Performance Analysis of Power Quality Improvement In Distribution Network Using Shunt Active Power Filter

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Abstract-In a distribution network power quality problems are most common for commercial, industrial and utility loads. A failure or bad operation of costumer equipment occurs due to deviation in voltage, current or frequency, which result in power quality problem. Voltage, current and frequency are the three physical characteristics that mostly define the power quality. So importance is being given to development of active power filters to solve these problems to improve power quality, among which shunt active power filter is used to eliminate voltage and load current harmonics and for reactive power consumption. The shunt active power filter considered as a controllable current source to supply the equal but opposite harmonic current. To handle large compensation current and provide better thermal management two or more parallel semiconductor switching device can be used.

The control strategy used in shunt active filter in such a way that it compensate load harmonics current and reactive power compensation by injecting equal and opposite harmonic component. With the installation of shunt active filter, it drains the distorted components of load currents from the grid. So that current become with small harmonic distortion and in phase with system voltages. The presented system is simulated for the distribution network in Matlab-simulink.

Keywords-*Power Quality, Shunt Active Power Filter, Compensation, MLI, PWM, THD.*

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I. INTRODUCTION

The term 'Power Quality'is defined by the International Standards as the physical characteristics of the electrical power supply provided under normal operating conditions that do not disturb the consumer's processes [1]. In distribution network power quality [2] problems are common in most commercial, industrial and utility networks. Natural phenomenon, such as lightning are the most frequent causes of power quality problems.

The increase in the deterioration of the power system voltages and currents waveforms with the generation of harmonics are caused due to the intensive use of power converters, power electronics equipment's, nonlinear loads in industry and at consumers end. These current harmonics will result in power losses in distribution, problems of electromagnetic interference in communication systems, operation failures of protection devices, power factor reduction, decrease in efficiency, power system voltage fluctuations and communications interference [3]. Between the different technical options available to improve power quality, active power filters have proved to be an important alternative to compensate current and voltage disturbances in power system distribution network. So it is important to develop active power filters to solve these problems and enhance the power quality of the distribution network.

The shunt active power filter (SAPF) inject a suitable compensating current with 180^0 phase opposition at a point of the line known as the point of common coupling (PCC) so that the current harmonics introduced by the nonlinear loads are cancelled out and sinusoidal nature of current and voltage waveforms are restored [4]. The harmonics current causes the adverse effect on power system distribution network, as a result effective harmonic reduction become important both to the utilities and users. The total harmonic distortion (THD) is the

ratio between the rms (Root Mean Square) values of the sum of all harmonic components and the rms value of the fundamental components, for both current and voltage which is shown by Eq. (1)

$$THD[\%] = 100 * \sqrt{\sum_{h=2}^{\infty} \left(\frac{I_h}{I_1}\right)^2} \quad (1)$$

In this paper a combination of three-phase universal bridge rectifier with an RLC load across it constitutes the nonlinear load which introduces the current harmonics into the network. The current harmonic compensation is implemented by using a shunt active power filter (SAPF). A three phase current controlled voltage source inverter (VSI) with a DC link capacitor across it is used as an active power filter [4].

II. SHUNT ACTIVE POWER FILTER

In power distribution network active power filters are widely used for the reduction of harmonics caused by nonlinear loads. This paper describes a shunt active power filter with a control system based on the multi-level inverter (MLI). Due to the wide spread of power electronics equipment in modern electrical systems and power convertor units causes the increase of the harmonics disturbance in the AC mains currents has become a major concern due to the adverse effects on all equipment and distribution network [4]. Shunt active power filter operates by generating a compensating current with 180^0 phase opposition and injects it back to the line so as to cancel out the current harmonics introduced by the nonlinear load. The active power filter (APF) is actually an inverter that is connected in parallel with the AC line at the common point of coupling which cancel out the current harmonics components from the nonlinear loads to insure that the resulting total current drawn from the main incoming supply is sinusoidal. The SAPFs are the most commonly used topology and they are connected in parallel with the AC line for the compensation of current harmonics caused by the nonlinear load. This principle is applicable to any type of load considered a harmonic source. Because of the advantages of active power filters over the passive power filters are known to be able to adapt concurrently to changing loads, can be expanded easily and will not affect neighborhood equipment's [5]. The shunt active power filters play a vital role in power quality improvement by reducing the harmonic currents and reactive power compensation.

