POWER QUALITY IMPROVEMENT WITH A SHUNT ACTIVE POWER FILTER USING 3-CONTROL STRATEGIES

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ABSTRACT

This paper mainly deals with design of active power filter to compensate harmonics which are caused due to the non linear loads. The effective method is to reduce the harmonics in power system by the use of shunt active power filter (SAPF). This paper presents a detailed analysis of comparison of performance of three control algorithms for obtaining the reference current for a shunt active power filter under balanced/unbalanced source voltage condition and with RL load and DC motor load. The algorithms are instantaneous active and reactive power theory (IRP), synchronous reference frame (SRF) theory, and unit template method in UPF mode of operation. The comparative analyses of all three control algorithms are carried out for SAPF using MATLAB/SIMULINK platform.

Keywords*: Active power filter, synchronous reference frame theory, unit template algorithm in UPF mode of operation.PWM based hysteresis current controller.*

I. INTRODUCTION

Power electronic switching device in conjunction with nonlinear loads causes serious harmonic problem in power system due to their inherent property of drawing harmonic current and reactive power from AC supply mains. With the widespread use of power electronics devices such as rectifier, inverter etc. in power system causes serious problem relating to power quality. To overcome the increased severity of harmonic distortion in power system networks, power electronics and power system engineers have to develop dynamic and adjustable solutions to the power quality[1]-[11] problems. Such equipments are generally known as Active Filters (AFs)[1]-[5].Among all the methods the effective method is to reduce the harmonics is shunt active power filter (SAPF)[2].The performance of the SAPF mainly depends on the control algorithms[2],[3] used for obtaining the reference current components. This Paper gives detail performance analysis of SAPF with balanced and unbalanced source voltage, for three control strategies namely, instantaneous active and reactive power theory (p-q)[3]-[8] and synchronous reference frame theory (d-q)[9][10] and unit template method-UPF mode of operation[9], and their comparative analysis is given. These three control algorithms are tested with RL and DC motor load [12]. In all methods a reference current is generated for the filter which compensates either reactive power or harmonic current component of the load. In this paper, a current controller called hysteresis current controller [10] is designed used to provide gating sequence to IGBT based inverter and thus helps to remove harmonic component.

Based on the reference current generated by the control algorithm, the hysteresis controller generates the switching sequence or switching pulses to the insulated gate bipolar transistor (IGBT). The VSC which is the combination of the IGBT and DC-capacitor generates the compensating current which is equal in magnitude and opposite i.e., with 180° phase shift to the source current and this compensates the harmonic current in source and this current is injected into power distribution network through interfacing inductor. After compensation source voltage and current are almost sinusoidal. The MATLAB/SIMULINK [6] platform is used to perform the simulation and compare the total harmonic distortion levels in all three control algorithms.

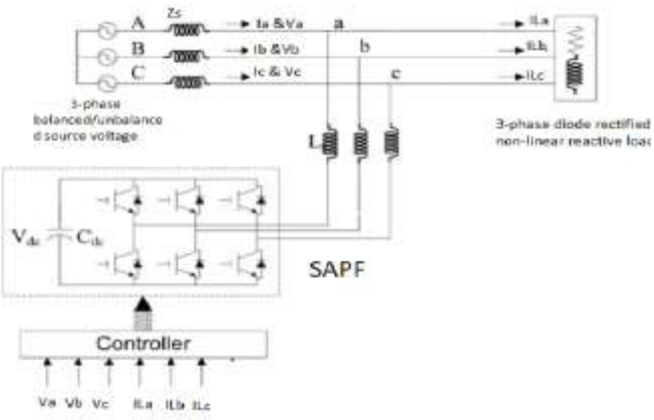

Fig: 1. Basic circuit diagram of the SAPF

II. SYSTEM CONFIGURATION

A fundamental circuit diagram of a SAPF system for a 3-phase, 3-wire AC system with nonlinear load [2], [3] in the three-phase distribution network is shown in fig 1. An IGBT-based current controlled voltage source inverter with an interface inductor and dc-bus capacitor is used as a SAPF. In general, a SAPF is connected at the Point of common coupling (PCC). A SAPF is realized using six insulated-gate bipolar transistors (IGBTs) with anti parallel diodes. At ac side, the interfacing inductors are used to filter the high-frequency components of compensating currents which are generated by the SAPF. Capacitor acts as a voltage source.

III. CONTROL ALGORITHMS

The performance of SAPF is studied with three control algorithms namely IRPT, SRF, UNIT TEMPLATE– UPF. These three control algorithms are implemented in balanced and unbalanced source voltage conditions with RL and DC MOTOR load.

A. Control algorithm of APF based on instantaneous reactive power theory:

IRPT algorithm used for control of APF is shown in the fig 2. This algorithm can be applied to 3-phase system for balanced and unbalanced source voltage with RL load and DC MOTOR load. With the help of Clark's transformation the 3-phase voltages and load currents are transformed to a 2-phase $\alpha-\beta$ coordinates for calculation of active and reactive power. The sensed inputs of 3-phase voltages and load currents are fed to the controller. Based on the inputs the reference currents are calculated and fed to the hysteresis controller to generate the switching signals for IGBT's of SAPF[1],[3]-[8].

The 3-phase voltages and load currents are transformed to the 2-phase $\alpha-\beta$ coordinates using Clark's transformation.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{L_a} \\ I_{L_b} \\ I_{L_c} \end{bmatrix} \quad (2)$$

Where α-β axes are orthogonal coordinates, therefore the instantaneous real and reactive powers as fallows;

$$p = V_\alpha I_\alpha + V_\beta I_\beta \quad (3)$$

$$q = -V_\beta I_\alpha + V_\alpha I_\beta \quad (4)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (5)$$

The calculated instantaneous active and reactive powers are fed to the low pass filter (LPF) and the output of the LPF is used for calculation of reference current.

