International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 05 | May 2026 www.irjet.net p-ISSN: 2395-0072

DESIGN AND ANALYSIS OF SERIES ACTIVE FILTERS FOR POWER QUALITY IMPROVEMENT

Chandana TH[1], Dr.B. Rajesh Kamath[2]

[1]PG student, Dept of EEE(CAID) Sri Siddharatha Institute of Technology, Tumakuru, Karnataka, India.
[2] Professor, Dept of EEE (CAID) Sri Siddharatha Institute of Technology, Tumakuru, Karnataka, India.

---***---

Abstract - *Power quality has become an important issue in modern power systems due to the increasing use of nonlinear and sensitive electronic loads. Devices such as rectifiers, inverters, adjustable speed drives and switched mode power supplies introduce harmonics, voltage sags, swells and distortions into the power system. These disturbances reduce system efficiency, degrade equipment performance and can even cause complete shutdown of industrial processes. Conventional passive filters have been widely used to mitigate these problems, but they suffer from limitations such as fixed compensation, bulky size, resonance problems and poor performance under changing load conditions. To overcome these drawbacks, active power filters have emerged as an effective solution. This project focuses on the design and analysis of a series active power filter (SAPF) for improving power quality. The series active filter is used to compensate voltage-related problems such as voltage sag, swell and harmonic distortion by injecting a compensating voltage in series with the supply. The proposed system improves voltage waveform quality and ensures a stable and reliable power supply to sensitive loads. Simulation and analysis demonstrate that the series active filter significantly enhances power quality and system performance.*

Key Words: Series Active Filter (SAF), Power Quality Improvement (PQI), Voltage unbalance, Power victorial theory

1. INTRODUCTION

Problems with power quality, such as a low power factor, harmonic pollution, imbalanced problem, etc., can arise as a result of the increasing usage of power electronics and motor loads in the power system. As a result, it's getting tougher for electric companies to serve consumers with voltage and current that meet regulations. Since the usage of these nonlinear loads cannot be limited due to the vast number of advantages that they offer, despite their demerits, it is necessary to come up with solutions to reduce their effects on power systems. Although the semi-conductor devices provide numerous advantages in effect to the proper operation of various end-user equipment, one major disadvantage of their usage is the injection of harmonics, which comes along with its adverse effects which include, lower efficiency of the entire power system, reduced power factor, mal-operation and tripping of fuses and switches which is undesirable, telephonic interferences and noise thus polluting the surrounding working environment, etc. The permissible limit for harmonics is 3% to 10% and for total harmonic distortions (THD) is 3% to 8%. Improvement of power quality has become a crucial feature of the present power system environment. Conventionally, power quality was enhanced using passive filters, shunt filters, and series filters, but they suffer from resonance, fixed compensation, and other power quality issues.

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipment's.

Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sags are not corrected within the limited time frame of mechanical switching devices.

Transformer taps may be used, but tap changing under load is costly.

There are basically two types of active filters: the shunt type and series type. The shunt connected active power filter, with a self-controlled dc bus used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. Series active power filters were introduced by the end of the 1980s and operate mainly as a voltage regulator and as a harmonic isolator between the nonlinear load and the utility system. The series-connected filter protects the consumer from an inadequate supply voltage quality. The series active filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side. Till now many control strategies have been developed but instantaneous active and reactive current (idiq) component method and instantaneous active and reactive power (p-q) method are more popular methods. This paper mainly concentrates on these two control strategies (id-iq and p-q) with PI controller. Both methods are compared under distorted main voltage condition and it is found that id-qi control method achieve superior harmonic compensation performance. The id-iq control is based on a synchronous rotating frame derived from the mains voltages without the use of a phase-locked loop (PLL). By the idiq control method many synchronization problems are avoided and a truly frequency independent filter is achieved.

