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Distribution-Level Power Quality Conditioning via Multilevel Converter–Enabled Shunt Active Compensation

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Abstract
Electric power systems are increasingly vulnerable to disturbances caused by harmonic pollution, which can lead to severe and unexpected consequences. Line current harmonics contribute to higher failure rates, reduced equipment lifespan, and voltage distortion. The widespread use of power electronic devices, converters, and nonlinear loads has significantly increased harmonic contamination in electrical networks. To mitigate harmonic currents, both passive and active filtering techniques are employed, either near harmonic-generating loads or at the point of common coupling. Active filters are commonly applied in low- and medium-voltage systems; however, at medium- and high-voltage levels, shunt passive filters are more effective in suppressing harmonic content. Passive filters are widely adopted in applications such as reactive power compensation and harmonic mitigation due to their simplicity, reliability, low cost, and lack of control requirements.Uncontrolled AC–DC converters introduce several power quality issues, including poor power factor, distortion of AC supply currents, fluctuations in DC-link voltage, excessive heating of equipment caused by harmonic currents, voltage distortion due to harmonic-induced drops across system impedances, and electromagnetic interference affecting communication and telephone lines. Various circuit topologies such as AC–DC converters, passive filters, and improved power-quality AC–DC converter configurations have been designed, analyzed, and implemented to address these challenges. The primary emphasis of this study is on achieving simple circuit structures, straightforward control strategies, and reduced component ratings, ultimately leading to lower overall system cost.

Keywords: ***Power, Quality improvement, multilevel inverter, Shunt active filter.***

1.Introduction

Concerns on Power System Harmonics and Power Quality

Increasingly, the issue of power quality (PQ) in electrical power systems is of concern to modern power system engineers. One of the most decisive causes of the degradation of the power quality is harmonic distortion. With current and unavoidable use of nonlinear loads, harmonic distortion has become a common problem in the electricity power distribution systems. High levels of such loads can result in large amounts of harmonic voltages and currents, which can have a negative impact on the performance and reliability of the system. IEEE standards have established the harmonic current and voltage limits (1).

Existing harmonics may lead to severe power quality issues in distribution feeders serving sensitive consumers, and their impacts will spread over the distribution system. In order to overcome PQ problems, a number of mitigation strategies have been investigated. Passive power filters (PPFs), which are combinations of capacitors and inductors, were once in use. These filters found their application especially in high-voltage direct current (HVDC) transmission systems to isolate the harmonics between the DC and the AC sides. Passive filters are however less effective at the distribution level since they are programmed at a set of system conditions or load characteristics and therefore cannot adapt to varying operating conditions. This led to the introduction of active power filters (APFs) so as to achieve dynamic compensation of reactive power and harmonic distortion.

2. Power Quality

The quality of power depends on the nature of voltage, current and frequency supplied to the final customer. Any alteration of the nominal magnitude of the voltage, frequency or waveform is a power quality issue. Electric utility and consumers are very concerned with these issues. The rising trend of power electronic equipment although it provides better control, less maintenance, and energy conservation has also contributed to more harmonic generation in the power systems(2).

Harmonic distortion may lead to imprecise energy measurement, unjustifiable neutral currents, capacitor fuse failures, electrical equipment overheating and unjustifiable capacitor fuse failures. As a result, the IEEE and the International Electrotechnical Commission (IEC) standards lay a lot of emphasis on the reduction of harmonic emissions(3). The quality of power is a cumulative of voltage quality and current quality. Voltage quality is the degree of resemblance between the real voltage waveform and a theoretical sinusoidal voltage of constant amplitude and frequency and current quality is the degree of dissimilarity among the real current waveform and an ideal sinusoidal current.

Industrial consumers are greatly affected economically by poor power quality and negatively influenced by poor power quality on the electrical grid performance. Harmonic of voltages and current disrupt system efficiency and reliability with residential customers receiving lower quality service. Thus, power quality concerns electricity companies that are strongly encouraged to focus on the power quality problem to satisfy customers and provide them with a stable, high-quality electricity.