The obtained reference currents in $\alpha-\beta$ coordinates are;

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{V_\alpha{}^2 + V_\beta{}^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (6)$$

The instantaneous active and reactive powers (p & q) are having DC component i.e., non oscillating component and oscillating or harmonic (ac) component. They are expressed as,

$$p = \bar{p} + \tilde{p}\,, \quad (7)$$

$$q = \bar{q} + \tilde{q}\,. \quad (8)$$

In this, the fundamental component or DC components of the load powers are represented as $\bar{p}$ and $\bar{q}$, and the harmonic or AC components are represented as $\tilde{p}$ and $\tilde{q}$.Now, the oscillating component of the active and reactive powers are eliminated by using low pass filters.

$$p^* = \bar{p} + p_{loss} \quad (9)$$

The difference or error between the actual and reference voltage is given to the PI controller. The output of the PI controller(p_{loss}) and the non oscillating component of the active power is used to calculate the currents α-β coordinates shown in equation (10). In this algorithm the reference current is calculated to compensate oscillating component in the active power and the instantaneous reactive power. The Currents in α-β coordinates are expressed as,

$$\begin{bmatrix} I^*_\alpha \\ I^*_\beta \end{bmatrix} = \frac{1}{{V_\alpha}^2 + {V_\beta}^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} + p_{loss} \\ 0 \end{bmatrix} \quad (10)$$

These currents can be transformed into 3-phase components to obtain reference current in a-b-c coordinates by applying inverse Clark's transformation.

$$\begin{bmatrix} {i_{sa}}^* \\ {i_{sb}}^* \\ {i_{sc}}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I^*_\alpha \\ I^*_\beta \end{bmatrix} \quad (11)$$

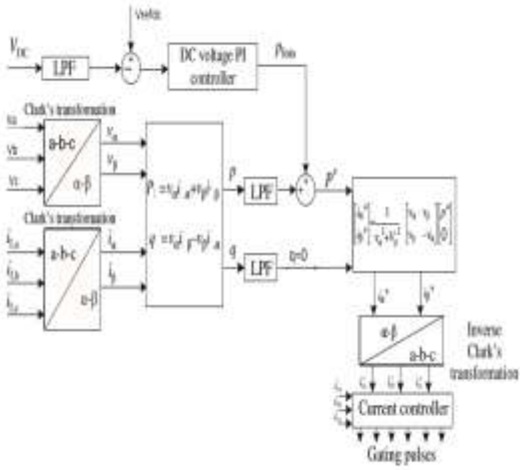

Fig2: control algorithm of APF usig IRPT

B. Control algorithm of APF based on SRF theory:

The block diagram of SRF theory [1], [3], [9], [10] which is used for the control of the APF is shown in figure 3. This algorithm is based on the currents are transformed in to rotating d-q frame. The sensed inputs of the 3-phase load currents are transformed to the 2-phase α-β coordinates by using Clark's transformation. The 3-phase source voltages are given to Phase-Locked Loop (PLL) for calculation of zero crossing points of voltages. By the use of zero crossing point, the α-β currents (iα and iβ) are transformed to the synchronously rotating d-q frame (park's transformation), then i_d and i_q are obtained with equation;

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (12)$$

The d-q frame currents are consisting of fundamental and harmonic components. The d-q frame currents are given to the low pass filter (LPF) to separate the DC components of i_d and i_q from harmonic or oscillating component.

$$\begin{bmatrix} i_{\alpha dc} \\ i_{\beta dc} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{ddc} \\ i_{qdc} \end{bmatrix} \quad (13)$$

The filtered signals are transformed back to the a-b-c quantities to obtained a reference current signals, using inverse park's and inverse Clark's transformation. These reference current signals fed to a hysteresis-based PWM signal generator to generate switching signals for IGBT's of the SAPF.

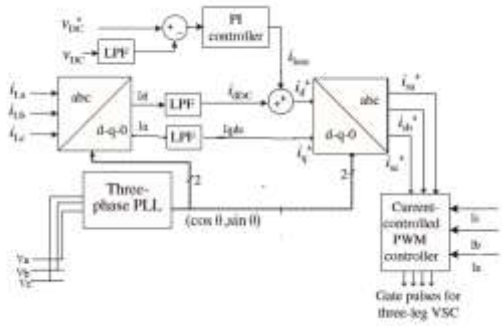

Fig3: Block diagram of SRF-based control algorithm

C.UNIT TEMPLATE ALGORITHM:

The design and implementation of the Unit Template-Based Control Algorithm of APFs is simple for compensation of harmonic which are injected due to the non linear loads and power factor correction (unity). In this algorithm the three phase supply currents and DC bus voltage of the APF are used to calculate the reference current.

C.1 Control algorithm of APF based on unit template -UPF theory:

The basic block diagram of the unit template algorithm in UPF mode of operation [1][9] shown in figure 4. For fundamental unity power factor supply currents, the reference

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currents are calculated such that it has to provide the amplitude and phase component of the currents. In this algorithm the PI controller is used to calculate the amplitude of the reference currents. The comparison of the actual and reference values of dc bus voltage of the APF is inputs ($V_{dcerror}$) to the PI controller. By choosing the proportional (Kp) and integral (Ki) gain constants such that a desired amplitude is provide for the reference currents.

$$V_{dcerror} = V_{dc}^{*} - V_{dc} \qquad (14)$$

The in phase components of the reference currents are used to provide 3-phase supply voltage. The amplitude of the supply voltage is calculated using equation 15.

