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POWER QUALITY IMPROVEMENT FOR DISTRIBUTION NETWORK BY DESIGN OF TWO CONTROL STRATEGIES FOR ACTIVE POWER FILTER.

S.K.EL-Sayed, A.M.AttiyaSoliman
Department of Electrical Engineering, Faculty of Engineering
Al - Azhar University, Cairo - Egypt.

ABSTRACT: *This paper introduces a design for two different control strategies (proportional integral (PI)-controller and Instantaneous Active and Reactive Power (PQ) method) based on hysteresis current control technique (HCCT) which are applied on shunt active power filter (SAPF) used in distribution system including of nonlinear load to achieve harmonics mitigation and reactive power compensation, where the presence of nonlinear load causes different disturbances and leads to poor power system quality, therefore shunt active power filter has been proposed to provides good harmonic compensation and limit the total harmonic distortion in distribution system to an acceptable values specified by power quality standard and finally get power quality improvement. Where the performance of shunt active power filter depends on the accuracy of the control theory, MATLAB / SIMULINK power system toolbox is used to simulate the proposed distribution system and simulation results are presented and discussed against two control method's performance to showing the effectiveness of the control algorithm.*

KEYWORDS: APF, PI-controller, PQ, HCCT, SAPF.

INTRODUCTION

Recently, Power Electronics technology has been increasingly used in many fields due to the rapid development in the efficiency of its equipment and devices which offer many economical and reliable solutions to provides efficiency enhancement in the control and management for electrical energy utilization [1]-[2], therefore this technology leads to an expansion and proliferation for the using of modern semiconductor switching devices which being increased more and more in a wide range of applications in distribution networks, particularly in domestic and industrial applications such as using of static power converters and adjustable speed drives (ASDS), diode and thyristor rectifiers, uninterruptible power supplies (UPSs), HVDC systems and also others [3]. But those semiconductor devices present nonlinear operational characteristics because of the current vary disproportionately with the applied voltage and hence such current is non-sinusoidal in nature and cause injection of harmonics and reactive power in distribution system which leads to poor power system quality [4]. For example, Static power converters such as single phase and three phase rectifiers which represents a nonlinear loads have been progressively utilized for some direct current applications where the conversions from AC to DC and vice versa are essential tasks in different parts of the network, such as generation, transmission and distribution[2]-[5].like in case of High Voltage Direct Current (HVDC) system which becoming an efficient technology with characteristics making it more desirable in certain transmission applications for modern power systems and also introduces a new technical and excellent solutions provides its ability to overcome the problems of HVAC system, namely the interconnection and exchange of power between of asynchronous grids and the reduction of losses results in HVDC investment gives less expensive and also HVDC system is environmentally superior instead of HVAC system [2]-[6]. As represented in figure (1), The most important element in HVDC system is the converter station which used to perform AC/DC and DC/AC conversion, but the operation and the switching action for these converters leads to harmonic generation in the nearest buses for distribution system and also consume reactive power due to the nonlinearity nature for these converters [6].

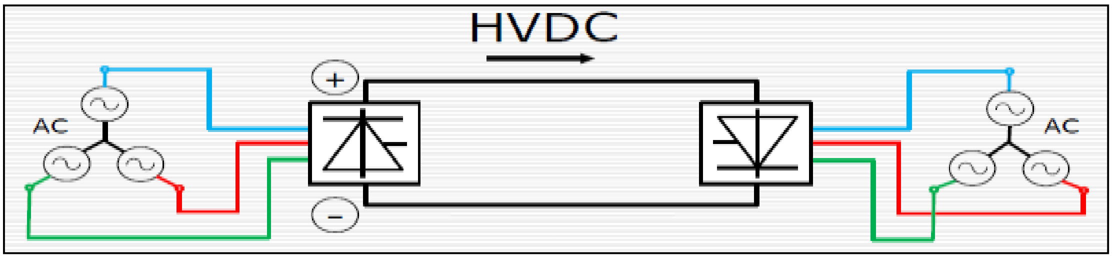


Figure (1): Representation of HVDC system.

POWER QUALITY CONCERNS

In a perfect AC power system, energy is supplied at a single constant frequency and specified voltage levels of constant magnitudes. However, this case is difficult achieve in practice.Where the undesirable deviation from a perfect sinusoidal waveform (variations in the magnitude and/or the frequency) is generally expressed in terms of power quality [7]. And also this Power Quality (PQ) issue leads to different types of power system disturbances such as harmonic distortion, transients, voltage variations, etc. Finally, Power Quality (PQ) issues are of most concern nowadays, where the real and major reasons of power quality problems are because of the wide spread application of power electronic nonlinear loads with characteristics causes many disturbances at the distribution level like increased reactive power demand in ac mains and also lead to break down the power systems voltage and current waveforms which causes harmonic pollution in distribution system. Also the presence of these harmonics leads to additional losses in distribution system equipment, low energy efficiency, harmonic resonances in the utility, incorrect operation of sensitive loads, interference with power equipment and communication networks. Also harmonics cause line voltage distortion at the Point of Common Coupling (PCC) where the linear and nonlinear loads are connected because they inject high power harmonic currents. And finally, presence of harmonics and reactive power has harmful effect and impacts leads to poor power factor and penetration of system power quality [2]-[7].

Mitigation of power quality problems

The Harmonic distortions to the sinusoidal waveforms are among the most widely recognized sort of waveform distortions which are considered as one of the common power quality disturbances. In order to govern and mitigate the power quality problem, there are two general approaches for decreasing or eliminating and taking out harmonics from distribution network. The first approach is called load conditioning, which ensures that the equipment is made less sensitive to power disturbances by utilizing of an appropriate circuit topologies like Phase multiplying rectifiers (12-pulse rectifiers,18-pulse rectifiers, etc) for the nonlinear load with large power demand, such that harmonic pollution is not created or prevented from being injected and this approach is based on harmonic cancellation scheme ,also this strategy allowing the operation even under significant voltage distortion remains and requires small capacity filtering equipment or no additional filtering is required at all[1]-[2]- [3].The second approach based on installing of line conditioning systems that suppress or cancel the power system disturbances by using of harmonics filtering technique, where this approach is utilized in standard six pulse rectifiers which have significant harmonic distortion, and this harmonics can be removed by putting harmonic filters close to the current injection source and this paper concerns with this technique [1]-[2]- [3].

Harmonic filtering techniques

Harmonic filtering techniques provide compensation against voltage and current harmonics to prevent these harmonics from negatively affecting on the utility lines and are generally utilized to suppress the impacts of harmonic pollution in power system by using of harmonic filters which should be designed when harmonic content has been exceeded to get limitation of the total harmonic distortion THD factor which is commonly used to define the harmonic content in voltage and current waveforms and finally, overcome or mitigation of the power quality problems can be achieved [7].The harmonic filters based on these harmonic filtering techniques are classified in three main categories[2]-[8]:

- Passive filters (PFs).
- Active power filters (APFs).
- Hybrid active power filter (combination of active and passive filters) (HAPFs).

Passive filtering technique

Most of traditional harmonic mitigation and reactive power compensation techniques utilized of passive filtering technique with configurations developed and constructed from passive elements based on RLC elements as shown in figure (2), where the basic principle of passive filtering is to prevent harmonic currents from flowing through the power system by either diverting them to a low impedance shunt filter path (parallel passive filter) or blocking them via a high series impedance (series passive filter) depending on the type of nonlinear load [1]. But passive filters PFs designs require excessive system studies, relatively high cost where the choice of filtering solution for harmonic mitigation is mainly cost dependent, and leads to different filter types for different kVA levels, therefore PFs are not commonly used in low power applications. and also, passive filters (PFs) have some disadvantages, for example large size according to increase of dominant harmonic components, mistuning, resonance with load and utility impedances, high cost, slow response, and in addition low order harmonics injection which represent the major limitations for these schemes [1]-[2].On the other hand, passive filters can only correct specific load conditions or a particular state of the power system and these filters are unable to take after the changing system conditions. Hence, the active power filters (APFs) was introduced to overcome the problems and drawbacks of (PFs) [2]-[9].