3. Simulation Results

A seven-level inverter-based shunt hybrid active power filter (ACSLISHAPF) with a thyristor-controlled reactor (TCR) is created in MATLAB/Simulink to reduce harmonic in a high-voltage power distribution system in this chapter. The simulation study is organized in a coherent way such that it starts with the model of the asymmetric cascaded seven level inverter-based shunt active power filter (ACSLISAPF), then the model of its control strategy, the tuned passive filter (TPF), and the TCR(4).

A full Simulink model of the high voltage test system with the proposed ACSLISHAPF compensation is then created. Moreover, there is a basic simulation model of the ACSLISAPF, which is developed without using hybrid compensation to be used as a basis to compare the relevant performance of the intended ACSLISHAPF with TCR. In order to gauge the moving performance of the proposed architecture, the compensated test system goes through a three-phase fault, which enables examination of its reaction to abrupt disturbances.

As depicted in Fig. 1, the high voltage test system that was considered comprises three phases AC source and is linked to a nonlinear diode rectifier load using transmission line. The following paragraphs give a detailed description of modeling and implementation of all functional blocks of the test system(5).

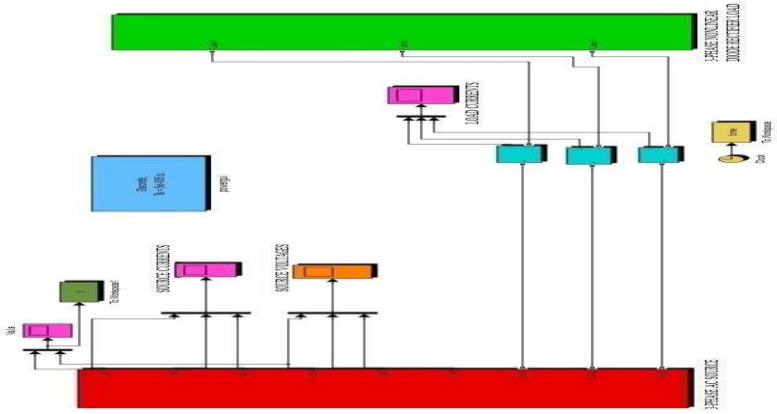


FIGURE 1 Simulink model of HV test system

3.1 Three Phase AC Source Model

The power source block in the simulation model of the HV test system shown in Fig. 5.2 was created by three single phase "AC Voltage Source" blocks of the library named Sim Power Systems / Electrical Source. It is an AC voltage source, 3 phase, 4500 V (peak), 50 Hz, sinusoidal, and has an inductance (Ls) in series with each phase to limit the current flowing during the initial operation of the equipment. It consists of the building using the Series RLC Branch block set. The reason is that the value of Lsis was selected to be 15 mH in every stage. The current and voltage signals are sensed with the help of the blocks Current Measurement and Voltage Measurement block sets of the library Sim Power Systems /Measurements(6).

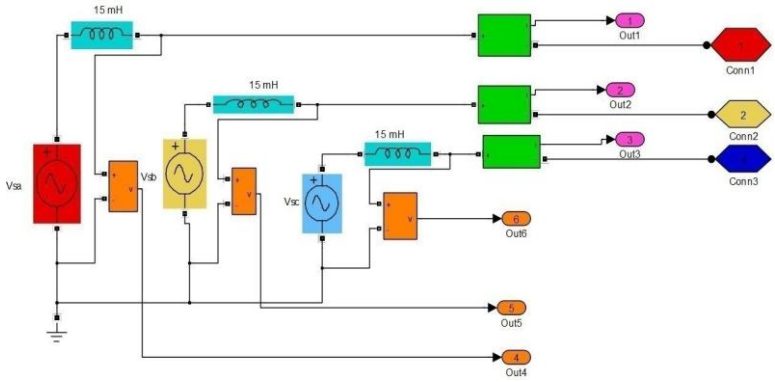


FIGURE 2 Simulink model of "Three phase AC Source" block.