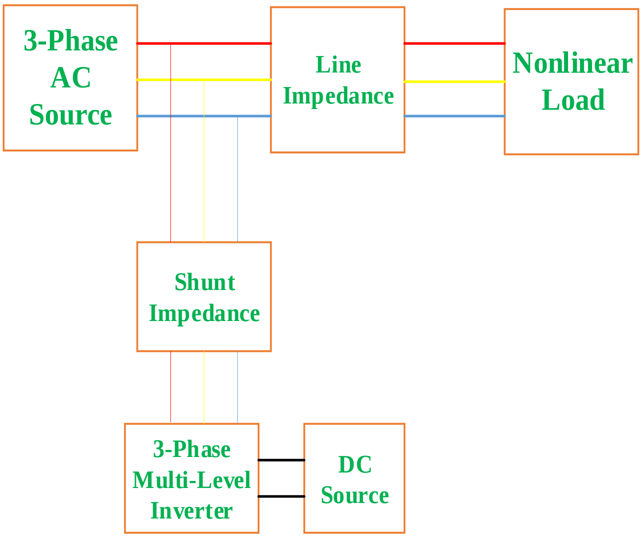

Figure 1. Shunt active power filter

III. MODIFIED HARMONICS PULSE WIDTH MODULATION ALGORITHM

This paper presents A Modified Harmonics Pulse Width Modulation (MHPWM) control strategy of the new active power filter. The modified controller is used to enhance the fundamental supply current and reduce the total harmonic distortion as lower as possible. Harmonics error current as reference signal and a triangular wave as carrier signals are used to generate MHPWM signals. The passive power filters have been used to minimize the effective harmonic components and compensate reactive power, which is limited by the high cost and space requirements. Due to the more flexibility and dynamics means of power conditioning, the active power filters are widely accepted and implemented in a system for harmonic compensation. The advantage of active a power filter (APF) is which provides flexible control and can be tuned to adapt the changes in system frequency and impedance. Therefore, APFs have better filtering performance than passive power filters. In this paper, a modified APF (MAPF) with modified harmonics PWM (MHPWM) algorithm is used as a controller for the shunt active power filter to improve the power quality [6]. The power circuit of the presented APF shown in Fig. 1.