1.1Power Quality

There are several power quality difficulties in today's electrical systems, which are undergoing rapid change. The principal origins of these power quality issues can be categorized as either natural or artificial depending on whether they are measured in terms of current, voltage, frequency, etc. Weather factors, such as interference, lightning, and storms, and equipment failures are the most common natural causes of poor power quality. However, the majority of human reasons are due to load or system operation. Non-linear loads, such as saturated transformers and other types of electrical equipment, as well as loads with solid-state controls, such as steam lamp-based lighting systems, ASDs, UPS, arc furnaces, computer power supplies, and televisions, can be nonlinear loads that contribute to load-related issues. Televisions and arc furnaces are two other common instances of load-related causes of power outages. Power quality issues that are caused by the operation of the system can be traced back to its transformers, capacitors, feeders, and switching at high loads. Typically, transitory power quality concerns are caused by natural factors, such as: B. Transient phenomena of voltage drop (dip), voltage distortion, expansion, and shock and vibration. However, human causes are responsible for both temporary and permanent power quality problems. However, harmonics are one of the most significant power quality concerns. This can be caused by loads that do not operate linearly, including classic loads like transformers, electric machines, and furnaces, as well as innovative loads like rectifiers and steam lamps. Switch mode power supply (SMPS), ASD with AC-DC converter, cyclo converter, AC voltage regulator, HVDC transmission, VAR static compensator, and other similar devices. All affected utilities, customers, and manufacturers incur considerable economic losses owing to process interruptions and damaged equipment as a result of power quality concerns. The loss of production, the squandering of raw materials, the erasure of critical data, and other associated costs. Even a momentary drop or sag in voltage can cause significant problems in a number of contexts and applications, such as automated industrial processes, the production of semiconductors, the pharmaceutical industry, and banking, where it can disrupt operations for several hours and result in the waste of raw materials and other resources.

Some power quality issues impact the protection systems and lead to malfunctioning protective equipment. These disrupt several industrial operations and procedures and other organizations. Additionally, these attributes have an impact on a diverse set of measuring equipment, in addition to the metering of quantities like voltage, current, power, and energy. In addition, the monitoring systems of a significant quantity of major, critical, emergency, vital, and expensive equipment are impacted as a direct result of these problems.

1.2 POWER QUALITY PROBLEMS

Due to increasing problems associated with poor power quality, such as financial loss, lost output, wasted raw materials, and so on, numerous mitigation strategies have emerged in the previous quarter century to try to fix the problem. Capacitors, reactors, and other specialized power devices are examples of passive components. Power filters, better power quality AC–DC converters, and matrix converters are further examples of passive components. In many cases, however, such as in distribution systems, when problems with voltage regulation, low power factor, load unbalancing, excessive neutral current, and so on are found, it is possible that harmonics are not the primary cause of the power quality concerns. This is because harmonics are a frequency-dependent phenomenon. By decreasing problems like low power factor resulting from reactive power demands, lossless passive devices like capacitors and reactors can improve power quality.

Specialized power devices such as DSTATCOMs, DVRs, and UPQCs can also be used to improve power quality by reducing current, voltage, or both. In single-phase two wire, and three-phase three-wire, and three phase four-wire systems, it is common practice to retrofit power filters of various types, such as shunt, series, or a combination of both, in order to mitigate power quality concerns caused by harmonics and other power quality issues. There are numerous filter circuits, and the best filter configuration depends on the type of load being fed electricity: voltage-fed, current-fed, or a hybrid of the two. The use of PFC converters, also referred to as IPQCs, Multi-pulse AC-DC converters, matrix converters for AC-DC or AC-AC conversion, and others in the input stage of newly designed and developed equipment is the basis for power quality improvement techniques. By receiving clean power from the utility, PFC converters automatically alleviate some of the power quality disturbances that exist within them and across the supply system. Numerous circuits of the boost, buck, buck-boost, multilayer, and multi-pulse converter sorts are available for unidirectional and bidirectional power flow with and without isolation in single-phase and three-phase supply systems.

2. PROPSED METHODOLOGY

Harmonic Filters are used to cut down on harmonic waveform distortion, which is a problem that affects the quality of the electricity. As a consequence of this, they lessen the possibility that reliability issues will be caused by harmonics restrict the thermal and electrical stress that is placed on the electrical infrastructure, and make it possible to achieve long-term improvements in energy efficiency and cost savings. Because the vast majority of today's electrical appliances are nonlinear, the use of harmonic filters will be necessary in order to achieve higher levels of power quality.