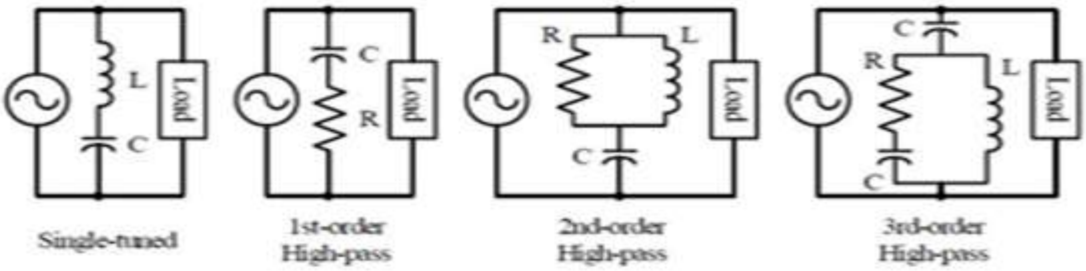


Figure (2): passive filter configurations [8].

Active filtering technique

Due to increasing demand for efficient a dynamic and adjustable solutions of power quality problems including harmonics problem, advances in control theory and application of modern control methods in power electronics and also, development of power electronics industry in recent decades encouraged and have played a significant role to introduce modern, flexible, and more efficient solutions for power quality problems. These modern solutions have been given the name of active compensators or active power filters (APFs) [10]. APFs become an alternative solution for controlling harmonics in distribution networks and it gives a better result for quality of power. Where APFs are used in place of PFs because of APFs have a number of advantages and various points of interest over the PFs, where the main advantages of APFs are their flexibility to fit load parameter variations and harmonic frequencies in addition to APFs provide dynamic compensation with power system dynamics and random behaviour of harmonics and responsible for simultaneous compensation of voltage, current harmonics and reactive power with high compensation performance [10]. Besides, active power filters are dissimilar to passive filters, where they do not cause harmful resonances with the systems and additionally smaller in physical size. Also, the APFs performance is free and independent of the power distribution system properties [11].

ACTIVE POWER FILTERS TOPOLOGIES

APFs have many topologies and configurations used for harmonic compensation and can be classified into many type like series or parallel and combinations of both calling unified power quality conditioners (UPQCs) as well as hybrid configurations (HAPFs) [10]-[12].Where Series APF is used for voltage harmonic compensation and Shunt APF is used for current harmonics and reactive power compensation. The UPQC is the integration of Shunt and Series APF in one device responsible for the simultaneous compensation of voltage, current harmonics and reactive power. The combinations between the modern APFs with the traditional PFS have been also used as a Hybrid APFs which combine the advantages of old PFs and new APFs and reject the drawbacks related to each of them when used individually , where HAPFs aims to enhance the compensation performance with minimization of cost and complexity of compensation system [10]-[12]. These active power filters also utilized to suppress voltage flickering, regulate load terminal voltages, balance voltages in a power system, and damp resonances and other additional objects depending on the type of nonlinear loads and the required functionalities [1]. This paper concerns with shunt APF because it the most recognized active filter configuration utilized in practical and technical applications.

SHUNT ACTIVE POWER FILTERS (SAPFs).

Recently, The Shunt active power filters APFs are the most common utilized configuration in active filtering applications and connected in parallel with the load being compensated at Point of Common Coupling (PCC), where the main function of shunt APFs is to cancel out or eliminate of current harmonic occurring in distribution power grid due to nonlinear loads and also compensation of reactive power which lead to power factor improvement [1]-[2]. The shunt APF implemented as a controlled harmonic current source because it injects non-sinusoidal harmonic current through the parallel branch of the network as shown in the figure (3) ,(4) and it has a controller detects the instantaneous load currents and then extracts its harmonics content to return injects equal magnitude and opposite sign for this contents of nonlinear demand load harmonic currents at PPC, a result they cancel each other and leads to compensation of harmonic currents and finally, the currents drawn from the utility grid becomes sinusoidal, free from harmonics, balanced, and in phase with distribution voltage source [1]-[2]

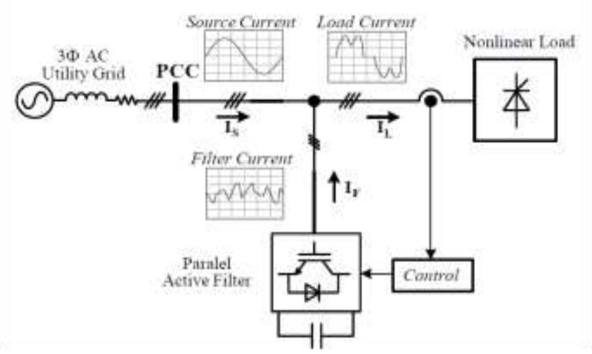


Figure (3): Basic Representation for SAPF [1]-[2].

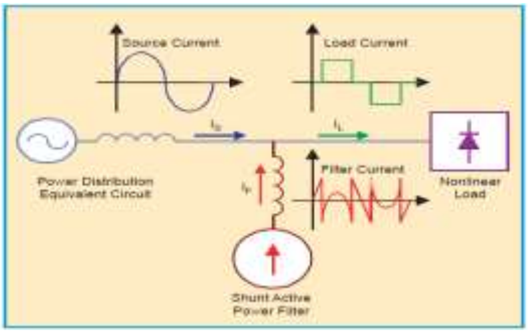


Figure (4): SAPF implemented as a controlled harmonic current source [2]-[3].

Configuration of SAPF

Most of the active power filter topologies use voltage source converters (VSC) which preferred over current source converter (CSC) because it is higher in efficiency and lower initial cost than the current source converters. The shunt APF consists of three mainly parts, namely:

- The voltage source inverter (VSI)
- Interfacing inductance (Lf)
- DC link capacitor (Cdc)

In addition to the associated control circuit, the general power circuit structure of the SAPF is composed voltage source inverter with a DC energy storage device connected at dc side of VSI as shown in the figure (5) , and the ac side of this inverter is connected to the ac bus at PCC through coupling inductance which used to suppressing the higher order harmonic components caused by the switching operation of the power transistors [1]-[2] -[12].

In this paper, a three-level VSI based shunt APF is used and investigated for harmonic and reactive power compensation, where recently multilevel (VSIs) have been applied with APFs for medium voltage applications due to their benefits such as its directly connected to medium voltage without any coupling transformer, generating output voltages with very low harmonic distortion and operating with a lower switching frequency and lower switching losses, also the multi-level inverter topology is allow for a lower dc voltage operation [13]-[14].The power circuit topology of a three-level inverter based SAPF is shown in the figure (6),it consists of a three power Switches H-bridge with a common neutral point, where an H-bridge is used in each phase and a total of three H-bridge and each H-bridge has four main switches transistor with a parallel diodes. These H-bridges are connected in parallel through a coupling inductance and resistance to the AC grid at PCC. In addition, each H-bridge is connected at dc side with a capacitor supplying dc voltage to H-bridge. the control multilevel inverters must be able to produce an output compensating current that follows the estimated reference current which contains the harmonic and reactive component required by the nonlinear load[13]-[15].

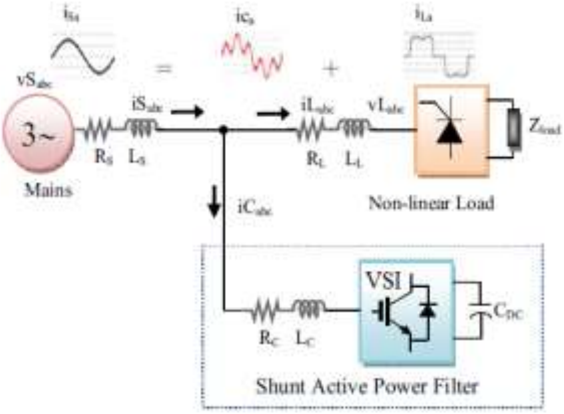


Figure (5): Configuration of shunt APF based on (VSI) [2]-[12].