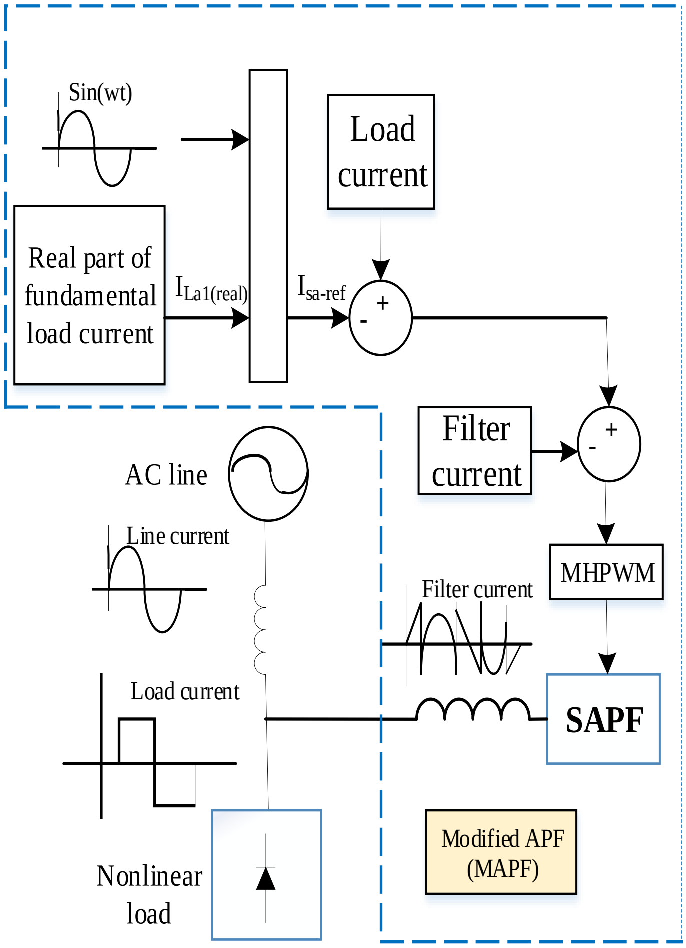

Figure 2. System overview with modified active power filter

The APF is modified to compensate harmonics and reactive power based on MHPWM algorithm. The MHPWM algorithm is used to produce PWM pulses to drive the switches (IGBTs') of the MAPF. The desired mains currents represents by Eq. (3) are obtained from the product of the real part of the fundamental load currents represents by Eq. (4) and a unity sinusoidal wave in phase with the mains voltage. The reference compensation currents represents by Eq. (2) are obtained as the differencebetween the actual load currents (I_L) and the desired mains currents [7] for the three phases.

$$\left.\begin{aligned} i_{a-comp} &= i_{La} - i_{sa-ref} \\ i_{b-comp} &= i_{Lb} - i_{sb-ref} \\ i_{c-comp} &= i_{Lc} - i_{sc-ref} \end{aligned}\right\} \quad (2)$$

Where,

$$\left.\begin{aligned} i_{sa-ref} &= I_{La1(real)} * \sin(wt) \\ i_{sb-ref} &= I_{Lb1(real)} * \sin\left(wt - \frac{2\pi}{3}\right) \quad (3) \\ i_{sc-ref} &= I_{Lc1(real)} * \sin\left(wt + \frac{2\pi}{3}\right) \end{aligned}\right\}$$

And

$$I_{La1(real)} = |I_{La1}| \cdot \cos(\theta_{a1}) \quad \}$$

$$I_{Lb1(real)} = |I_{Lb1}| \cdot \cos(\theta_{b1}) \quad (4)$$

$$I_{Lc1(real)} = |I_{Lc1}| \cdot \cos(\theta_{c1})$$

Where, $\theta$is the fundamental phase angle of the load current with respect to phase supply voltage. In the MHPWM algorithm the compensation currents are compared with the MAPF currents and the results, harmonics error signals (HES), are used as reference current signals for the PWM model [7]. The PWM signals are obtained by comparing the harmonics error signals,reference signal with a triangular signal as shown in Fig. 1.

IV. MULTI-LEVEL INVERTER

A multi-level inverter is simply an arrangement of series switching devices to perform power conversion in incremental steps of voltage by synthesizing the staircase voltage [8] from several levels of DC capacitor voltages. Multi-level inverter technology has becomes a very important alternative in the area of high-power medium-voltage energy control. This paper presents the three level inverter for the reduction of total harmonics distortion in the output waveform. The diode-clamped inverter topology with sinusoidal pulsewidh modulation (PWM) control strategy [9] is used for design of multi-level inverter. The most important feature of multi-level inverter (MLI) is the total harmonics distortion is reduced in the output waveform without decreasing in inverter output power. By increasing the number of levelsin the inverter like five level or seven level the output voltages have more steps generatinga staircase waveform, which has a reduced harmonic distortion. However, as high number of levels increases that reduces the total harmonics distortion in output waveform more effectively [10]. As the number of voltage levels increases, there is more decrease in harmonic content of the output voltage waveform. Multi-level inverter improve the power quality, power factor and offer a low total harmonic distortion (THD) for output voltage. The multi-level inverter offers a higher efficiency because of the devicescan be switched at a low frequency [8]. Fig. 2 represents the overall simulation model of the presented system.