3.2 Three Phase Nonlinear Load Model

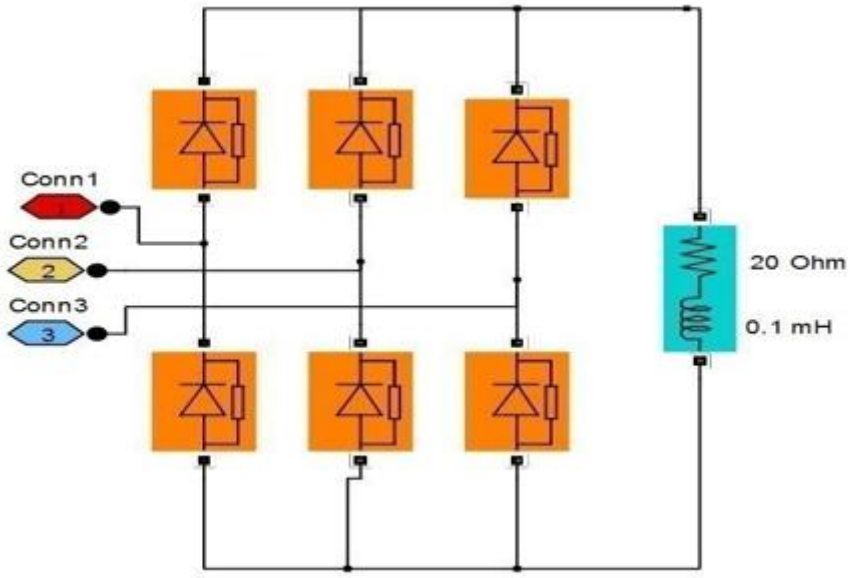


FIGURE 3 Simulation model of" Three phase Nonlinear Load" block

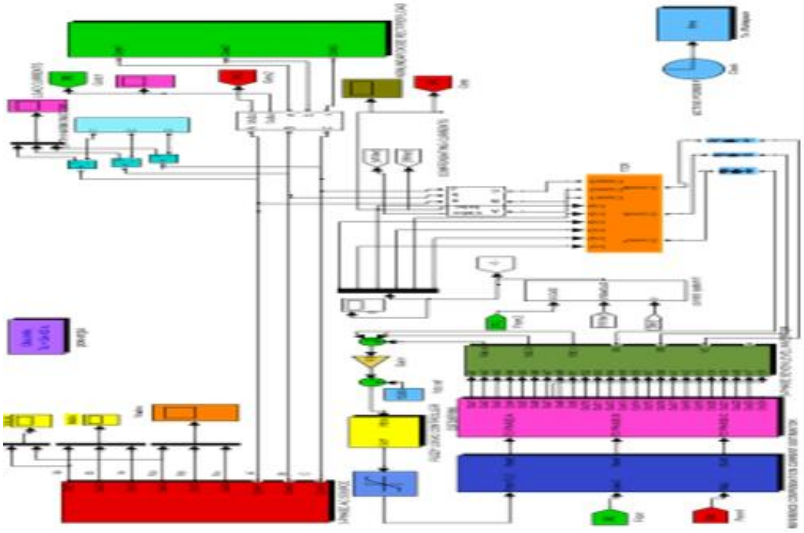


FIGURE 4 The proposed ACSLISHAF compensation consists of an asymmetric cascaded seven level inverter (ACSLI) and its entire control system

3.3 Matlab/Simulink model of hv test system with proposed 7 level shapf with tcr compensation

The entire Simulink diagram of the HV test system beyond which the proposed ACSLISHAF with TCR compensation is included is created through MATLAB/Simulink environment as shown in Fig. 3.4. The compensation scheme to be proposed is the ACSLISHAF, which is an asymmetric cascaded seven-level inverter (ACSLI) and an in-built control system. The control architecture involves the reference compensation current estimator on the basis of the d-q-0 theory, constant switching frequency subharmonic PWM approach in the production of the ACSLI gating signals, and a fuzzy logic controller in controlling the DC bus voltage(7). Besides this, parallel-connected tuned passive filters and a thyristor-controlled reactor (TCR) are used to augment harmonic mitigation and reactive power compensation. The following sections will provide a description of how the MATLAB/Simulink model of each of these functional blocks will be developed.