V_{SP} is the amplitude of the supply voltage computed as;

$$V_{SP} = \sqrt{\left\{ {}^{2}/_{3} \left(\left(V_{sa}^{2} + V_{sb}^{2} + V_{SC}^{2} \right) \right) \right\}} \qquad (15)$$

The in phase components of the unit current vectors are calculated using with the in phase supply voltage and amplitude of the supply voltage.

$$U_{sa} = \frac{V_{sa}}{V_{sp}}, U_{sb} = \frac{V_{sb}}{V_{sp}}, U_{sc} = \frac{V_{sc}}{V_{sp}} \qquad (16)$$

Where U_{sa}, U_{sb}, and U_{sc} are in-phase unit current vectors.

Now, three-phase in-phase components of the reference supply currents are derived using their amplitude (I_{spp}^{*}) and in-phase unit current vectors (U_{sa}, U_{sb}, U_{sc}) and are given as

$$i_{sa}^{*} = I_{spp}^{*} U_{sa}, \quad i_{sb}^{*} = I_{spp}^{*} U_{sb},$$

$$i_{sc}^{*} = I_{spp}^{*} U_{sc} \qquad (17)$$

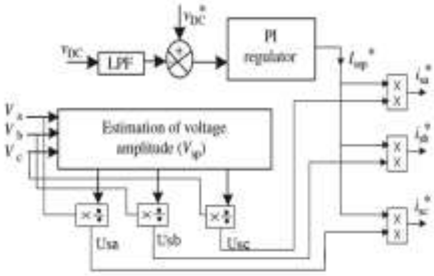

Fig 4: Block diagram of unit template-UPF based control algorithm

IV. HYSTERISISCONTROLLER OPERATION:

The hysteresis controller [10] is used to generate the current signals or pulses which are fed to the VSC. The reference currents and input source currents are fed to the hysteresis based PWM current controller to control the source current by fallowing the reference current. Hysteresis current control method is used to provide the accurate gating pulse and sequence to the IGBT inverter by comparing the current error signal with the given hysteresis band. The error signals which is from the reference current and the source current is compared with the hysteresis band. There are two limits in the hysteresis band i.e., upper and lower bands and the current is limited around these two bands. When the current is tends to increase above the hysteresis band the upper switch is turned off and the lower switch is turned on, therefore the current is in the hysteresis band. Similarly when tends to decrease below the lower band the lower switch is turned off and upper switch is turned on. Thus current lie within the hysteresis band and compensating current follow the reference current. The output signal of the comparator is then passed through the active power filter to generate the desired compensating current that follow the reference current waveform.

V. ANALYSIS AND DESIGN OF SAPF

The APF is used for harmonic mitigation, reactive power compensation and load balancing. The three phase three wire SAPF consisting of the voltage source converter (VSC) and interfacing inductor. For reducing the ripple in the compensating current and to eliminate the high frequency switching components at AC side of the voltage source converter, the interfacing inductors are used. The main block of the APF is the VSC; it required the DC voltage source, DC capacitor and IGBT's i.e., semiconductor switches. The SAPF is connected parallel/shunt to the power distribution network through the coupling inductance called transformer leakage reactance. The three phase non linear load is used in this network. The non linear load is modelled with three-phase uncontrolled rectifier with constant DC current.

The non linear load is injecting the harmonics into the system. The designed active power filter is generating the compensating current by continuously monitoring the load current with the source current with help of the control algorithms. The control algorithms are calculating the reference current. The obtained reference current and the supply currents are generate the switching pulses or switching sequence to the IGBT with help of the hysteresis controller. The inverter then generates the required current which is equal in magnitude to the harmonic current but of opposite phase i.e., with 180° phase shift with respect to the source current, so that the harmonic currents are cancelled and the supply currents become sinusoidal.

VII. SIMULATION PARAMETERS OF A THREE-PHASE THREE-WIRE SHUNT ACTIVE POWER FILTER SYSTEM

Table 1: Simulation parameters of the circuit

Supply voltage(balanced)	415V for 3-Phase
Supply voltage (unbalanced)	410V-Phase(A) 415V-Phase(B) 420V-Phase(C)
Frequency	50Hz
Load resistance, inductance	R_l = 200ohm, L_l = 5e-3F
DC Motor load	Power:5HP,V:240V, speed:1750RPM, DCvoltage:150V TORQUE: 5 (constant)
Line impedance	R_s = 0.5ohm, L_s= 0.1e-3F
DC side smoothing inductor	L=0.01e-3F
Reference Dc link voltage	500 Volts
DC link capacitor value	C=1200UF

VI. MODELING, SIMULATION, AND PERFORMANCE OF SHUNT ACTIVE POWER FILTERS

The model of the SAPF is developed with the non linear load, VSC and passive components. The simulation of the APF with MATLAB\SIMULINK and Sim Power System toolboxes are described.

A. Simulation and operation of the SAPF:

The first step is the calculation of the reference current and in these models three control algorithms (IRPT, SRF and Unit template-UPF) are used. These three control algorithms [2],[3] are used with both balanced and unbalanced source voltage[12] conditions. The calculated reference current is given to the hysteresis controller for generation of the switching pulses to the IGBT. By giving proper switching pulses to the IGBT and with suitable value of DC capacitor the VSC is generates the current which is equal in magnitude but opposite in phase i.e. 180° phase shift to the source current. The generated reference current is injected to the network through a leakage reactance i.e. interfacing inductor. The value of inductor is to be adjusted to a low value so that the required and proper reference current is injected into the network. The source parameters and the line parameters i.e., resistance, inductance and capacitance are set or adjusted to a proper value based on the load parameters. With proper adjustment of all parameters of system, the harmonics are minimized to a low value in the source current.