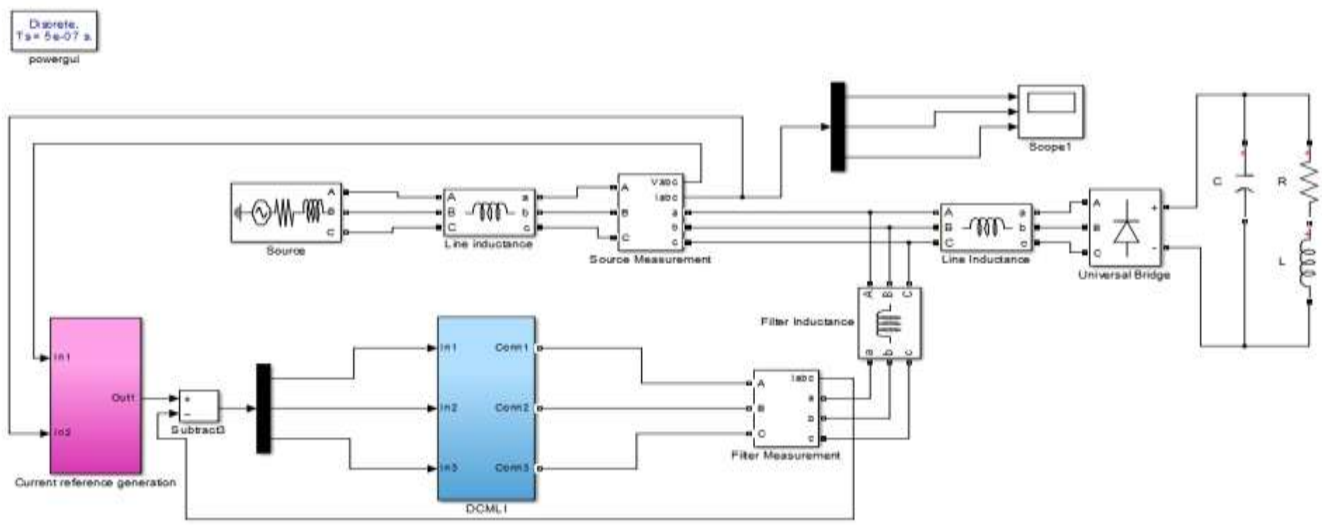

Figure 3. Overall simulation model of shunt active power filter

V. SIMULATION RESULTS

In this paper the harmonic current compensation is implemented by using a shunt active power filter. A three phase current controlled voltage source inverter (VSI) with a DC link capacitor across it is used as an active filter. The shunt active power filter is connected in parallel with line through coupling inductor to compensate the current harmonics. The rms value of source voltage of the system is set as 440V and a combination of three-phase universal bridge rectifier with an RLC load across it constitutes the nonlinear load which introduces the harmonics into the network [4].The various circuit parameters and design specifications used in this simulation is shown in the Table I.

The Fig. 4 shows the source current waveform of a phase without SAPF. The Total Harmonic Distortion (THD) spectrum in the system without SAPF is shown in Fig. 5 which indicate a THD of 22.19%.The source current after the injection of compensating current and with implementation of SAPF is shown in Fig. 6.

TABLE I. SIMULATION PARAMETERS

Parameters	***Values***
Dc bus voltage	440V
Dc link capacitor voltage	440V
Line inductance	0.060mH
Filter inductance	25mH
Load resistance	80Ω
Load inductance	6mH
Load capacitance	0.0075μF

The THD spectrum in the system with active power filter included is observed to be 4.18% which is within the

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allowable harmonic limit. Fig. 7 shows the THD spectrum with shunt active power filter in the circuit.