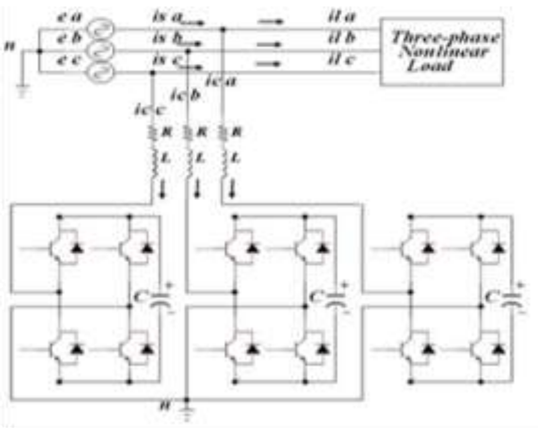


Figure (6):Power circuit topology of three-level cascaded H-bridge inverter based SAPF [13].

Compensation Principle of SAPF

The basic principle for shunt APF compensating system depending on extracting the additional harmonic current drawing by nonlinear load demand from the source, beside the fundamental component at PCC and cause harmonic distortion of the source current(IL = ILF + ILH) [8]. Therefore SAPF is controlled to operates as a current source injecting the same harmonic components with phase shifted of (180^0) (IF = −ILH). A result, components of load harmonic currents are cancelled and the source currents becomes sinusoidal (IS=ILF) as shown in Figures (7) and (8) [9]-[12].

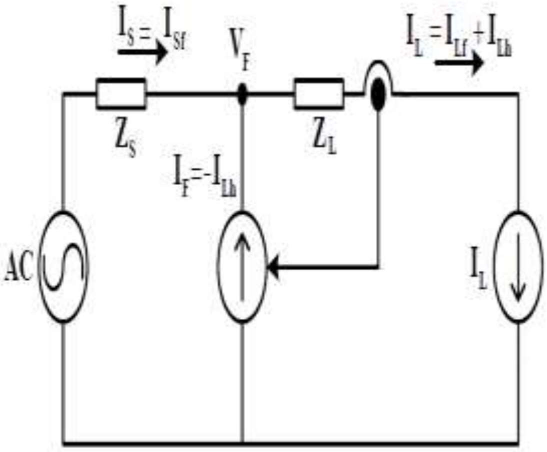


Figure (7): Compensating principle for SAPF.

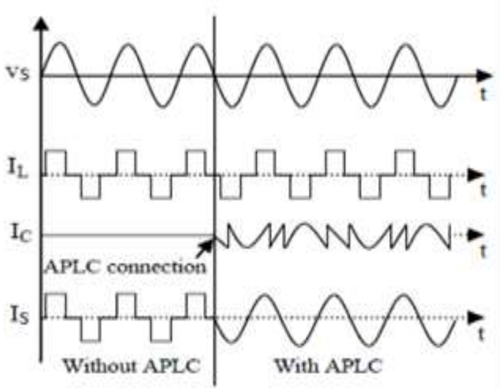
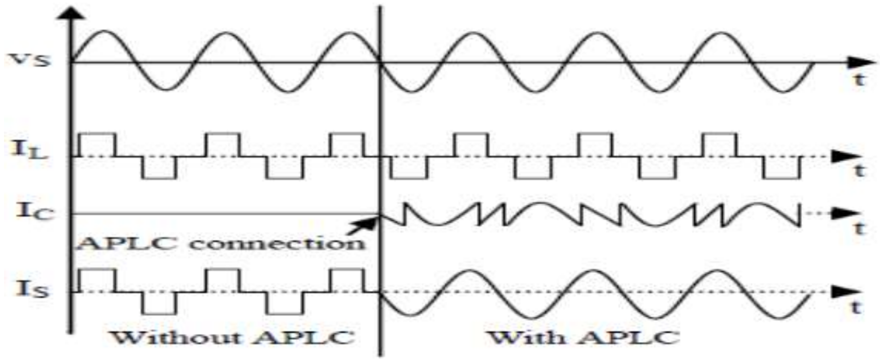


Figure (8): Waveforms for SAPF Compensating system [2]-[12].

Control strategies of SAPF.

Shunt APFs are superior in filtering performance comparing to traditional passive filters but the performance of the SAPF depends not only on the choice of its power circuit, but also on the control strategy, where the control methodology that is employed to formulate the accurate control algorithm of the SAPF is the key element for enhancing its performance in mitigating of the harmonic current waveform. The control system for SAPF can be introduces into essentially two steps as shown in the figure (9), where the first step is implemented by using of fast response controller methods in the time domain based on instantaneous derivation for the compensating signals and leads to generate or extract the compensating currents (reference signals) from the distorted load harmonic currents to be injected in the grid at PCC and this step is known as the reference current extraction method and this paper concerns with using of two different methods namely the instantaneous real active and reactive power (PQ) theory and the proportional integral (PI) controller method based on simple algebraic computations [2]-[10]-[12].The second step is represented by the current control technique based on simple hysteresis strategies (HCCT) which implemented to generate the appropriate gating signals or pulses for the inverter and lead to control the switching devices of VSI based on the extracted reference signals to get high compensation performance [2].



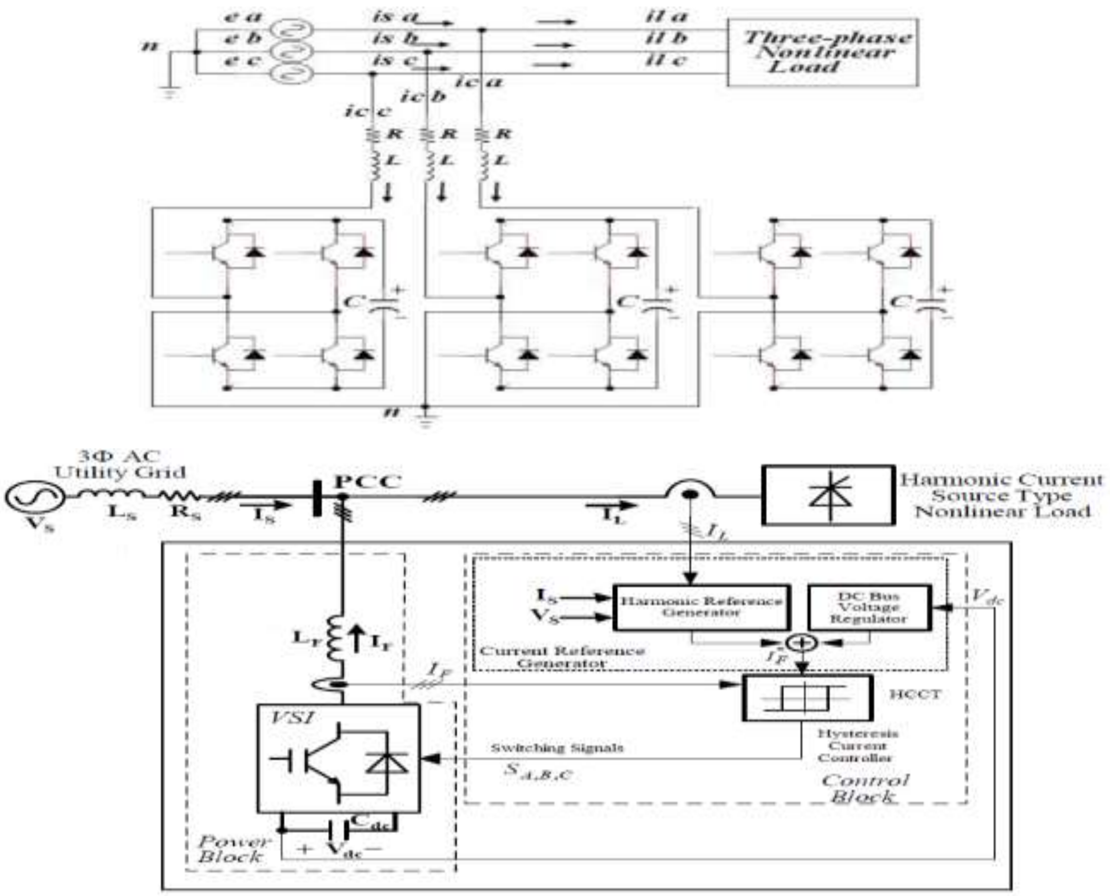


Figure (9): Diagram for general control system of SAPF [1]-[2].

