Harmonic Mitigation and Reactive Power Compensation Using Shunt Active Filter With PI Controller

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Abstract*: Due to the advancement of electrical equipment as most of the load is the nonlinear poor quality of electric supply caused. This paper describes a shunt active filter for power quality improvement. It deals with the problem related to harmonics due to the nonlinear load. The Harmonic current is drawn with the aid of the nonlinear burden from the supply which results in a distortion of the voltage waveform in a supply-side. This distorted voltage and current may make conductors heat up and can lessen the effectiveness and future of the gear. With the goal that the decrease of harmonics is significant in nowadays life. This filter is utilized to make up for sounds reduced harmonics and receptive power. Three-phase thyristor loads are taken as a nonlinear load. For thyristor 180° scheme is used here. Thyristors are fired for seven different values of firing angle from 0° to 60°. The exhibition of a three-stage shunt dynamic power channel utilizing the instantaneous power hypothesis with a PI controller is clarified in this paper. Simulations are carried out using MATLAB/SIMULINK. simulation results are presented.

***Keywords*: nonlinear load, Shunt Active power filters (SAPF), voltage source inverter, Total Harmonic Distortion (THD).**

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I. INTRODUCTION

A wide meaning of power quality that incorporates the definitions of technical quality and supply continuity expresses that the cutoff points determined in the norms and guidelines ought not to be surpassed by electrical PQ. Any clear issue in voltage, current that offers to ascend to any frequency varieties prompting breakdown or glitch of client gear is named as the PQ issue. [6] The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network. [8] recently most of the electrical equipment used are advanced devices based on power electronics whose working is highly sensitive to the quality of power supply so, power quality is unquestionably a major issue that makes it particularly significant. power electronics-based equipment has nonlinear characteristics, which is the main cause of a harmonic generation. Because of the expanding tension over providing unadulterated electrical power to the purchasers in the accessibility of non-sinusoidal waveforms, PQ has increased a lot of enthusiasm for ongoing years. [2] As a result of the nonlinear nature of the load input source current will be nonsinusoidal. Along these lines, if another load associated with a similar source will be harmed need to take out the source current harmonic need to wipe out. To compensate reactive power and harmonics created by nonlinear load the most efficient technology is ACTIVE POWER FILTER (APF). [1]

II. ACTIVE FILTER

The Active filter is a kind of simple circuit actualizing an electronic channel which uses dynamic segments like an amplifier, it incorporates into channel structure for improving execution and cost. The dynamic channel is a device that generates harmonics in the same amount as generated by load but it is shifted by 180°. [4] In this way, when these sounds are embedded into the line at the purpose of normal coupling the heap current sounds are wiped out and the utility supply ends up sinusoidal. To deal with problems related to current and voltage harmonics, active filters are used. Also, they are capable of dealing with problems related to poor power factor and reactive power compensation. Active filters are classified as shunt, series, and hybrid active filters. Shunt active filters for compensation of current harmonics, series active filters are used for compensation of voltage harmonics, and hybrid active filters for compensation of both current and voltage harmonics (Akagi,1996).

Shunt active power filter solves the problem of harmonic current in the power system. It also compensates reactive power and balances the load of three-phases (if the load is unbalanced). It uses Clarke transformation to calculate the value of p_0, p, and q, filters out the constant part of p and thus finding the compensating part of p_0, p, and q. Then, it calculates compensating current by the inverse-Clarke transformation. The compensating current is injected into the network via a three-phase voltage controlled PWM inverter using the hysteresis current control method. In this way, the harmonic and reactive component of the load is supplied by this shunt active power filter.