SERIES ACTIVE FILTER

For a three-phase, three-wire AC system, the fundamental circuit of the active series compensator is as follows. It is depicted in Figure. The DVR is an IGBT-based VSC with a DC bus capacitor. Utilizing controls by predicting the injected reference voltage, the algorithm directly controls the injected voltage. Hysteresis is used to create the DVR's gate pulse (carrier less). PWM (fixed frequency) voltage control for reference and measured load voltage indirect control of voltage. Voltage spikes, surges, Flickering, dips, swells, notches, fluctuations, waveform distortion, voltage imbalances, and harmonics can all be avoided when using a DVR with the right control algorithm. Compensation is attainable.

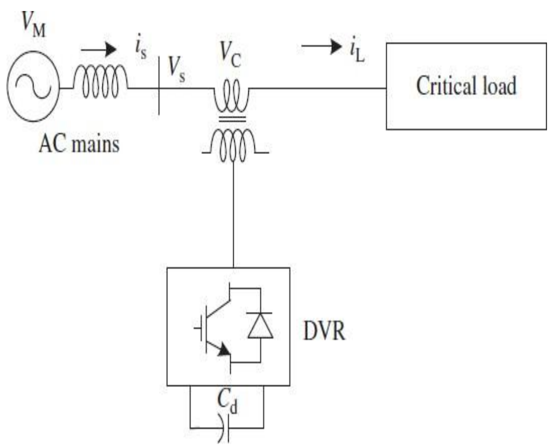

Fig 2.1.series active filter

SHUNT ACTIVE FILTER

The shunt-connected active power filter has an architecture that is comparable to a static compensator (STATCOM), which is used in power transmission networks for reactive power compensation. Shunt active power filters inject equal-but-opposite harmonic compensatory current to balance load current harmonics. Here, the shunt active power filter acts as a current source, injecting the load's harmonic components 180 degrees out of phase.

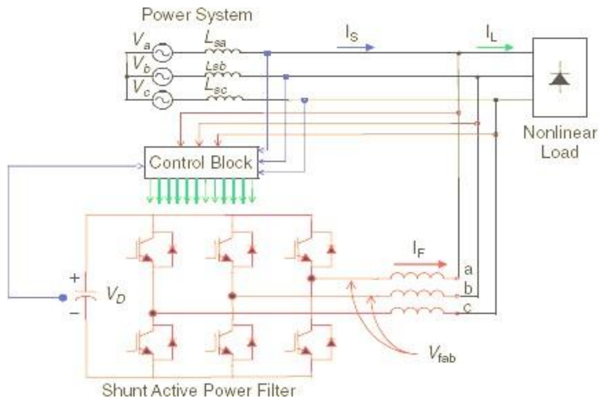

Fig2.2 Shunt active power filter topology.

3. SIMULATION & RESULTS

The below figure 3.1is the schematic diagram of the modelled diagram of distribution system which has uncontrolled rectifier feeding an Resistive-Inductive load. PCC is the point on the transmission line at which the active filter can be connected. The non-linear load connected at the load side can either be single phase or three phase supply based on the industrial requirement. The MATLAB Simulink model of three phase uncontrolled rectifier feeding an Resistive Inductive load is depicted here which has the voltage source and impedance connected to the single-phase electric arc furnace. The measurement devices are connected to the load block which kept inside the subsystem connected at the end.

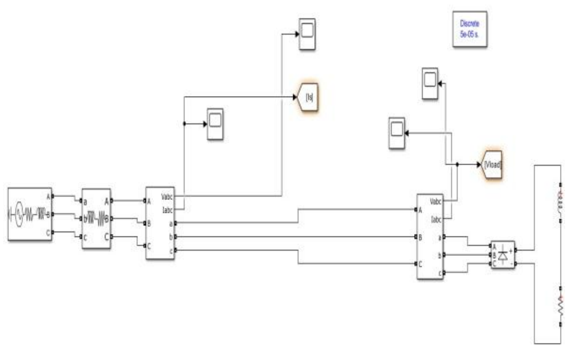

Fig 3.1 single line diagram of system

In order to create a harmonic injecting load for the harmonic analysis and its impact on the supply, an uncontrolled rectifier feeding a Resistive-Inductive load is taken into the consideration and the specification of the realized rectifier is as depicted in the figure 3.2