PQ - control method based on hysteresis technique.

The instantaneous active and reactive power (PQ) control theory is based on a set of instantaneous values for active and reactive powers defined in the real time domain and it commonly used for harmonic mitigation and power factor improvement due to its simplicity and effectiveness [2]-[9]. The control algorithm for the integration of (PQ) theory based on sensing of source voltage and load current as shown in the figure (10),and implemented under condition, where three phase distribution source voltage must be balanced with perfectly sinusoidal waveforms. Also, (PQ) theory is based on the transformation from three-phase frame “abc” to bi-phase stationary frame “α-β” transformation for sensed sinusoidal source voltage and distorted load current signals to compute the instantaneous active and reactive powers in terms of these transformed signals, then harmonics active and reactive powers are extracted from these instantaneous signals by using of low-pass filter, then compensating reference currents are derived from harmonic active and reactive powers by using reverse “α-β” transformation with simple algebraic computation as shown in the figure (11) [2]-[9].

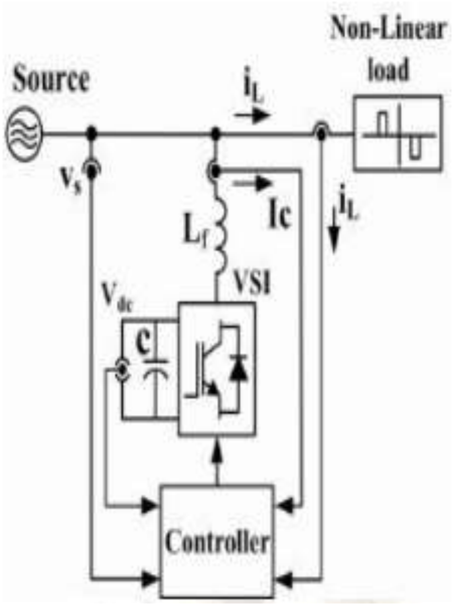


Figure (10): Sensing signals for (PQ) control method.

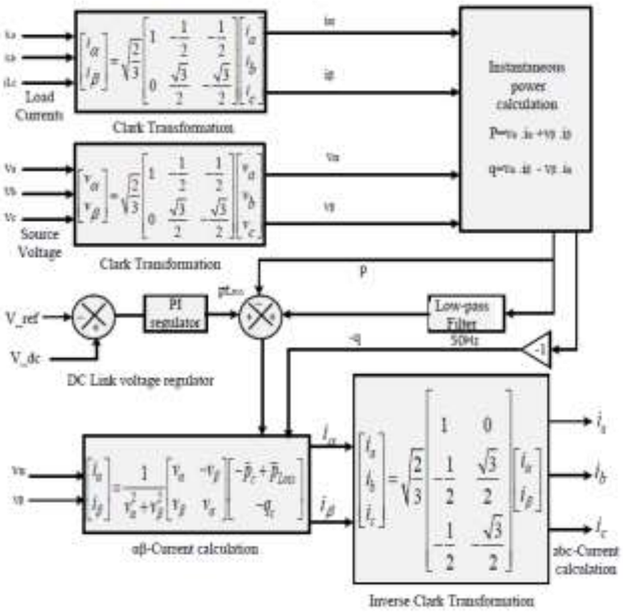


Figure (11): The (PQ) control algorithm for calculation of reference currents [2]-[9].

PI - control method based on hysteresis technique.

The closed loop proportional integral (PI) controller theory is based on control of DC link capacitor voltage value for SAPF to generate reference source current by sensing the actual DC voltage value and comparing it with its set reference value in the error detector to eliminates the steady state error in the DC- side voltage, where the voltage error signal is processed to PI controller to get the output which taken as the peak value of supply current (Imax). The unit vector u(t) in phase with supply voltage is achieved by using sensed source AC voltage, then the output of PI controller is multiplied to unit sine vector to generate reference sinusoidal supply current (Is*= u(t) × Ism*) which become in phase with AC source voltage and lead to unity power factor for the source current as shown in the figure (12), then reference compensating currents are derived by subtracted the distorted line current from the reference source current (ic*= is*- icon), then compared with the actual injected currents by using of a hysteresis strategy as shown in the figure (13) [2]-[12]

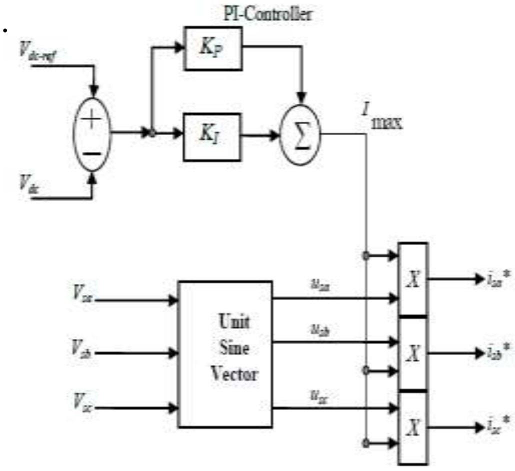


Figure (12): The (PI) block diagram for calculation of reference source currents.

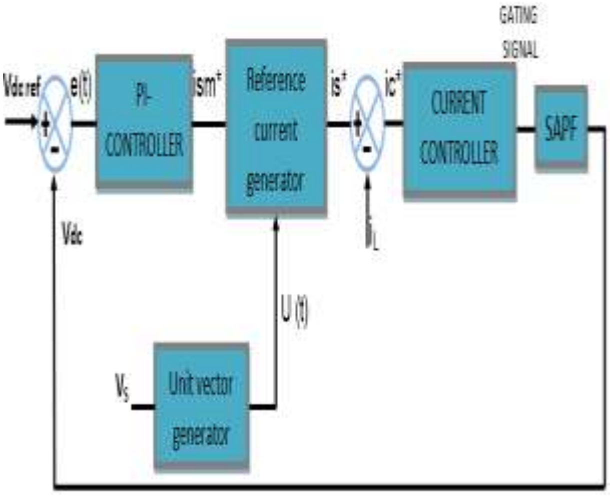


Figure (13): Control Loop for PI with SAPF [16].

In addition to, PI control algorithm decreases sensors by sensing only dc-link voltage, three phase supply voltages and source currents as shown in the figure(14) [2]-[12].

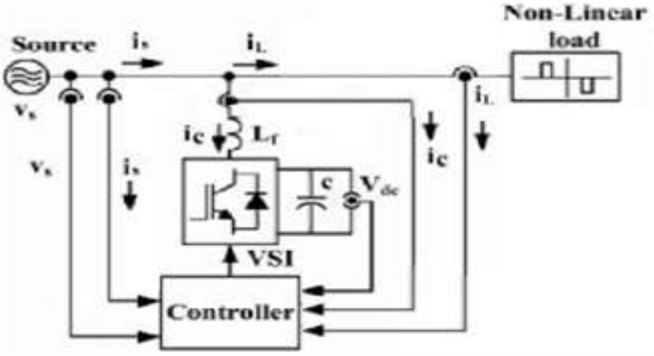


Figure (14): Sensing signals for (PI) control method.

Hysteresis current control technique (HCCT)

The generation of appropriate gating signals for switching devices of (VSI) based on the estimated reference currents is represented by hysteresis current control technique, which widely used due to its implementation of fast response and excellent dynamic performance, and this strategy lead to control the switches of the inverter so that the output current remains between pre-defined bands around the desired reference current, where in this technique a signal deviation (H) is imposed on the reference signal to form the upper and lower limits of a hysteresis band (HB) and then actual signals are compared with the estimated reference signals to get error signal which compared against this hysteresis bands using a comparator to generate the controlled switching pulses for the inverter as shown in figures (15) and (16) [2]-[8].