III. INSTATANEOUS POWER THEORY

Proposed hypothesis dependent on quick values in three-stage control frameworks with or without nonpartisan wire, and is legitimate for unfaltering state or short-lived tasks, just as for conventional voltage and current waveforms called as Instantaneous Power Theory or Dynamic Reactive (p-q) hypothesis which comprises of a logarithmic change (Clarke change) of the three-stage voltages in the a-b-c directions to the α-β- 0directions, trailed by the count of the p-q hypothesis quick control segments. [9]

The Clarke Transformation:

the αβ0 change or the Clarke change maps the three-stage instantaneous voltages in the abc stages, va, vb, and vc, into the quick voltages on the αβ0-to Vα, Vβ, and v0. the Clarke transformation and its opposite transformation of three-stage nonexclusive voltages are given by

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -{}^{1}\!/_{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

and its inverse transformation is

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \quad (2)$$

Also, three-stage nonexclusive quick line flows, ia, ib, and ic can be changed on the αβ0 axes by

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -{}^{1}\!/_{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3)$$

and its inverse transformation is

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}$$

(4)

One preferred position of applying the αβ0 change is to isolate zero-succession segments from the abc-stage segments. the α and β axes do not contribute zero-grouping segments. No zero-arrangement current exists in a three-stage, three-wire framework so that i0 can be wiped out from the above equations, consequently bringing about rearrangements. If an event that the three-stage voltages are adjusted in a four-wire framework, no zero-arrangement voltage is available, so that can be disposed of. v0 Nonetheless, when zero-arrangement voltage and current segments are available, the complete change must be considered.

On the off chance that v0 can be wiped out from the change frameworks, the Clarke change and its converse change become

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -{}^{1}\!/_{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (5)$$

And

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \quad (6)$$

Comparative conditions hold in the line flows. [3]

From these active and reactive components are

$$p = v\alpha\, i\alpha + v\beta\, i\beta \quad (7)$$

$$q = v\alpha\, i\beta - v\beta\, i\alpha \quad (8)$$

The active and reactive powers in matrix form are given below

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (9)$$

Active and reactive powers can be separated into two parts which are the AC part and DC part as shown below

$$p = \bar{p} + \tilde{p} \quad (10)$$

$$q = \bar{q} + \tilde{q} \quad (11)$$

To get the DC part of the active and reactive power, the signals should be filtered utilizing a low pass filter. The low-pass filter will evacuate the high-frequency segment and give the fundamental part. Where $\overline{p}$ is the DC segment of the instantaneous power p is identified with the customary principle active current. $\tilde{p}$ is the ac segment of the instantaneous power p, it does not have average value, and is identified with the harmonic currents brought about by the ac part of the instantaneous real power $\bar{q}$ is the dc segment of the imaginary instantaneous power q, and is identified with the reactive power produced by the central parts of voltages and flows**.** $\tilde{q}$ is the ac segment of the instantaneous imaginary power q, and it is identified with the harmonic currents brought about by the ac segment of instantaneous reactive power. To remunerate reactive force and current harmonics produced by non-direct loads, the reference sign of the shunt active force filter must incorporate the estimations of $\tilde{p}, \bar{q}\ and\ \tilde{q}$. To get better the power factor, q has to be completely (cosϕ=1) or moderately (cosϕ<1) compensated by the shunt active filter. Right now, reference flows required by the shunt active force filter are determined with the following expression:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\bar{p} \\ -\bar{q} \end{bmatrix}$$

The final compensating currents components in a, b, c reference frame in terms of αβ given as

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

These are the compensation current injected by the shunt active filter to reduce harmonics in three phase-three wire systems. [1] It is to be stated that, when using this approach, a PLL is not needed.

IV. HYSTERESIS CURRENT CONTROLLER

For the development of a shunt active filter current control strategy assumes a significant job. To get exact momentary current control, the present control strategy must supply quick current controllability, along with these lines' speedy reaction. [5] Hysteresis current controller infers the switching signals of the inverter power switches in a way that diminishes the present mistake. There are different current control strategies proposed for such dynamic force channel setups, yet as far as fast current controllability and simple execution hysteresis band current control strategy has the highest rate among other current control techniques, for example, sinusoidal PWM. Hysteresis-band PWM is fundamentally an immediate feedback current control strategy for PWM where the real current consistently tracks the command current inside a hysteresis band. [5] Hysteresis control plans depend on a nonlinear feedback loop with two-level hysteresis comparators. The switching signals are developed straightforwardly when the mistake surpasses a predefined tolerance band. The current error which is created because of the distinction between APF repaying current and reference compensating current, development whenever confined inside a predefined limit will help in compensating for harmonics. [7] The switches are controlled nonconcurrent to slope the current through the inductor high and low with the goal that it follows the reference. At the point when the current through the inductor surpasses the upper hysteresis limit, a negative voltage is applied by the inverter to the inductor. This makes the current through the inductor decline. When the current arrives at the lower hysteresis limit, a positive voltage is applied by the inverter through the inductor and this makes the current increment and the cycle rehashes. The current controllers of the three stages are intended to work autonomously. They decide the changing signs to the particular period of the inverter.