The simulation results are shown in section B. Here the source current before compensation and after compensation is observed. The source current before compensation is observed in IL_{abc} and after compensation the source current is observed in I_{abc}. The capacitor value of VSC is to be adjusted based on the DC bus voltage levels. For smoothing the DC capacitor voltage proportional plus integral controller (PI) is used. The PI values are set for getting the required capacitor voltage value i.e., which is nearly equal to the dc voltage values. A total harmonic distortion (THD) level before and after compensation is observed in the simulation for all control algorithms.

The 3-phase source voltage for all control algorithms of SAPF in power distribution network is getting around 415V for both balanced and unbalanced source voltage with RL/DCMOTOR loads.

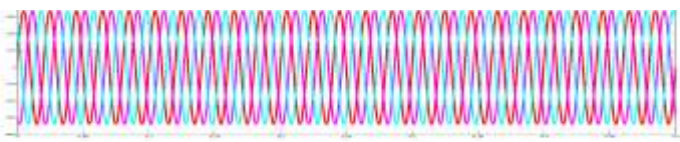

Fig5: Source Voltage (V_{Abc})

B. *Simulation of sapf-irpt control algorithm*

The SAPF is designed to mitigate the harmonics in the power distribution network, for that the SAPF generate the compensating current by using the different control algorithms. One of the control algorithms is IRPT based model. In this paper the IRPT based algorithm is designed for balanced and unbalanced source voltage conditions and comparison of the total harmonic distortion levels in both conditions studied. For calculation of the reference current in IRPT algorithm Clark's and inverse Clark's transformation is used.

The modelling and simulation of IRPT- based control algorithm is carried out in MATLAB/SIMULINK platform [6]. To separate the DC components i.e., non oscillating component the LPF is used. A three phase rectifier feeding RL and DC MOTOR is used as a nonlinear load.

B.1 IRPT-based model: balanced source voltage condition with RL load:

The IRPT based model is designed and implemented in a 3-phase balanced voltage with RL load [1]-[6], [12]. The simulation results are shown in Figure 6-10. It is observed that the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal shown in figure 5, the current before compensation IL_{abc} which is showing non sinusoidal and by dynamic performance of the SAPF and all the network parameters the compensated current is I_{abc} which is showing sinusoidal , therefore the injected harmonics are neglected, capacitor voltage (V_{dc}) is 300V. The total harmonic distortion (THD) before compensation is 27.93% and after compensation is 3.22%. The dynamic performance of the APF with the selected network parameters, the THD values are shown.

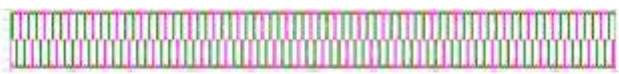

Fig6: Load Current(IL_{abc})

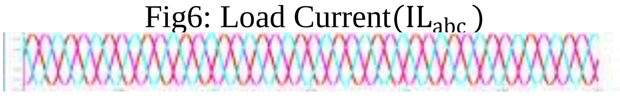

Fig7: Source Current(I_{abc})

Fig8: Capacitance Voltage (V_{dc})

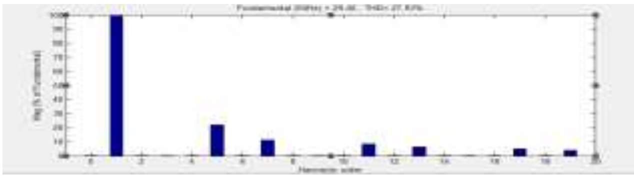

Fig9: THD of Load Current

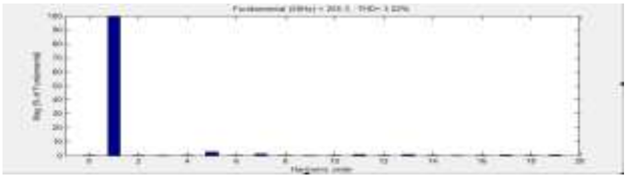

Fig10: THD of Source Current

B.2 IRPT-based model: unbalanced source voltage condition with RL load:

The simulation IRPT based model is performed in the MATLAB/SIMULINK platform in 3-phase unbalanced source voltages with RL load [1]-[6], [12]. The simulation results are shown in figure 12-16. It is observed that the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal as shown in figure 5, the current before compensation is IL_{abc} which is non sinusoidal and by dynamic performance of the SAPF and all the network parameters the compensated current is I_{abc} is sinusoidal, capacitor voltage (V_{dc}) is 280V. The total harmonic distortion (THD) before compensation is 28.21% and after compensation 4.18%.

Fig12: Load Current(IL_{abc})

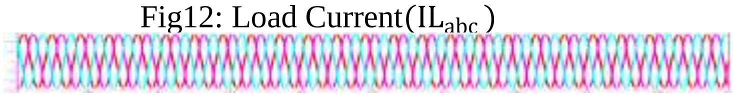

Fig13: Source Current(I_{abc})

Fig14: Capacitance Voltage (V_{dc})

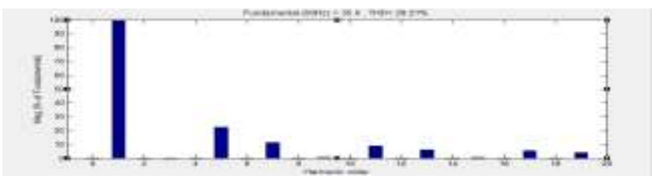

Fig15: THD of Load Current

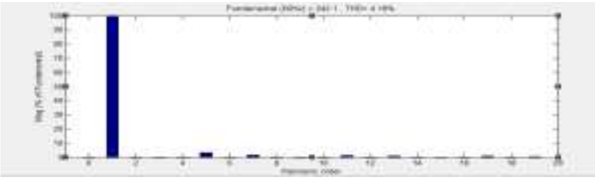

Fig16: THD of Source Current

B.3 IRPT-based model: balanced source voltage condition with DC motor load:

The SAPF is implemented with IRPT control algorithm with DC MOTOR load. The simulation IRPT based model is performed in the MATLAB/SIMULINK platform with balanced source voltage condition [6], [12]. The torque is set to be a constant at 5. It is observed that the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal as shown in figure 5,current before compensation IL_{abc} which is non sinusoidal and by dynamic performance of the SAPF and all the network parameters the compensated current is I_{abc} is sinusoidal, capacitance voltage (V_{dc}) 150V. The total harmonic distortion (THD) before compensation is 26.79% and after compensation is 4.29%.The corresponding waveforms are given figure 18-22.