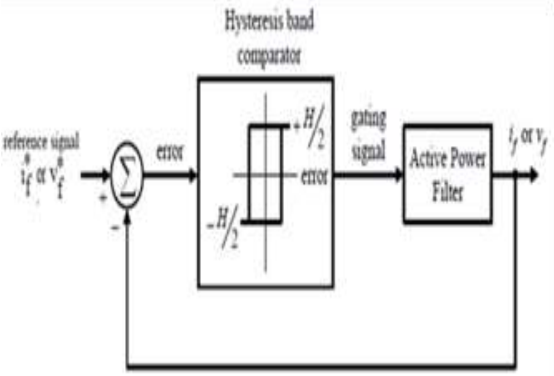


Figure (15): Block diagram of hysteresis strategy [8].

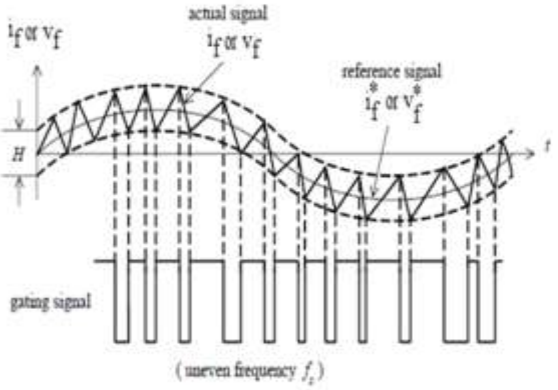


Figure (16): Switching signal generation by HCCT [8].

SIX- Bus Network Simulation results:

Simulation tool based on MATLAB/SIMULINK Modelling is developed for the proposed SAPF to study its dynamic performance for harmonic mitigation and reactive power compensation in power distribution system. The complete SAPF system includes power circuit based on (VSI) and control circuit using (PQ) and (PI) controller methods based on (HCCT). This SAPF topology is inserted in a small distribution network with six-bus as shown in the figure (17) with details illustrated in table (1), where the proposed network is first simulated without SAPF compensation and find out the total harmonic distortion (THD) for the current, then it is simulated again with SAPF compensation to observe the difference in THD of the current and comparing between these results obtained from two controller methods.

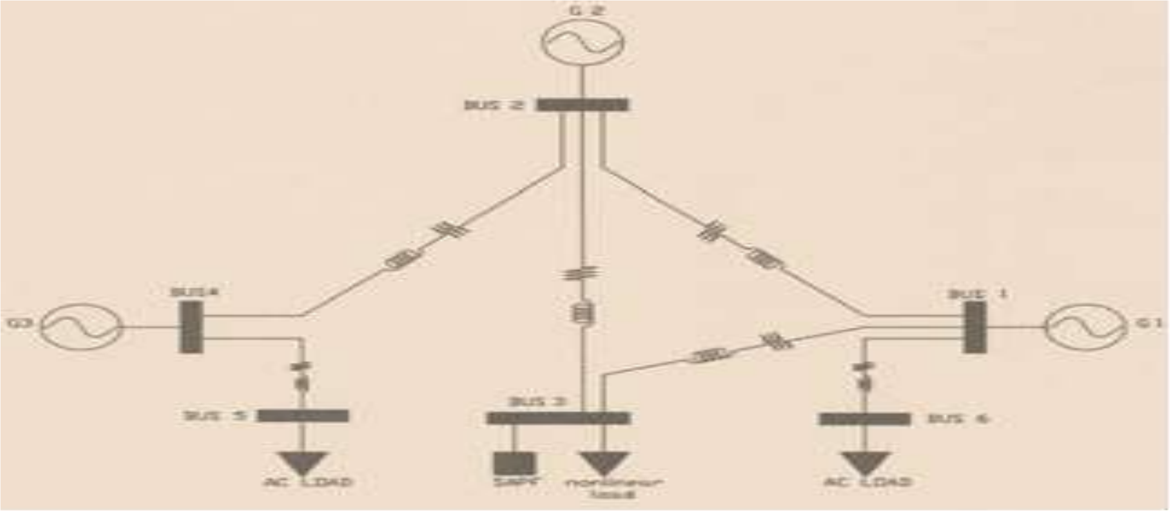


Figure (17): SIX-BUS DISTIBUTION NETWORK WITH SAPF COMPENSATION.

System Description

The proposed network have three distribution sinusoidal voltage sources connected at generation buses (1,2,4) and also have two AC three-phase series (R-L-C) loads connected at load buses (5,6), and the nonlinear load is connected at load bus (3) in parallel with the shunt active power filter (SAPF).

TABLE (1): PARAMETERS OF THE ANALYZED NETWORK

BUS	TYPE	Parameters
BUS (1)	**Generation**	➢ Three phase balanced AC supply with (L-to-N) voltage of 220V (RMS), frequency of 50 Hz, with line resistance of Rs = 1μΩ and line inductance of Ls = 0.2mH.
BUS (2)	**Generation**	➢ Three phase balanced AC supply with(L-to -N) voltage of 220 V(RMS), frequency of 50 Hz.
BUS (3)	**LOAD**	➢ Nonlinear load of three phase diode bridge rectifier with DC load resistance of Rdc =100 Ω. ➢ SAPF represented by three single phase MOSFETs bridge inverter with common neutral point and connected in parallel with nonlinear load at bus (3) through filter line resistance of Rf = 0.01 Ω in series with filter line inductance of Lf = 5.12 mH , and has DC bus capacitor of Cdc = 8 mF , and the reference DC link capacitor voltage of Vdc = 650V.
BUS (4)	**Generation**	➢ Three phase balanced AC supply with (L-to-N) voltage of 220 V (RMS), frequency of 50 Hz, with line resistance of Rs = 100μΩ and line inductance of Ls = 0.5 mH.
BUS (5)	**LOAD**	➢ Three phase series (R-L-C) load with power rating of (P=10 kw, QL= QC=100 var).
BUS (6)	**LOAD**	➢ Three phase series (R-L-C) load with power rating of (P=5 kw, QL = QC = 100 var).
Transmission lines		➢ All buses are connected through a short transmission line with impedance including a resistance of (1f Ω) and an inductance of (1mH).

Results without SAPF compensation

Before insertion of SAPF in the network at bus (3) which nonlinear load is connected, Running MATLAB/SIMULINK model for the proposed six-buses network to observe harmonic spectrums for phase voltages and phase currents for all buses as shown in figure (18-a), (18-b) and its details illustrated in table (2). Display values for buses current, voltage, active and reactive power , system power factor for all sources and buses with details illustrated in table (3), also take simulation waveforms for sources current and voltage, loads current, SAPF current which must be equal to zero as shown in figures (19), also. All results introduces with (PI) and (PQ) controller methods based on hysteresis technique.

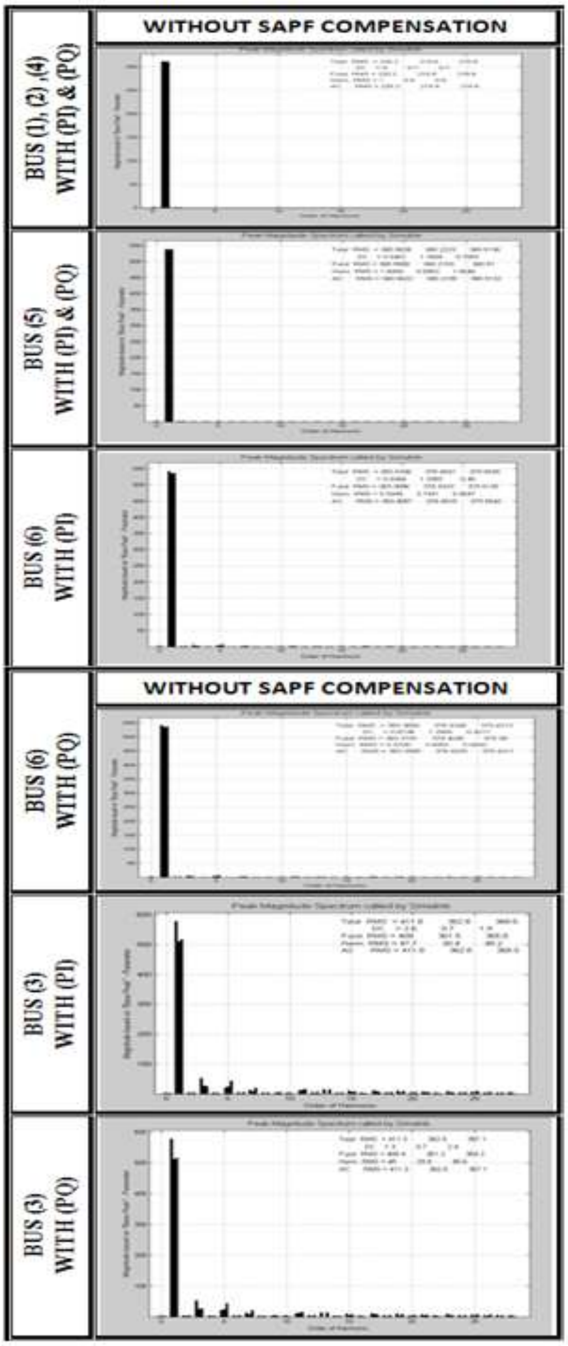


Figure (18-a): BUSES VOLTAGE SPECTRUMS.