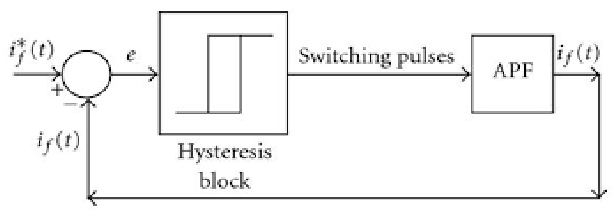

Fig. 1 Fixed-band hysteresis current control loop.

Among the different current control procedures, HCC is the most broadly utilized method because of the noncomplex usage, exceptional stability, absence of any tracking error, extremely quick transient reaction, characteristic constrained the greatest current, and intrinsic robustness to load parameters variations. HCC gives a superior low- order harmonic concealment than PWM control, which is the fundamental objective of the active power filter. It is simpler to acknowledge with high exactness and quick reaction. In any case, as a disadvantage, its switching frequency might fluctuate. In the HCC procedure, the mistake work is focused on a preset hysteresis band. At the point when the blunder surpasses the upper or lower hysteresis limit, the hysteretic controller settles on a fitting changing choice to control the mistake inside the preset band and send these heartbeats to VSI to create the reference current as appeared in Fig.1. The yields of the hysteresis blocks are directly fed as the firing pulse of VSI switches. [10] Thus, hysteresis current control for active power filter line currents can be actualized to produce the switching design the inverter.

V. THREE-PHASE INVERTERS

The dc to ac converters all the more normally known as inverters, depending upon the type of the supply source and the related topology of the power circuit, are classified as voltage source inverters (VSIs) and current source inverters (CSIs).

The VSI creates an ac outputs voltage waveform made out of discrete qualities (high dv/dt); accordingly, the load should be inductive at the consonant frequencies to produce a smooth current waveform. A capacitive burden in the VSIs will create huge current spikes. If so, an inductive filter between the VSI ac side and the load should be utilized. Then again, the CSI creates an ac output current waveform made out of discrete qualities (high di=dt); in this manner, the load should be capacitive at the consonant frequencies to deliver a smooth voltage waveform. An inductive burden in CSIs will create enormous voltage spikes. On the off chance that this is the situation, a capacitive channel between the CSI ac side and the load should be utilized.

Single-phase VSIs cover low-run power applications and three-phase VSIs cover medium to high power applications. The principal reason for these topologies is to give a three-stage voltage source, where the amplitude, phase, and frequency of the voltages can be controlled. The three-stage dc/ac voltage source inverters are widely being utilized in engine drives, active filters and unified power flow controllers in power frameworks and continuous power supplies to produce controllable frequency and ac voltage magnitudes.

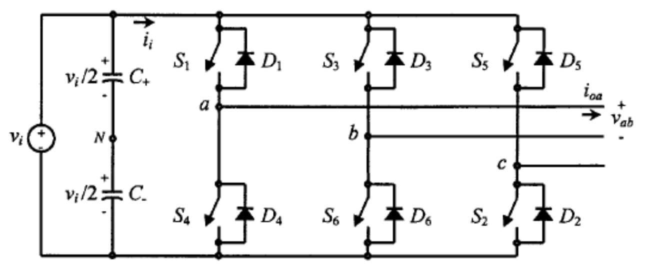

Fig. 2 Three-phase VSI topology.

Fig. 2 shows a six- pulse VSI supply with a steady voltage Vdc with a large capacitor. The VSI comprises six transistors, each associated with an anti-parallel diode. The transistors are the metal oxide semiconductor field impact transistors (MOSFETs). They are chosen because of their predominant exhibition qualities, for example, low forward voltage drop, quick exchanging occasions, and high-power handling capacity. The rationale inverters guarantee that each MOSFET on a similar leg supplement each other maintaining a short circuit problem of the DC-bus. [11]

VI. PI CONTROLLER

The fundamental downside of utilizing linear current control is, have to detect framework voltage. In any case, it's not reliable. There is a need for some extra calculations. Here PI controller with hysteresis current control strategy is discussed.