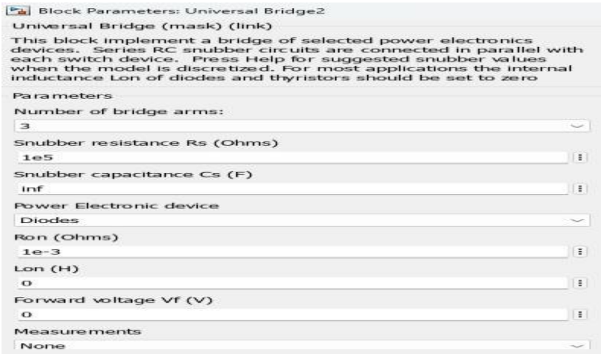

Fig 3.2 Load description of an uncontrolled rectifier

The circuit is simulated to assess the performance of the system for evaluating the harmonics of the system parameters

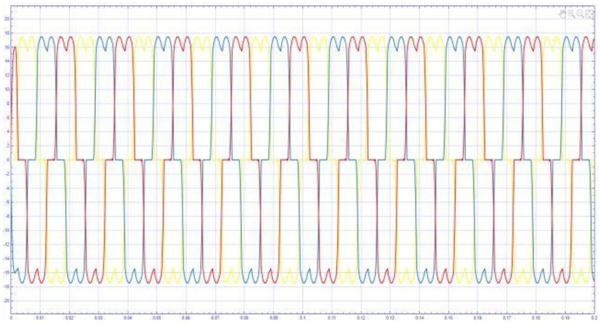

Fig 3.3-phase load current of an uncontrolled rectifier

The fig3.3 depicts the three-phase load current of an uncontrolled rectifier and it is observed from the figure that the current drawn by the load is non-linear in nature and signifying the presence of harmonics leading to the distortion of the waveform.

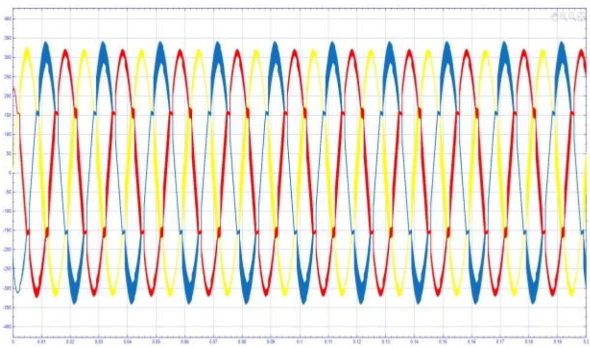

Fig 3.4 Three phase load voltage of an uncontrolled Rectifier

The figure 3.4 depicts the three phase load voltage of an uncontrolled rectifier and it is observed from the figure that, since current drawn by the load is non-linear in nature results in the distortion of the voltage at the point of common coupling, and the voltage waveform is deviated from its pure sinusoidal form.

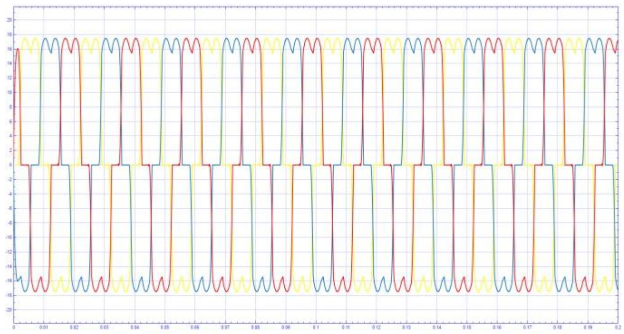

Fig 3.5 three phase source current

The fig3.5 depicts the three phase Source current of the system, since the load is an uncontrolled rectifier and it is observed from the figure that the current drawn by the load from the source is also non-linear in nature and signifying the presence of harmonics leading to the distortion of the waveform.