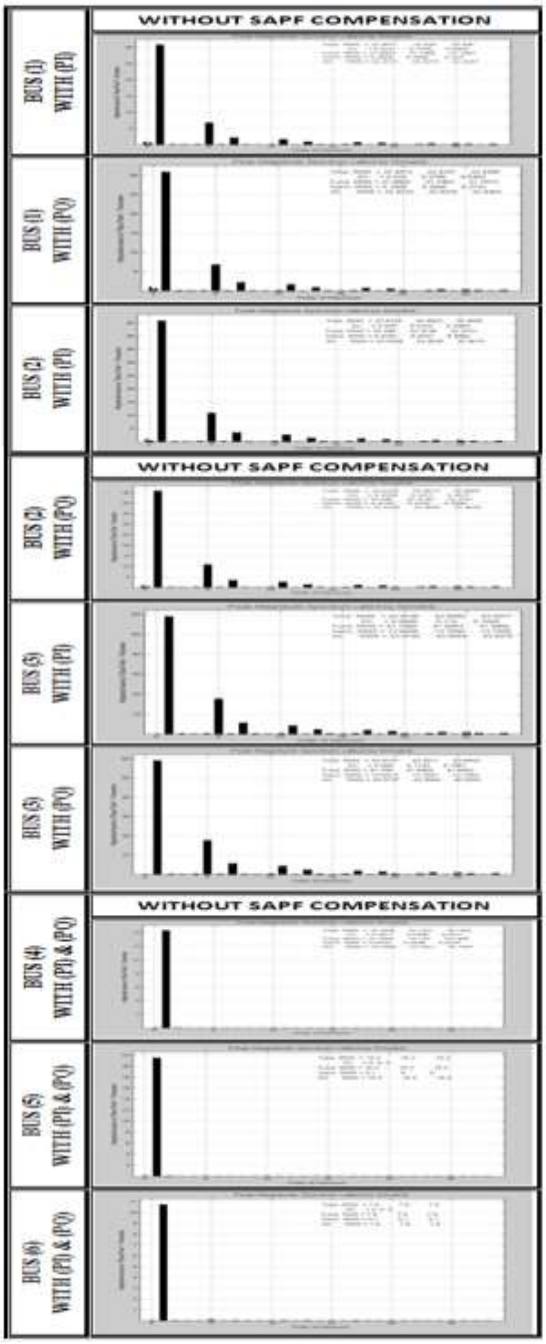


Figure (18-b): BUSES CURRENT SPECTRUMS.

TABLE (2)

Generation buses	BUS (1)		BUS (2)		BUS (4)	
Factors	**Sources phase voltage For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	220.2	220.2	220.2	220.2	220.2	220.2
DC Component	0	0	0	0	0	0
AC (RMS)	220.2	220.2	220.2	220.2	220.2	220.2
Fundamental (RMS)	220.2	220.2	220.2	220.2	220.2	220.2
Harmonic (RMS)	1	1	1	1	1	1
T.H.D (%)	0.4541	0.4541	0.4541	0.4541	0.4541	0.4541
Factors	**Sources phase current For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	22.4911	22.4912	33.5333	33.5334	10.1605	10.1605
DC Component	0.9241	0.9240	0.9290	0.9294	0.0011	0.0011
AC (RMS)	22.4721	22.4722	33.5204	33.5205	10.1605	10.1605
Fundamental (RMS)	21.8502	21.8502	32.4460	32.4460	10.1604	10.1604
Harmonic (RMS)	5.2504	5.2506	8.4187	8.4189	0.0476	0.0476
T.H.D (%)	24.0291	24.0299	25.9468	25.9474	0.4685	0.4685
Factors	**BUS (3)**		**BUS (5)**		**BUS (6)**	
Factors	**Sources phase voltage For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	411.8	411.3	380.9628	380.9628	383.4106	383.3605
DC Component	2.6	3	0.6401	0.6401	0.8384	0.8738
AC (RMS)	411.8	411.3	380.9622	380.9622	383.4097	383.3595
Fundamental (RMS)	409	408.4	380.9588	380.9588	383.3696	383.3191
Harmonic (RMS)	47.7	48	1.6084	1.6084	5.5445	5.5706
T.H.D (%)	11.6626	11.7532	0.4222	0.4222	1.4463	1.4533
Factors	**Sources phase current For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	43.9745	43.9747	15.2	15.2	7.6	7.6
DC Component	0.0056	0.0060	0	0	0	0
AC (RMS)	43.9745	43.9747	15.2	15.2	7.6	7.6
Fundamental (RMS)	41.7889	41.7890	15.2	15.2	7.6	7.6
Harmonic (RMS)	13.6908	13.6913	0.1	0.1	0.1	0.1
T.H.D (%)	32.7618	32.7629	0.6579	0.6579	1.3158	1.3158

TABLE (3)

QUANTITY				BUS (1)		BUS (2)		BUS (3)	BUS (4)		BUS (5)	BUS (6)
POWER	(PI)	Source	BUS	0.9997	0.8673	0.9997	0.8537	0.7596	0.9995	0.8536	0.8659	0.8578
	(PQ)	Source	BUS	0.9997	0.8672	0.9997	0.8537	0.7579	0.9995	0.8536	0.8659	0.8577
ACTIVE	(PI)			21.12		31.33		34.25	9.896		15.05	7.365
	(PQ)			21.11		31.33		34.14	9.896		15.05	7.363
REACTIVE	(PI)			12.12		19.11		29.33	6.039		8.695	4.413
	(PQ)			12.12		19.11		29.38	6.039		8.695	4.414
BUS	(PI)			379.2		380.9		367.3	380.8		380.7	378.2
	(PQ)			378.1		380.9		366.9	380.8		380.7	378.1
BUS	(PI)			21.46		32.11		40.92	10.15		15.22	7.568
	(PQ)			21.46		32.12		40.92	10.15		15.22	7.568

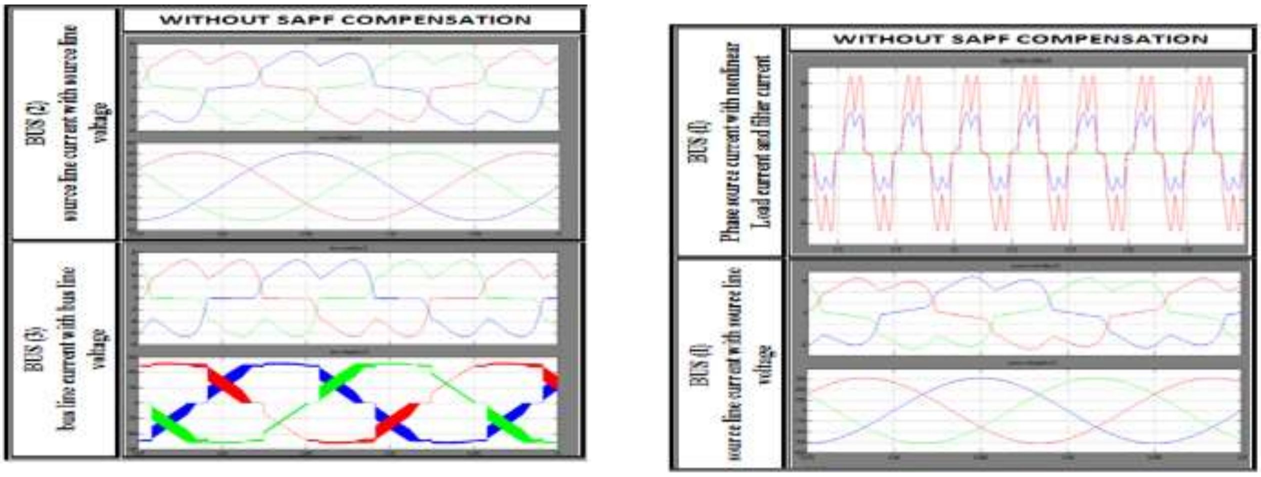


Figure (19): Buses Simulation Waveforms.