A proportional–integral– derivative controller (PID controller) is a conventional control circle criticism component (controller) broadly utilized in modern control frameworks – a PID is the most normally utilized input controller. A PID controller figures a "mistake" esteem as the distinction between a deliberate procedure variable and an ideal set point. The controller attempts to limit the mistake by modifying the procedure control inputs. PI controller (corresponding Integral Controller) is an extraordinary instance of the PID controller where the derivative (D) of the error isn't utilized. The absence of subordinate activity may make the framework steadier in the consistent state on account of noisy information source voltage and source current qualities are given to the reference generator. It will create Iref and the sign is given to the PI controller. Utilizing the PI controller, the reference contribution for an inverter is created. [12]

VII. SIMULATION RESULTS AND ANALYSIS.

The MATLAB simulation-based schematic of a three-phase thyristor system with RL load with shunt active filter is shown in Fig 3. The simulation is carried out in a discrete mode with an ode45 solver. Here in shunt active filter instantaneous power theory for current compensation, 3 phase inverter, hysteresis current control technique is used. Fig 3 consists of a series RL branch (coupling inductor), Compensating Current Calculation, Compensating Current Measurement, 3 Phase Inverter, Ploss Calculation, and Hysteresis Current Controller block. Here PI controller is used, the proportional and integral gains are set at 0.5 and 0.1 respectively.

The different parameters of the Shunt Active Filter are taken as

System Data:

Three-phase source Vrms =400v (line to line)

Source inductance Ls = 1mh

Load inductance LL= 100mh

Load resistance RL= 1 Ω

Filter data:

Capacitance= 1200e-3F

D.C reference voltage=130v

Coupling inductor=0.1mh

Coupling Resistance= 0.1m Ω

PI controller gain value

Kp=0.5

Ki=0.1

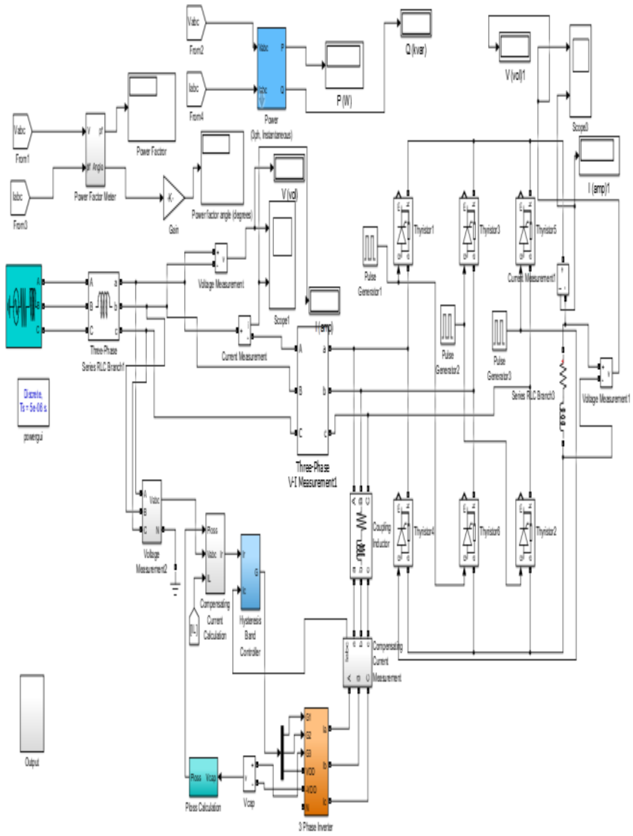

Fig. 3 simulation of three-phase system using shunt active filter

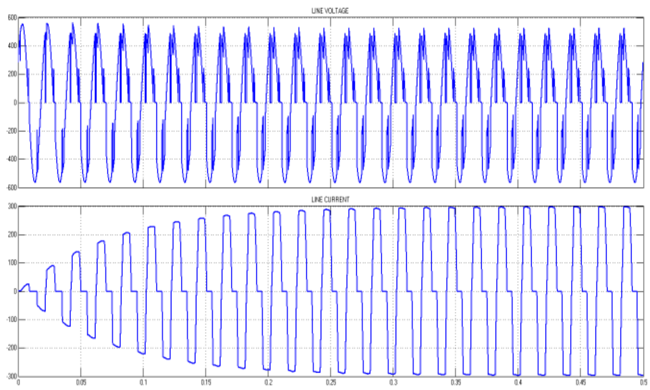

Fig 4-line voltage and current waveform for three-phase thyristor system for α=30° without filter