Fig18: Load Current(IL_{abc})

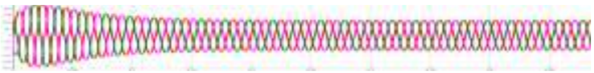

Fig19: Source Current(I_{abc})

Fig20: Capacitance Voltage (V_{dc})

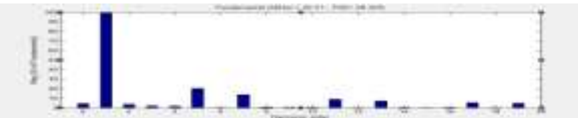

Fig21: THD of Load Current

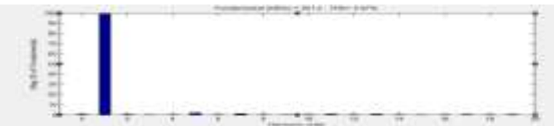

Fig22: THD of Source Current

B.4 IRPT-based model: unbalanced source voltage condition with DC motor load:

The simulation of the SAPF with IRPT-MODEL is performed in MATLAB/SIMULINK platform [1]-[6], [12]. The IRPT model is designed with the unbalanced source voltage with the three phase rectifier with DC MOTOR is taken as a load. It is observed that the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal as shown in figure 5, current before compensation is IL_{abc} is non sinusoidal and by dynamic performance of the SAPF and all the network parameters the compensated current is I_{abc} is sinusoidal. which is shown in figure 24-28. capacitance voltage (V_{dc}) is 150V. The total harmonic distortion (THD) before compensation is 28.93% and after compensation the THD is 2.85%.

Fig24: Load Current(IL_{abc}

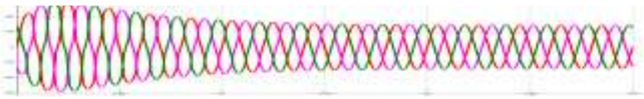

Fig25: Source Current(I_{abc})

Fig26: Capacitance Voltage (V_{dc})

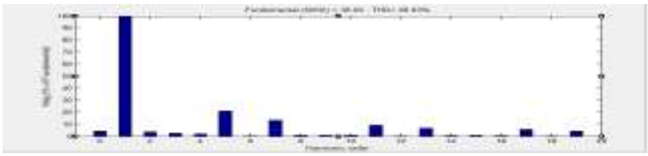

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Fig27: THD of Load Current

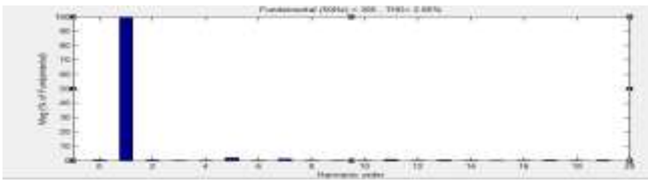

Fig28: THD of Source Current

C SIMULATION OF SRF CONTROLS ALGORITHM FOR SAPF:

The MATLAB/SIMULINK platform is used to perform the simulation of SRF control algorithm in both balanced and unbalanced voltage conditions. For calculation of the reference current in SRF algorithm Phased Locked Loop (PLL) and Clark's transformation is used. The PLL transformation is very easy, less time taking for calculation of reference current. A three phase rectifier with RL AND DC MOTOR is used as non liner load.

C.1 SRF-BASED MODEL: BALANCED SOURCE VOLTAGE with RL load:

The SRF based model is designed with the 3-phase balanced voltage conditions [9],[10],[12]. The dynamic performance of the SAPF-SRF mode of operation is performed and the obtained results are observed that the 3-phase source voltage at point of common coupling (V_{abc}) is sinusoidal as shown in figure 5, current before compensation is IL_{abc} which is non sinusoidal and by dynamic performance of the SAPF the compensated current is I_{abc} is sinusoidal. The total harmonic distortion (THD) before compensation is 28.23% and after compensation the THD is 5.82%. Based on the load by adjusting the network parameters, the sinusoidal source voltage and source currents are obtained. The results are shown in figure 30-34

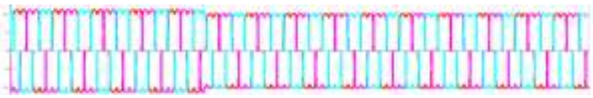

Fig30: Load Current(IL_{abc})

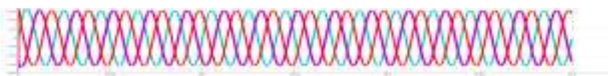

Fig31: Source Current(I_{abc})

Fig32: Capacitance Voltage (V_{dc})

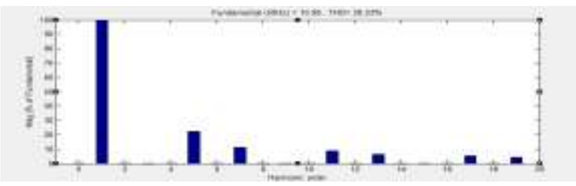

Fig33: THD of Load Current

Fig34: THD of Source Current

C.2 *SRF-BASED MODEL: UNBALANCED SOURCE VOLTAGE with RL load:*

The MATLAB/SIMULINK platform is used to implement the SAPF-SRF based model in unbalanced source voltage condition [10], [12]. The simulation is performed and the obtained results are observed that the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal shown in figure 5, current before compensation is IL_{abc} is non sinusoidal and by dynamic performance of the SAPF the compensated current is I_{abc} which is sinusoidal, and capacitance voltage (V_{dc}) is 280V. The total harmonic distortion (THD) before compensation is 28.61% and after compensation the THD is 1.33%. By observing the results and the sinusoidal source voltage and source current there is satisfactory operation APF is obtained. The results are shown in figure 36-40.