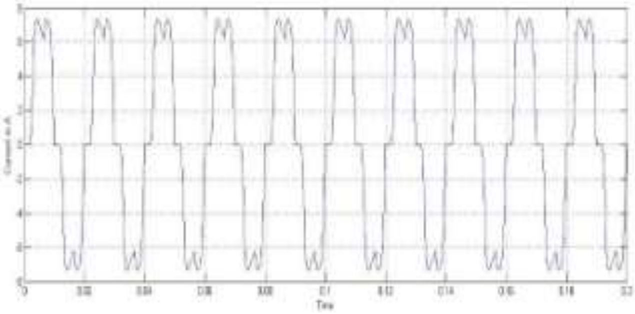

Figure 4. Source current in phase a without filter

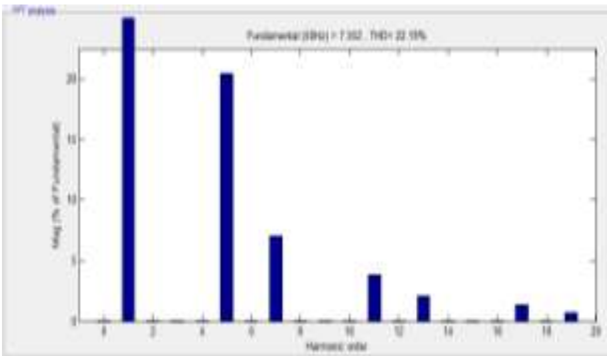

Figure 5. THD spectrum without filter

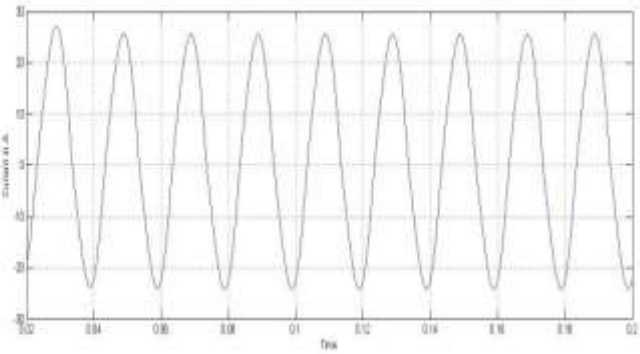

Figure 6.Source current in a phase after compensation

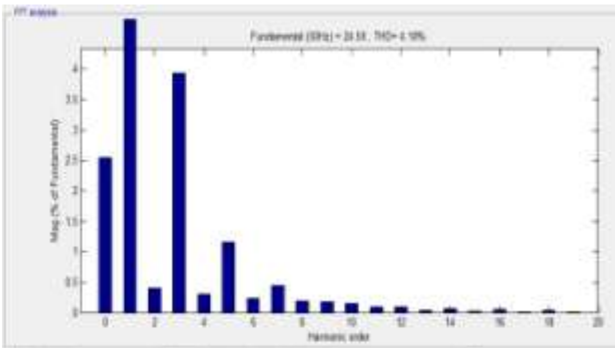

Figure 7.THD spectrum with shunt active power filter

From above simulation results, the SAPF is one of the solution for the improvement of power quality of distribution network by reducing the current harmonics caused by the nonlinear load.

The overall comparative results of THD of the system with or without SAPF is shown in Table II. Which shows the effective reduction in THD.

TABLE II. COMPARATIVE THD RESULTS

PWM Techniques	***System***	***THD (%)***
MHPWM	Without filter	22.19
	With filter	4.18

VI. CONCLUSION

This paper deals with the power quality improvement of distribution Network by using SAPF which compensate the line current harmonics generated due to the nonlinear loads in the system. The MHPWM algorithm is used to produce PWM gate pulses to drive the switches(IGBTs').Due to use of multi-level inverter based SAPF method it seems to be reduction in the THD of the system. Thus, SAPF has been proved that it improves the power quality of distribution system by maintaining the harmonic content in power lines within the permissible limit of IEEE standards.

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