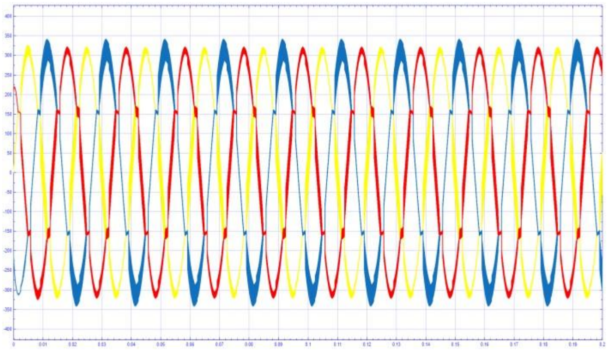

Fig.3.6 Three phase Source voltage at source

The fig3.6 depicts the three-phase source voltage of the system comprising of an uncontrolled rectifier and it is observed from the figure that, since current drawn by the source is non-linear in nature results in the distortion of the voltage at the source, and the voltage waveform is deviated from its pure sinusoidal form. the harmonic analysis is carried out for the source voltage and the harmonic spectrum of the source voltage is depicted in figure 4.6 It is observed from the fig.4.7 the total voltage THD of the source voltage is 13.82% and the voltage harmonics is mainly due to the presence of the lower order harmonics like 5th and 7th harmonic, while 5th harmonic contributing to 4.25% and 7th harmonic contributing to 2.75%. these data suggest that the voltage THD is above the prescribed limit and signify the necessity of a suitable compensator to mitigate the effect of harmonics.

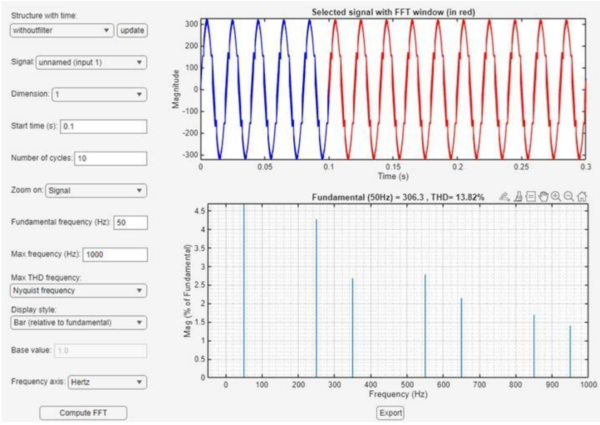

Fig.3.7 Harmonic spectrum of the source voltage.

It is observed from the figure 37. the total voltage THD of the source voltage is 13.82% and the voltage harmonics is mainly due to the presence of the lower order harmonics like 5th and 7th harmonic, while 5th harmonic contributing to 4.25% and 7th harmonic contributing to 2.75%. these data suggest that the voltage THD is above the prescribed limit and signify the necessity of a suitable compensator to mitigate the effect of harmonics. The series active filter is found to be an effective solution in suppressing the voltage harmonics and the designed series active filter is simulated to assess the effectiveness of series active filter.

The Simulink model of the system with series Filter is depicted in figure3.8

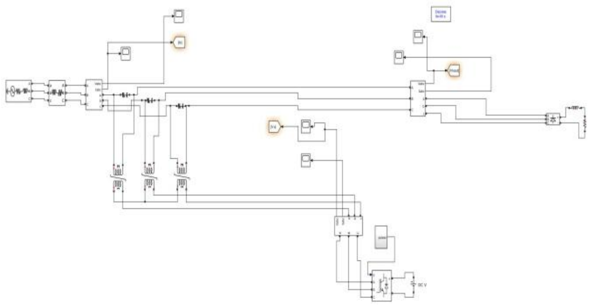

Fig 3.9 System description of control algorithm

The propose active reactive power theory/ PQ theory is designed and the voltage and current measurement from the source and load are taken an an input signal for the estimation of the reference harmonic signal. The compensation signal generated by the series active filter is as shown in figure 3.10.