From the obtained results, the highest values for the THD in voltage and current for all buses is observed at bus (3) where nonlinear load is connected and also current distortion is observed at generation buses (1),(2), which in the nearest range from nonlinear load, therefore, waveforms concerns with these three buses (1),(2) and (3) as in figure (19), and all others remote buses have sinusoidal waveforms for current and voltage and non-approximately affected with distortion generate from the load.

Results with SAPF compensation

After insertion of SAPF in the network at bus (3) which nonlinear load is connected, Running MATLAB/SIMULINK model for the proposed six-buses network) and repeated take all spectrum and waveforms as in figures (20-a).(20-b) and (21) with details illustrated in tables(4) and(5).Where all buses voltage have the same spectrums as explained above in figure (18-a), besides buses (3) and (6).And For current distortion, buses (4) and (5) have the same spectrums as explained above in figure (18-b) because they remote and out of range where nonlinear load is linked with buses(1), (2), (3),(6) and cause distortion at these buses.

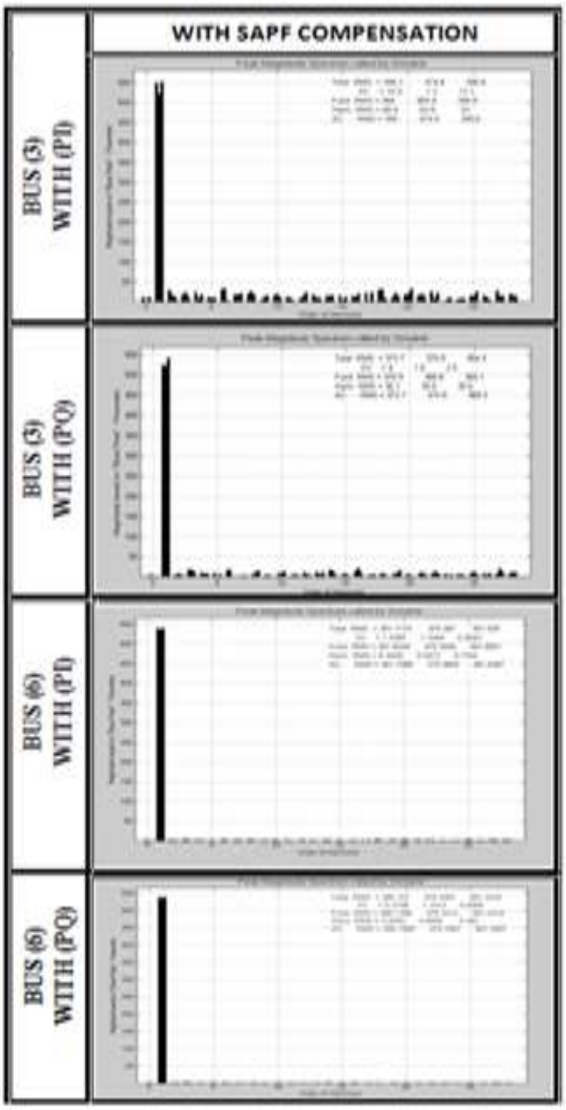


Figure (20-a): BUSES VOLTAGE SPECTRUMS.

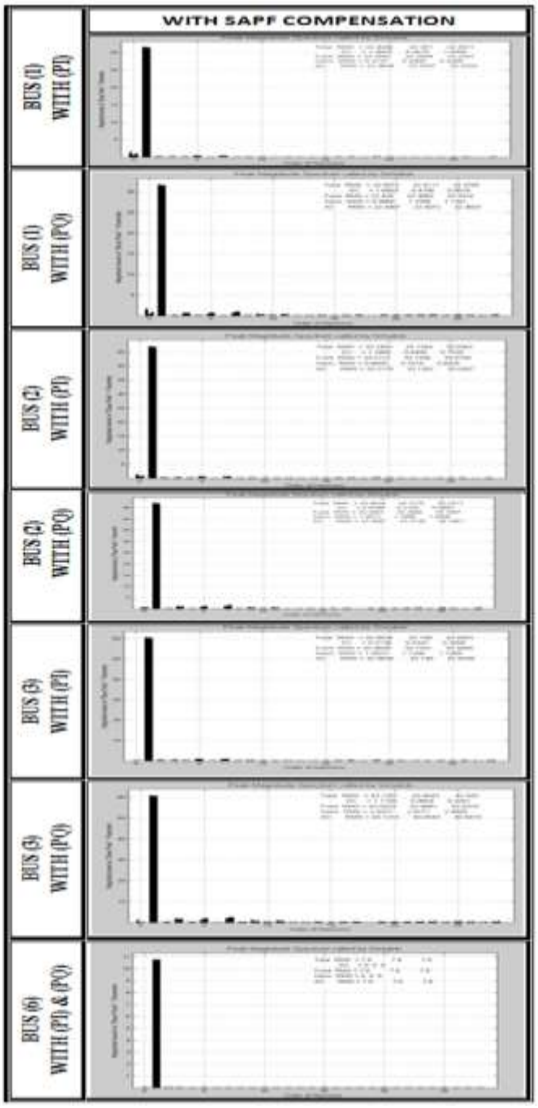


Figure (20-b): BUSES CURRENT SPECTRUMS.

TABLE (4)

Generation buses	BUS (1)		BUS (2)		BUS (4)	
Factors	Sources phase voltage For phase (a) And other phases values Showing on spectrum.					
	(PI)	(PQ)	(PI)	(PQ)	(PI)	(PQ)
Total (RMS)	220.2	220.2	220.2	220.2	220.2	220.2
DC Component	0	0	0	0	0	0
AC (RMS)	220.2	220.2	220.2	220.2	220.2	220.2
Fundamental (RMS)	220.2	220.2	220.2	220.2	220.2	220.2
Harmonic (RMS)	1	1	1	1	1	1
T.H.D (%)	0.4541	0.4541	0.4541	0.4541	0.4541	0.4541
Factors	**Sources phase current For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	22.4046	22.5072	33.2453	33.3623	10.1605	10.1605
DC Component	1.3653	1.6503	1.3485	0.5348	0.0011	0.0011
AC (RMS)	22.3629	22.4467	33.2179	33.3581	10.1605	10.1605
Fundamental (RMS)	22.3591	22.4250	33.2112	33.3201	10.1604	10.1604
Harmonic (RMS)	0.4137	0.9868	0.6659	1.5917	0.0476	0.0476
T.H.D (%)	1.8503	4.4004	2.0050	4.7769	0.4685	0.4685
Factors	**BUS (3)**		**BUS (5)**		**BUS (6)**	
Factors	**Sources phase voltage For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	395.1	372.7	380.9628	380.9628	383.7119	380.1510
DC Component	10.9	4	0.6401	0.6401	1.5387	0.2708
AC (RMS)	395	372.7	380.9622	380.9622	381.7088	380.1509
Fundamental (RMS)	389	370.9	380.9588	380.9588	381.6544	380.1306
Harmonic (RMS)	68.5	36.1	1.6084	1.6084	6.4428	3.9292
T.H.D (%)	17.6093	9.7331	0.4222	0.4222	1.6881	1.0336
Factors	**Sources phase current For phase (a) And other phases values Showing on spectrum.**					
	(PI)	**(PQ)**	**(PI)**	**(PQ)**	**(PI)**	**(PQ)**
Total (RMS)	42.8835	43.1357	15.2	15.2	7.6	7.6
DC Component	0.0138	1.1155	0	0	0	0
AC (RMS)	42.8835	43.1213	15.2	15.2	7.6	7.6
Fundamental (RMS)	42.8698	43.0433	15.2	15.2	7.6	7.6
Harmonic (RMS)	1.0823	2.5921	0.1	0.1	0	0
T.H.D (%)	2.5246	6.0221	0.6579	0.6579	0	0