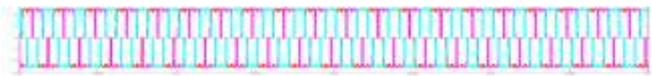

Fig36: Load Current(IL_{abc})

Fig37: Source Current(I_{abc})

Fig38: Capacitance Voltage (V_{dc})

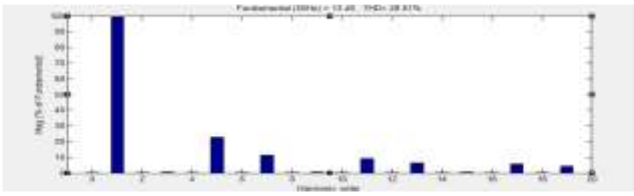

Fig39: THD of Load Current

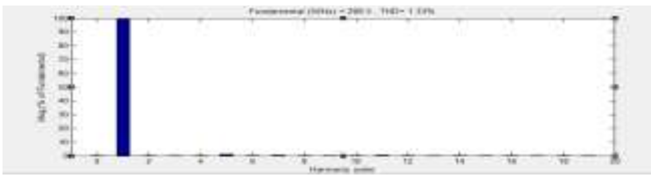

Fig40: THD of Source Current

C.3 SRF-BASED MODEL: BALANCED SOURCE VOLTAGE with DC MOTOR LOAD:

The SAPF is designed in SRF based modal in balanced source voltage condition with three phase rectifier with DCMOTOR as a nonlinear load. The MATLAB/SIMULINK platform [6], [12] is used to implement the simulation. The sinusoidal source voltage and sinusoidal source current Iabc are obtained shown in figure 42-45. The THD before compensation is 29.91% and after compensation is 1.32%.

Fig42: Load Current(IL_{abc})

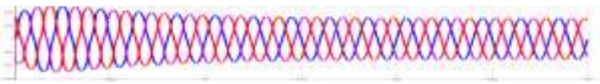

Fig43: Source Current(I_{abc})

Fig44: Capacitance Voltage (V_{dc})

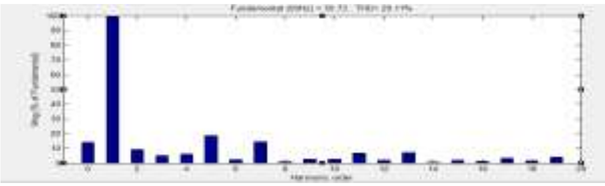

Fig44: THD of Load Current

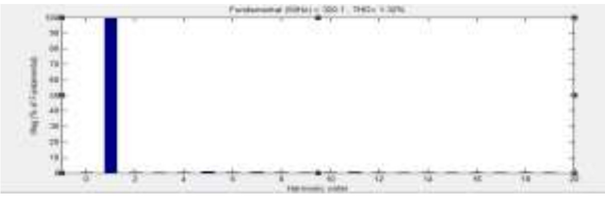

Fig45: THD of Source Current

C.4 SRF-BASED MODEL: UNBALANCED SOURCE VOLTAGE with DC MOTOR LOAD:

The SAPF with SRF control algorithm in unbalanced source voltage with three phase rectifier with DC MOTOR is taking as a load [9], [12]. The results are shown in figure 47-51. The THD values before compensation is 28.93% and after compensation is 2.84%.

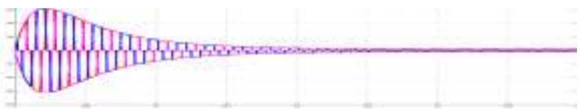

Fig47: Load Current(IL_{abc})

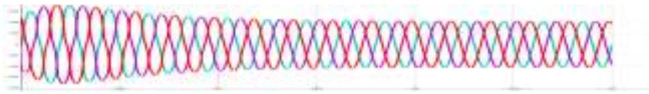

Fig48: Source Current(I_{abc})

Fig49: Capacitance Voltage (V_{dc})

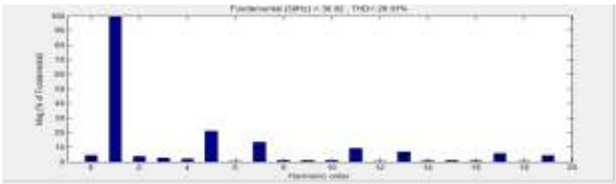

Fig50: THD of Load Current

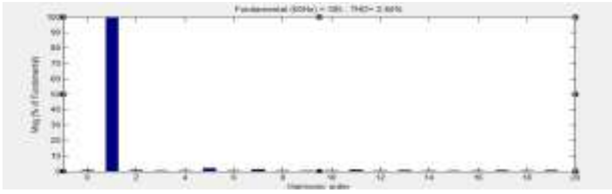

Fig51: THD of Source Current

D. SIMULATION OF SAPF with UNIT TEMPLATE - UPF CONTROL ALGORITHM:

The third method is unit template -UPF mode of operation used by SAPF for calculation of the reference current [9]. In this method the source voltage and DC voltage are used to calculate the reference current. This algorithm is designed with the balanced and unbalanced voltage conditions. The MATLAB/SIMULINK platform [6] is used to implement the simulation. The three phase rectifier with RL and DCMOTOR is used as nonlinear load.