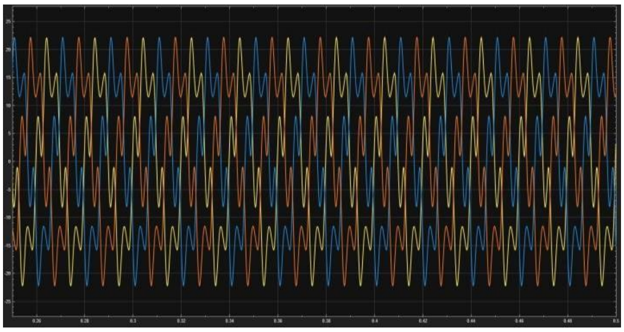

Fig 3.10 Compensating Signal

The compensating signal generated by a series active filter is injected to the system which suppresses the voltage harmonics injected by the load and thereby reducing the voltage harmonic at the source.

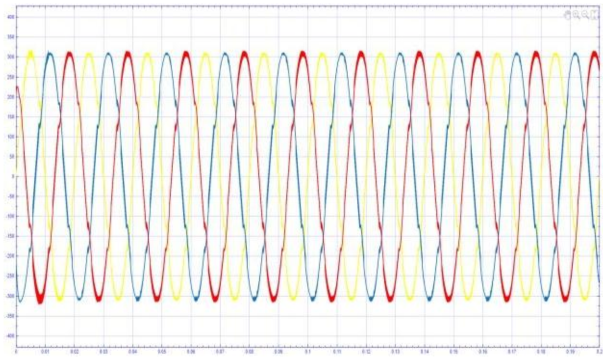

Fig 3.11 three phase Source voltage at source after compensation

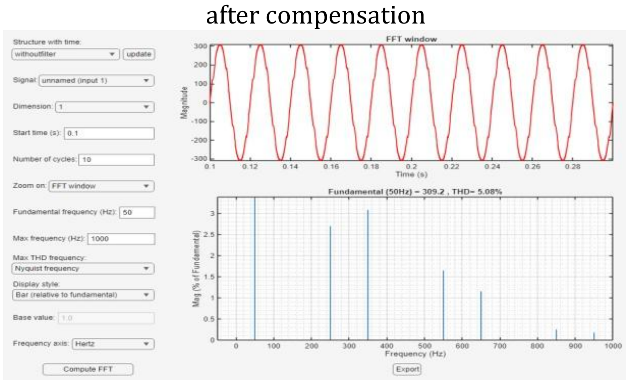

Fig3.12 Harmonic spectrum of Source voltage at source after compensation.

The figure 3.11 and 3.12 represent the three-phase voltage waveform at the source and its harmonic spectrum. It is observed from the figure 3.11 that the source voltage waveform has less distortion in comparison with the figure 3.6 justifying the effectiveness of series active filter and also the figure 3.12 suggest that the voltage THD has reduced from 13.52% to 5.08%, also there is a significant reduction in the 5th and 7th harmonic in the range of 2.75% and

3.0% from the previous value of 4.25%. Also, the THD has been reduced below the prescribed limit of 10% as per the IEEE standards.

4. CONCLUSIONS

Through the implementation of this project, an effort has been made to mitigate the harmonics flickers and other power quality disturbances that occur in the unregulated rectifier that is feeding a highly inductive load, which is regarded as a highly non-linear load. Initial consideration is given to the performance of the nonlinear load. There has been a recording of the waveforms of both the source current and the source voltage. The waveforms make it very clear that the allowable limit for harmonics has been exceeded. It is 13.52% that the voltage THD of the source current is. In order to find a solution to this issue, a literature review has been carried out just now. Active filters, due to their dynamic nature, have been identified as a potential method to effectively counteract the power quality disruptions. The series active filter and the shunt active filter are the two types of active filters that may be used. Essentially, a series active filter is nothing more than a dynamic voltage restorer that is coupled in series with both the load and the source power supply. In order to alleviate the voltage-related power quality issues, it gives the circuit the appropriate compensating voltage that it needs. A series filter has been observed to be capable of addressing voltage related issues. It has been observed that the total harmonic distortion (THD) of the voltage in a series filter is 5.08%, whereas the THD in the absence of the compensator was 13.52%. Additionally, there is a significant reduction in the 5th and 7th harmonic, which went from a value of 4.25% to a range of 2.75% and 3.0%. In addition, the total harmonic distortion (THD) has been decreased to a level that is lower than the recommended limit of 10%, as stipulated by the IEEE standards.

