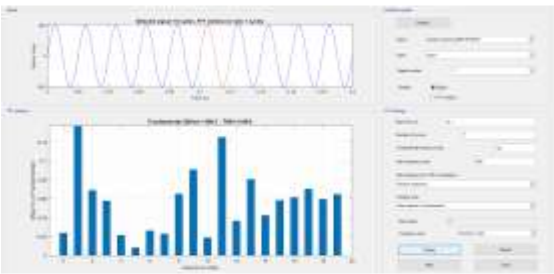

Fig.28 THD% of source current is 0.94%

CASE 2: Under Unbalanced nonlinear load

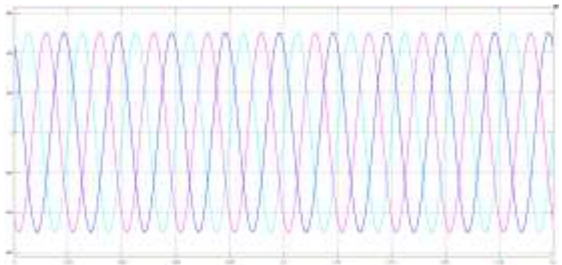

Fig.29 Source current with compensation

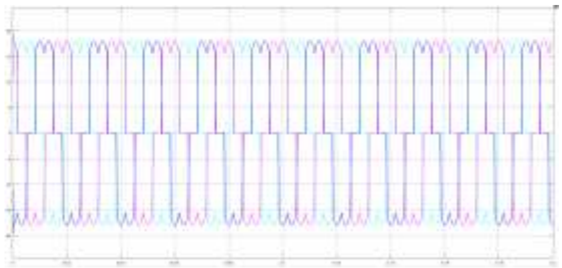

Fig.30 Load current

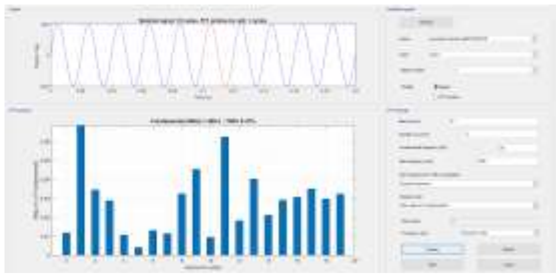

Fig.31 THD% of source current is 0.47%

COMPARISION TABLE

	Balanced nonlinear load	**Unbalanced nonlinear load**
Without SAPF Source current THD%	28.71%	15.40%
With SAPF Source current THD%	1.89%	1.18%
With proposed five	0.94%	0.47%

level cascaded MLI based SAPF Source current THD%		

CONCLUSION

CMLI-based SAPFs for harmonic reduction is studied in a 3-phase scheme with stable and unstable nonlinear loads in this research. SAPF's reference compensating currents were estimated using PQ theory. For the five-level CMLI, the LSPWM approach was used to generate gating pulses. To kept the DC voltage constant, the error among the reference and real voltages was processed using a PI controller. These SAPF were observed and the related waveforms were shown to demonstrate their performance. The percentage of total harmonic distortion (THD) in the source currents was compared. Comparing three level-inverter-based SAPF to five level-based SAPF, it was found that the percent THD of source current and load currents was lower when these SAPF were linked to the system. The five-level SAPF using a PI controller provided better current harmonic mitigation than the three-level SAPF.

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