D.1 UNITTEMPLATE-UPF-BASED MODEL: BALANCED VOLTAGE CONDITION-RL load

The SAPF-unit template in UPF mode of operation is implemented with the 3-phase balanced source voltage [2],[9],[12] . The simulation is performed and the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal shown in figure 5, current before compensation is IL_{abc} which is showing non sinusoidal and by dynamic performance of the SAPF and all the network parameters the compensated current is I_{abc} which is showing sinusoidal., and capacitance voltage (V_{dc}) is 200V. The total harmonic distortion (THD) before compensation is 21.38% and after compensation the THD is 1.25%. The results are shown in figure 52-57. By adjusting all the parameters of network with respect to the load, the sinusoidal source voltage and the sinusoidal source current is obtained.

Fig53: Load Current(IL_{abc})

Fig54: Source Current(I_{abc})

Fig55: Capacitance Voltage (V_{dc})

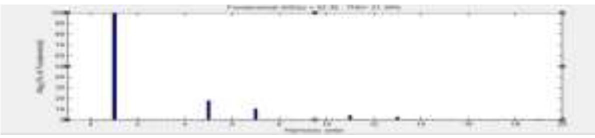

Fig56: THD of Load Current

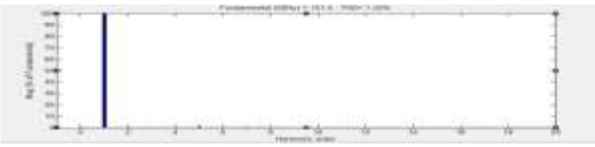

Fig57: THD of Source Current

D.2 UNITTEMPLATE-UPF-BASE MODE: UNBALANCED SOURCE VOLTAGE with RL load:

The SAPF with unit template in UPF mode of operation is implemented with 3-phase unbalanced source voltage [9],[12]. The simulation is performed and the obtained results are observed that the 3-phase source voltage at point of common coupling (V_{abc}) is getting sinusoidal shown in figure 5, current before compensation is IL_{abc} which is showing non sinusoidal and by dynamic performance of the SAPF and all the network parameters the compensated current is I_{abc} which is showing sinusoidal, and capacitance voltage (V_{dc}) is 200V. The total harmonic distortion (THD) before compensation is 25.97% and after compensation the THD is 0.92%. The results are shown in figure 59-63. The satisfactory performance of the APF is obtained by getting the sinusoidal source voltage and the sinusoidal source current.

Fig59: Load Current(IL_{abc})

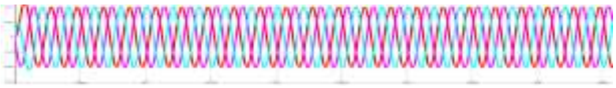

Fig60: Source Current(I_{abc})

Fig61: Capacitance Voltage (V_{dc})

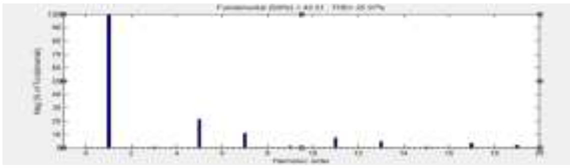

Fig62: THD of Load Current

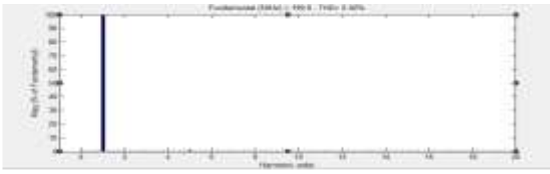

Fig63: THD of Source Current

D.3 UNITTEMPLATE-UPF-BASEDMODE: BALANCED SOURCE VOLTAGE with DC MOTOR:

The SAPF with UNITTEMPLATE - UPF based algorithm is designed with balanced source voltage condition with three phase rectifier with DC MOTOR as a non liner load. The dynamic performance of the SAPF with the performance of all network parameters is used to compensate the harmonics and sinusoidal source current is obtained [2],[9],[12]. The THD values before compensation is 21.60% and the after compensation is 0.79%. By observing the results the harmonics are neglected and the required sinusoidal source current and voltage is obtained.

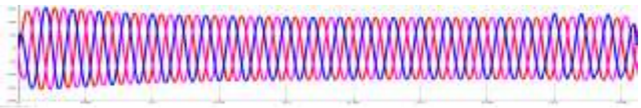

Fig65: Source Current(I_{abc})

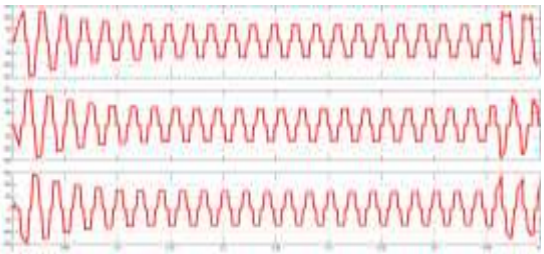

Fig66: Load Current(IL_{abc})

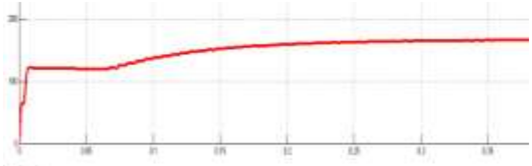

Fig67: Capacitance Voltage (V_{dc})