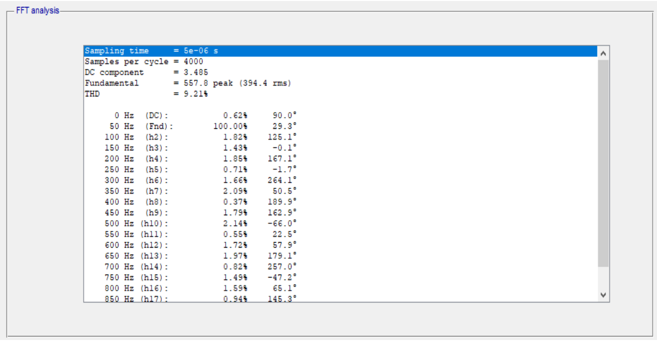

Fig 5 FFT analysis – Source voltage harmonic spectrum for three-phase thyristor system for α=30° without filter

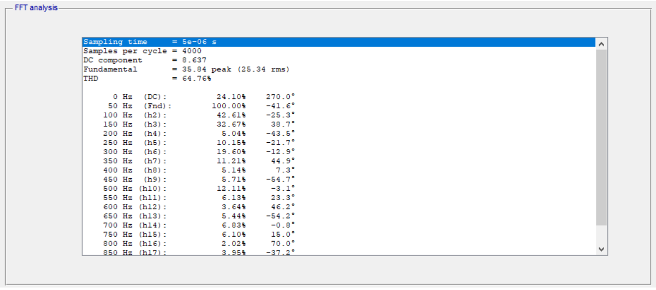

Fig 6 FFT analysis – Source current harmonic spectrum for three-phase thyristor system for α=30° without filter

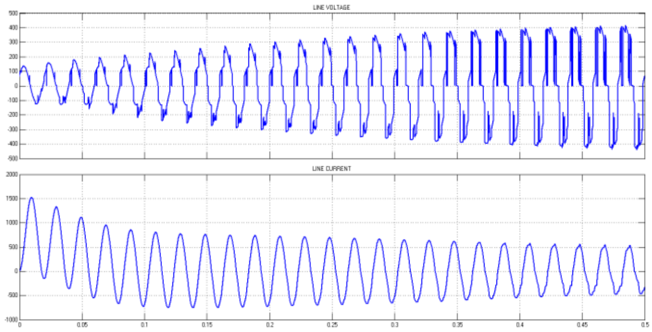

Fig 7-line voltage and current waveform for three-phase thyristor system for α=30° with shunt active filter

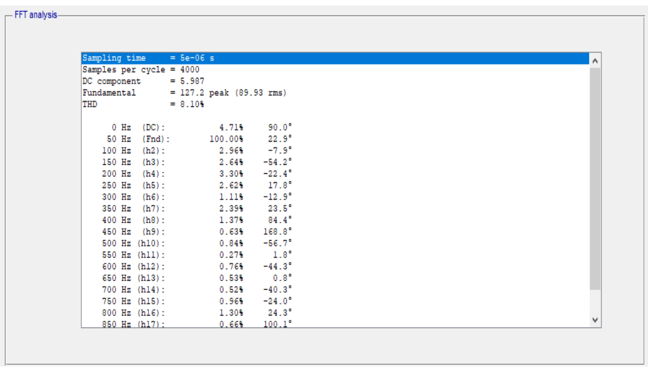

Fig 8 FFT analysis – Source voltage harmonic spectrum for three-phase thyristor system for α=30° with shunt active filter