TABLE (5)

QUANTITY				BUS (1)		BUS (2)		BUS (3)	BUS (4)		BUS (5)	BUS (6)
POWER FACTOR %	(PI)	Source	BUS	0.9992	0.8855	0.9994	0.8485	0.8636	0.9995	0.8536	0.8659	0.8645
	(PQ)	Source	BUS	0.9998	0.8811	0.9991	0.8447	0.8869	0.9995	0.8536	0.8659	0.8668
ACTIVE POWER (Kw)	(PI)			21.16		32.04		40.35	9.896		15.05	7.473
	(PQ)			22.20		32.09		41.90	9.896		15.05	7.499
REACTIVE POWER (KVAR)	(PI)			11.63		19.98		23.56	6.039		8.695	4.345
	(PQ)			11.92		20.34		21.82	6.039		8.695	4.313
BUS VOLTAGE (RMS)	(PI)			379.1		380.9		367.7	380.8		380.7	379.3
	(PQ)			379.1		380.9		368.7	380.8		380.7	379.5
BUS CURRENT (RMS)	(PI)			22.01		33.04		42.35	10.15		15.22	7.596
	(PQ)			22.17		33.27		42.75	10.15		15.22	7.6

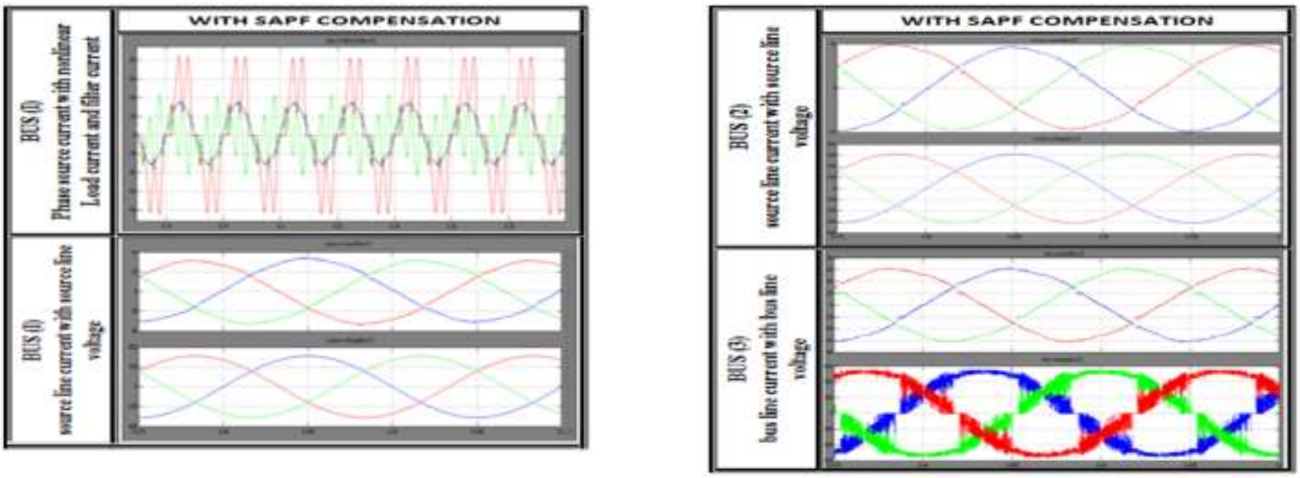


Figure (21): Buses Simulation Waveforms.

From the obtained results, the THD in the current waveforms for generation buses (1),(2) and load bus (3) where nonlinear load and SAPF are connected is reduced and the waveforms become sinusoidal and free from harmonic distortion and currents also become in phase with buses voltages which leads to power factor improvement as in figure (21).

Comparison between (PI) and (PQ) controller methods based on HCCT

A comparison between two controller techniques is indicated in figure (22), which illustrate the shunt active power filter injected current and nonlinear load current which supplying from bus (1) and bus (2) and also source current drawn at bus (1) which become sinusoidal after SAPF compensation.

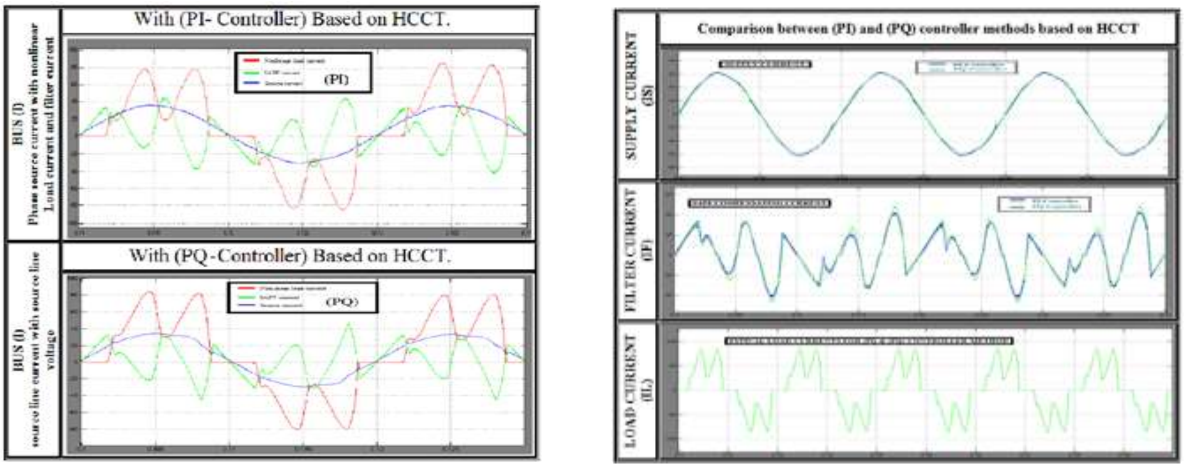


Figure (22): Comparison between two controller techniques.

CONCLUSION

The SAPF introduces an efficient solution to improve power quality in distribution network, where SAPF is mainly designed for both reactive power compensation and mitigation of harmonics by inject of a harmonic current at the PCC for compensation of nonlinear load current harmonics to make the sources current perfectly sinusoidal with unity power factors. But the performance of the SAPF is based on the efficiency of the control theory, therefore this work provides a design of two control strategies for SAPF, where simulation results showing that the instantaneous (PQ) theory and proportional-integral (PI) control method offers a very good performance based on simple hysteresis technique with high compensation performance leads to limit the propagation of harmonics into distribution buses nearest from nonlinear load and decrease the distortion level in the current waveforms to an acceptable values within the range for power quality standard, also it keeps the distortion of the voltage waveforms at very low level. where without SAPF compensation system, the harmonic spectrum showing higher values for THD in the current waveforms reaches (24.03 %) at bus (1) and (25.95 %) at bus (2) and (32.76 %) at bus (3) which nonlinear load is connected, and other buses have very low levels for THD. With SAPF compensation the THD in the current waveforms reaches an acceptable values (within 5% of the magnitude of the fundamental component), but observing that the performance for (PI) control method is approximately better than (PQ) control method where THD at bus (1) with (PI) reaches (1.85%) but with (PQ) reaches (4.4%) and at bus (2) THD with (PI) reaches (2%) but with (PQ) reaches (4.78%) and also at bus (3) THD with (PI) reaches (2.5%) but with (PQ) reaches (6%).

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