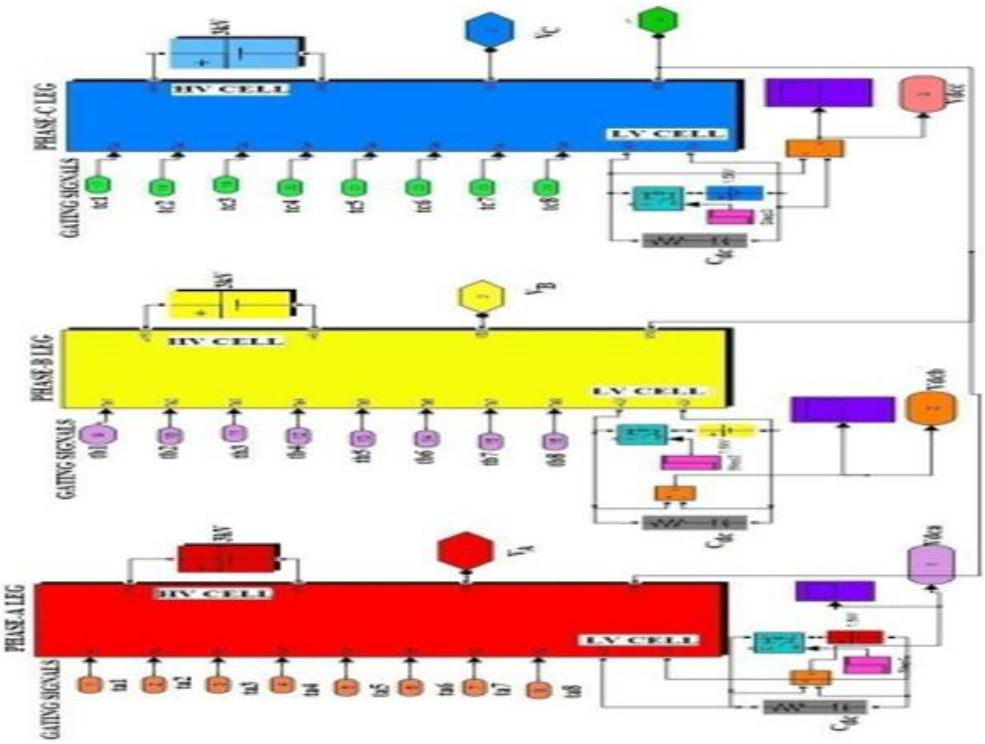


FIGURE 5 Three phase asymmetric cascaded seven level inverter models

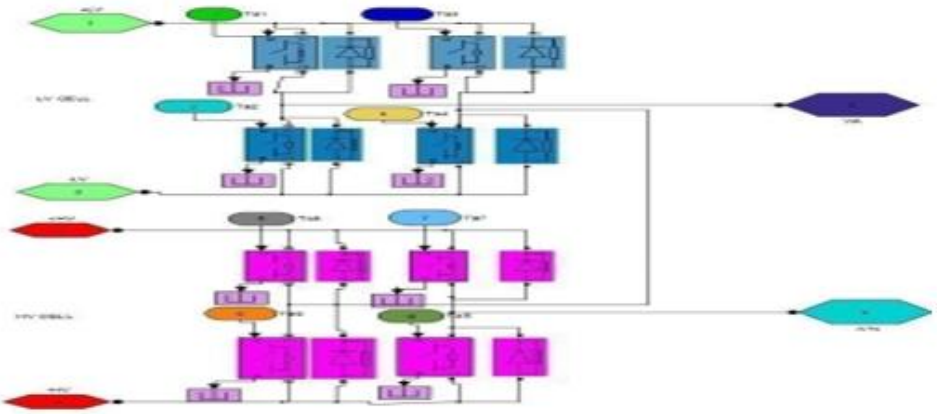


FIGURE 6 Details of a symmetric cascaded seven level inverter model for phase–a

ACSLI is connected with the point of common coupling (PCC) with the help of a coupling capacitor and an insulating interface. Constant Switching Frequency Subharmonic PWM (CSFSH-PWM) block produces the gate control signal of the ACSLI. In phase-a, the gating signals are represented by . In Fig. 3.6, the MATLAB/Simulink implementation of the Phase-a ACSLI block is shown(8).