REFERENCES

1) Roger Caddigan, Mark F. McGranaghan, Surya Santoso and H.WayneBeaty," Electrical Power System Quality", McGraw –Hill.

2) Hirofumi Akagi, Edson Hirokuzu Watanabe, Mauricio Aredes, - "Instantaneous Power theory and applications to power conditioning", IEEE Press, Wiley-Interscience A John Wiley & Sons, Inc., Publication.

3) K. Bimal. Bose, in Modern Power Electronics and AC Drives, Knoxville, Tennessee, ELSEVIER, 2006, pp. 105-111.

4) K. Akagi and R. Hirofumi, in Instantaneous Power Theory and Applications to Power Conditioning, Aredes Mauricio, Wiley-IEEE Press, 2007, pp. 12-45.

5) C. Y. Hsu and H. Y. Wu, "A new single-phase active power filter with reduced energystorage capacity," Electric Power Applications, IEE Proceedings-, vol. 143, pp. 25-30, 2006.

6) M. El-Habrouk, M. K. Darwish, and P. Mehta, "Active power filters: a review," Electric Power Applications, IEE Proceedings-, vol. 147, pp. 403-413, 2021.

7) B. Dobrucky, H. Kim, V. Racek, M. Roch, M. Pokorny. "Single-phase power active filter and compensator using instantaneous reactive power method", in proc. Power conversion conference, Vol 1, pp.167-171, (2022)

8) S. Fukuda, T. Endoh. "Control method for a combined active filter system employing a current source converter and a high pass filter", IEEE Trans. On industry applications, Vol.31, pp.590-597, (1995)

9) H. L. Jou, J. C. Wu, H. Y. Chu. "New single-phase active power filter", in proc. IEE Electric Power Applications, Vol.141, pp. 129-134, (1994)

10) P. C. Tan, Z. Salam, A. Jusoh. "A single-phase hybrid active power filter using extension p-q theorem for photovoltaic application", in Proc. IEEE international Conference on Power Electronics and Drives systems, vol.1, pp.1250-1255 (2015).

11) C. Y. Hsu, H. –Y. Wu. "A new single-phase active power filter with reduced energystorage capacity", in proc. IEEE power applications, Vol.143, pp.25-30,(1996)

12) B. Dobrucky, H. Kim, V. Racek, M. Roch, M. Pokorny. "Single-phase power active filter and compensator using instantaneous reactive power method", in proc. Power conversion conference, Vol 1, pp.167-171, (2002)

13) S. G. Jeong, M. H. Woo. "DSP-based active power filter with predictive current control", IEEE Trans. On industrial Electronics, Vol.44, pp.329-336, (1997) H. Akagi. "New trends in active filters for power conditioning", IEEE Trans. On Industry Applications, vol.32, pp.1312-1322(1996)

14) Karuppanan P., Mahapatra K.K., "PLL with fuzzy logic controller based shunt active power filter for harmonic and reactive power compensation" IEEE Conference, IICPT, Power Electronics, (2021):pp.1-6.

15) Charles. S and G. Bhuvaneswari, "Comparison of Three Phase Shunt Active Power Filter Algorithms", International Journal of Computer and Electrical Engineering, vol. 2, no. 1, February 2010,

pp. 175-180.

16) Sagu Ravindra, V. C. Veera Reddy and S. Siva Nagaraju, "Design of Shunt Active Power Filter to Eliminate The Harmonic Currents and to Compensate the Reactive Power under Distorted and/or Imbalanced Source Voltages in Steady State", 2011 International Journal of Engineering Trends and Technology, vol. 2, no. 3, pp. 20-24.

17) T. Naron grit, K. L. Areerak and K. N. Areerak, "The Comparison Study of Current Control Techniques for Active Power Filters", World Academy of Science, Engineering and technology 60, Vol. 5, December 2011, pp. 471-476.