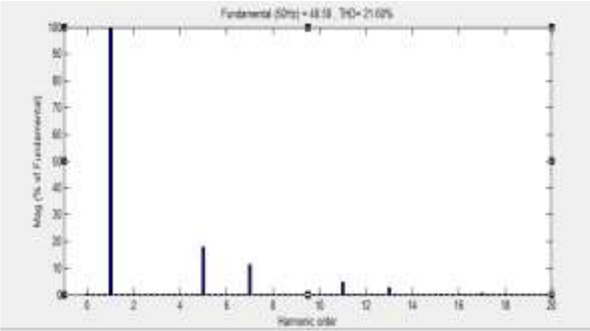

Fig68: THD of Load Current

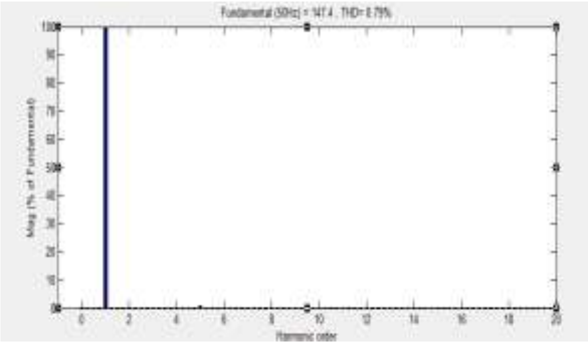

Fig69: THD of Source Current

D.4 UNIT TEMPLATE UPF BASED MODE: UNBALANCED SOURCE VOLTAGE with DC MOTOR load:

The unbalanced source voltage is taken for design of SAPF with UNITTEMPLATE algorithm [6],[9],[12].In three phase rectifier with DC MOTOR is taken as nonlinear load. By adjusting the network parameters, the harmonics are minimized and the required sinusoidal source current and voltage is obtained. THD before compensation is 22.09% and after compensation THD is 0.97%.

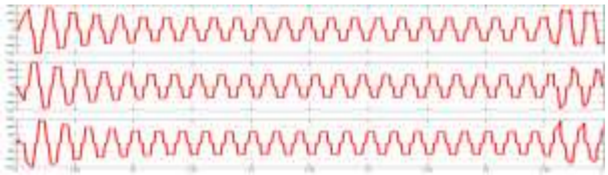

Fig71: Load Current(IL_{abc})

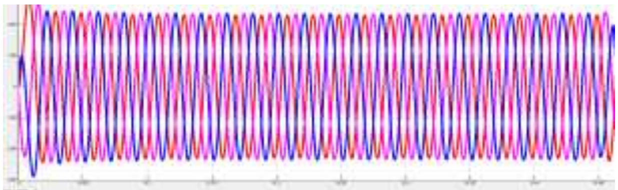

Fig72: Source Current(I_{abc})

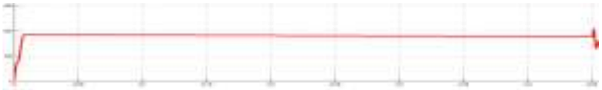

Fig73: Capacitance Voltage (V_{dc})

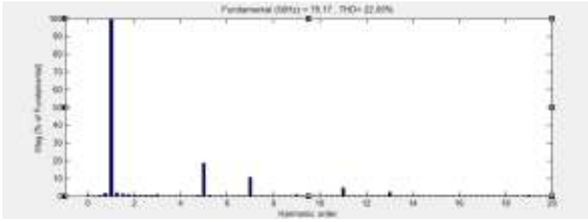

Fig74: THD of Load Current

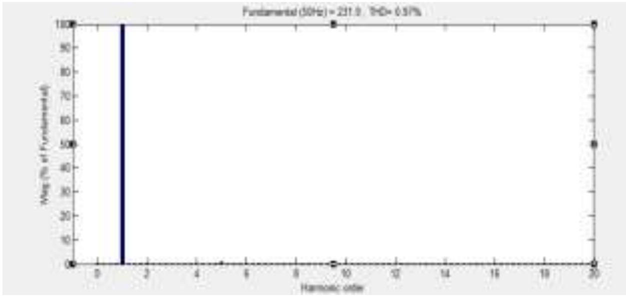

Fig75: THD of Source Current

COMPARISION OF THE CONTROL STRATERGIES:

The dynamic performance of the SAPF [2],[3] is to mitigate the harmonics in current, which are produced due to the non linear loads/network parameters. In this paper for mitigation of the harmonics the SAPF used three control algorithms namely IRPT, SRF and UNITTEMPLATE-UPF algorithms. The reference current is calculated by using these three control models to compensate the harmonics. The three control models are designed and performed in both balanced and unbalanced source voltage conditions and with

RL-load and DCMOTOR load[1]-[12] . By the observation of simulation result, the harmonics are reduced in the network with three control algorithms, but the unit template-UPF mode of operation with balanced/unbalanced condition and in both types of loads i.e., RL-load and DC motor is performed a satisfactory operation.

TABLE.2: Comparison of THD analysis

ALGORITHM	IRPT		SRF		Unit template	
	Balanced voltage	Unbalanced voltage	Balanced voltage	Unbalanced voltage	Balanced voltage	Unbalanced voltage
THD (RL-load)	3.22%	4.18%	5.32%	1.33%	1.25 %	0.92 %
THD (DCMOTOR)	4.22%	2.55%	1.32%	2.84%	0.79 %	0.97 %

CONCLUSION

SAPF is design to mitigate the power quality problems of harmonics in current, reactive power produced by nonlinear loads. The SAPFs is used PWM/hysteresis-based voltage source inverters for generating the switching pulses, because of low cost, reduced size, light weight, and reduced losses. The IRPT, SRF, UNITTEMPLATE-UPF algorithms are perform a satisfactory operation for the SAPF to compensate the harmonics. These three control algorithms are implemented with balanced/unbalanced source voltage and with RL load and DCMOTOR load. The three control algorithms are compensating the harmonics in both conditions. By comparing the THD values, in the unit template algorithm the more number of the harmonics are reduced ad it is giving best results in terms of the harmonics compensation by better THD values in two loads, and it is very easy to design.

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