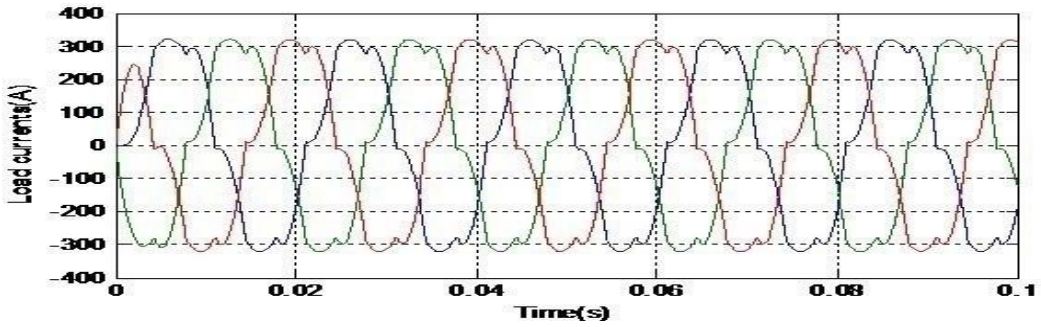
Two H-bridge cells, that is, low-voltage (LV) cell and high-voltage (HV) cell, are series-connected in each stage of the ACSLI. Every H-bridge cell is made of four optimal switches with diodes anti-parallel to each other. Each H-bridge will have separate DC-side energy storage elements. The appropriate DC voltage of the LV and HV cells is 1.5 kV and 3 kV respectively. According to the equation (3.24) in Chapter 3, the HV cell is capable of producing seven output voltage levels because its DC voltage was currently two times the LV cell. The 3 kV HV cell uses a DC voltage source as its energy storage device and a capacitor of 4000 001.5 kV LV cell uses a capacitor of 4000 001.5 kV LV cell is used on the DC side of the 3 kV HV cell. The capacitor value is selected using the general design rule that the capacitor load time constant must be at least equal to ten times the fundamental period in order to reduce the DC voltage variation to a minimum.

The general ACSLI control system includes a Constant Switching Frequency Subharmonic PWM (CSFSH-PWM) method of signal gating generation, a DC bus voltage controller system, which is fuzzy-logic-based, and a reference compensation current estimator system using d -q -0 theory(9).

3.4 Harmonic Reduction Effects in the HV Test System

This segment shows the simulation outcomes of the proposed seven level SHAF with TCR harmonic mitigation in an HV distribution system. The first part is the discussion of the simulation outcome of the HV test system with no compensation, then the outcome with the standard seven-level SAPF. The analysis of the performance of the HV system using the proposed seven-level SHAPF with TCR compensation is done afterward. To examine the performance of the ACSLSAF in the high-voltage test system, the performance of the harmonic mitigation is measured with and compared to that of the proposed ACSLSHAPF with TCR. 3.3 HV Test System Performance Without Compensation To investigate the capability of the ACSLSAF in high-voltage test system, 3-phase full-bridge diode rectifier load is applied to a three-phase distribution source with 4.5 kV peak voltage in the MATLAB/Simulink simulation of the HV test system developed(10).

a)



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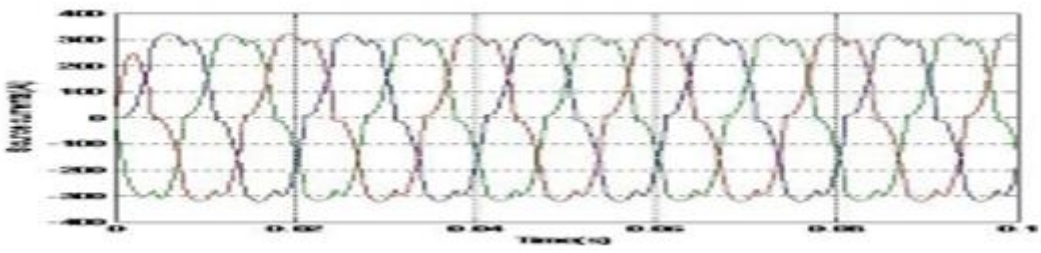

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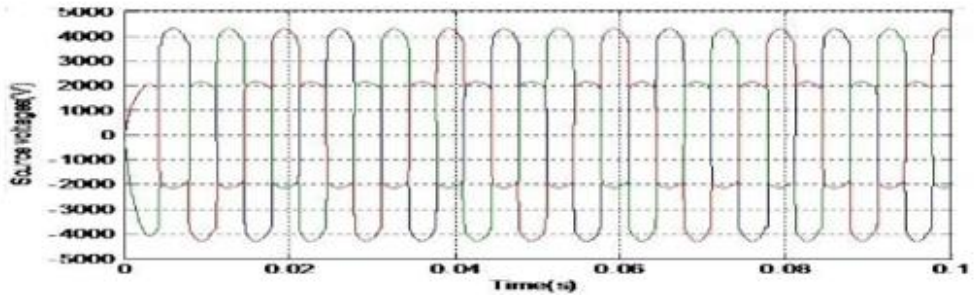