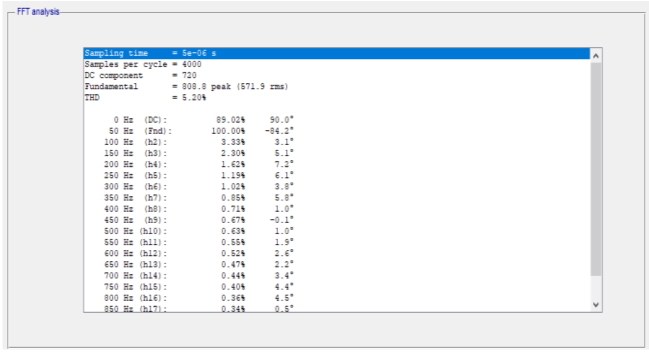

Fig 9 FFT analysis – Source voltage harmonic spectrum for three-phase thyristor system for α=30° with shunt active filter

Here 3 phase thyristors with RL load are connected it is a nonlinear load, so the source voltage and current waveform become non-linear as shown in fig 4. The voltage THD is 9.21% as shown in fig 5 for α=30° without a filter. The current THD is 64.76% as shown in fig 6 for α=30° without a filter. when shunt active filter is connected in the system and simulation is run, the input voltage is found near to sinusoidal and the input source current is found to be sinusoidal as shown in fig 7. For α=30° the THD value of voltage and current is reduced to 8.10% and 5.20% respectively. Which is shown in Fig 8 and Fig 9 respectively. The Power factor improved from 0.7499 to 0.9291 after harmonic compensation. The value of Active power improved from 257.6 to 537.4. Reactive power is compensated from 445.9 to 234.1.

Table 1 Comparison of Simulation Result of without filter and with Shunt active filter using a PI controller

sr no	***Firing angle***	**Without filter**					**Shunt active filter using a PI controller**				
		Power factor	***Active power***	***Reactive power***	***Voltage THD***	***Current THD***	***Power factor***	***Active power***	***Reactive power***	***Voltage THD***	***Current THD***
1	0	0.9358	333.6	574.8	9.03	46.55	0.9731	583.7	396.1	7.62	5.22
2	10	0.8964	314.1	541.8	9.31	51.50	0.9709	582.6	395	7.84	5.22
3	20	0.8356	288.7	498.8	9.35	57.61	0.9604	574.4	263.3	8.00	5.21
4	30	0.7499	257.6	445.9	9.21	64.76	0.9291	537.4	234.1	8.10	5.20
5	40	0.6404	221.3	383.9	9.48	70.27	0.8901	496.8	202.7	8.14	5.19
6	50	0.5147	181.1	314.9	9.53	74.35	0.8506	453.2	168.6	8.31	5.16
7	60	0.3877	139.3	242.8	8.93	77.28	0.8127	399.4	125	8.38	5.14

Table 1 shows a Comparison of Simulation Result of without filter and with Shunt active filter using a PI controller for each firing angle from 0° to 60°. As shown in the table the THD value obtained for shunt active filter in every simulation for voltage and current is not below 5% as per the IEEE standard 519-2014.

VII. CONCLUSION

The proposed idea is to design, develop shunt active filter with proper control scheme. The author used nonlinear load so power quality issues occur. So, the main objective of this work is to reduced power quality issues that occurred like reduced THD, compensate reactive power, improve power factor, and improve active power. In THD aim is to reduced lower order harmonics. Here the author considered 3^{rd},5^{th}, and 7^{th} order harmonics. Table 1 shows a Comparison of Simulation Result of without filter and with Shunt active filter using a PI controller. From the table, it is analyzed that in the case of a shunt active filter using the PI controller, the THD value is not below 5% which is under the limits of the IEEE standard 519-2014. Simulation Result shows the proposed system improves power quality to a good value by using the PI controller.

VIII. FUTURE SCOPE

Here in this paper, the performance of a shunt active filter is discussed by using a PI controller, by using this value of THD are reduced but it is not as per IEEE standard 519-2014. So, instead of this PI controller, any other controller can be used like fuzzy, ANFIS, etc. by using this controller THD values can be reduced as per IEEE standard 519-2014.

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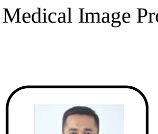

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