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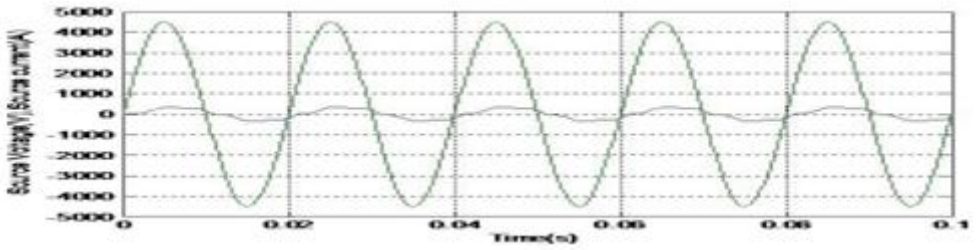

FIGURE 7 simulation results of HV test system without compensation three phase nonlinear load currents a) Three phase source currents b) Three phase source voltages c) phase angle comparison between source voltage d) current for phase-a.

5. Conclusion and Future work

A SHAPF-TCR compensator based on a shunt hybrid active power filter (SHAPF) and thyristor-controlled reactor (TCR) is suggested in this paper in reference to harmonic reduction and reactive power compensation purposes. The given SHAPF-TCR compensator is developed and tested by the means of a linear control strategy. This synchronized work of the shunt active power filter and the passive filter will increase the overall filtering performance and the power rating of the active filter will be greatly reduced. The findings on the simulation indicate that the SHAPF-TCR compensator is very useful in eliminating current harmonics and reactive power compensation over a large operating range across steady and transient operating conditions. In addition, the proposed system is known to minimise the total harmonic distortion (THD) of the supply currents to values that are significantly less than the 5% limit indicated by the IEEE-519 standard, is fast dynamic responsive and is robust in both steady-state and transient operation.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Shilpa R, Puttaswamy PS. A review on power quality issues in power systems. International Journal of Industrial Electronics and Electrical Engineering. 2014;2(10):1–6.
2. Rasool SM, Mary D. Active control for power quality improvement using unified power quality conditioner (UPQC) in hybrid power systems. International Journal of Innovative Research in Science, Engineering and Technology. 2016;5(5):1–8.
3. Shisiali SA, Amuti MO. Power quality improvement using hybrid filters. International Journal for Research in Electronics & Communication Engineering. 2014;8(1):1–7.
4. Senapati R, Senapati RN, Maharana MK. Study and analysis of performance of three-phase shunt active filter in grid-tied PV–fuel cell system employing sinusoidal current control strategy. International Journal of Renewable Energy Research. 2018;8(1):1–9.
5. Pujiantara M, Anggriawan DO, Tjahjono A, Permadi D, Priyadi A, Purnomo MH. A real-time current harmonic monitoring system based on Stockwell transform method. International Review of Electrical Engineering. 2016;11(2):1–8.
6. Sivakumar D, Srividhya JP, Shanmathi T. A review on power quality monitoring and its controlling techniques. Proceedings of the 8th International Conference on Latest Trends in Engineering and Technology. 2016;1(1):1–6.
7. Antony A, Mathew GK. A comparative study on power quality improvement in a hybrid system using DVR and STATCOM versus distributed power flow controller (DPFC). International Research Journal of Engineering and Technology. 2016;3(9):1–7.
8. Puttaswamy PS, Singh B, Al-Haddad K, Chandra A. A review of active filters for power quality improvement. IEEE Transactions on Industrial Electronics. 1999;46(5):960–971.
9. Badi M, Mohan N, Underland T, Robbins W. Power electronics. John Wiley & Sons. 2005;1(1):1–700.
10. Annapoorani I, Samikannu R, Senthilnathan K. Series active power filter for power quality improvement based on distributed generation. International Journal of Applied Engineering Research. 2017;12(22):1–6.