Performance of Synchronous Reference Frame Controller (SRF) Based Multi-Level Voltage Source Converter (VSI) for Harmonic Control

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Abstract— In this paper, a power line conditioner using a cascade multilevel inverter based on Synchronous Reference Frame Controller (SRF) is presented for voltage regulation, reactive power (var) compensation, and harmonic filtering. The SRF based compensation is developed by sensing load currents only, which require for harmonics and reactive power compensation due to non-linear loads. . Using Reference Frame Transformation, the current is transformed from a − b − c stationery frame to rotating 0 − d − q frame. Using the PI controller, the current in the 0 − d − q frame is controlled to get the desired reference signal. The cascaded multilevel voltage source inverter switching signals are generated from proposed triangular-carrier current controller. It gives better dynamic performance under both transient and steady state conditions. The proportional integral (PI) controller is used to maintain the capacitance voltage of the cascaded inverter almost constant. Shunt APF is usually connected across the loads to compensate all current related problems, such as reactive power compensation, neutral current compensation, dc link voltage regulation and load unbalance compensation. Synchronous reference frame based control method for the Shunt Active Power line conditioner system is optimized without using voltage, load and filter current measurement, so that number of the current measurements are reduced and the system performance is improved. From the simulation results it is observed that the cascaded multilevel inverter based active power filter using the synchronous reference frame controller effectively Compensates the current harmonics and reactive volt amperes under both steady state and transient conditions. This paper aims at the simulation study of three phase multilevel inverters. The role of SRF control strategy in active power filter for harmonic filtering is studied and simulated in MATLAB/SIMULINK. Firstly, the three phase systems with non-linear loads are modeled and their characteristics are observed. Secondly, the active power filters are modeled with the inverters and suitable switching control strategies (SRF technique) are employed to carry out harmonic elimination.

Index Terms— Active Power Filter; cascaded multilevel Voltage Source Converter (VSC); harmonic elimination; matlab simulink; non-linear loads; Synchronous Reference Frame Controller (SRF);

1 INTRODUCTION

BOTH electrical utilities and end users of electrical power are becoming increasingly concerned about the quality of electrical power so the power utility has become one of the most prolific buzzword in the power industry since the late 1980's.The issue in electricity power sector delivery is not confined to only energy efficiency and environment but more importantly on power quality and continuity of supply or power quality and supply quality electrical power. Power quality is the degree of any deviation from the nominal values of the voltage magnitude and frequency. Power quality may also be defined as the degree to which both utilization and delivery of electric power affects the performance of electrical equipment .From a customer perspective, a power quality problem is defined as any power problem manifested in voltage, current or frequency deviations that result in power failure or disoperation of customer of equipment. With the advent of power semi-conductor switching devices like thyristors, GTO' (Gate turnoff thyristors), IGBT's (Insulated gate bipolar transistor) and many more devices, control of electric power has become a reality. Such power electronic controllers are widely used to feed electric power to electrical loads such as adjustable speed drives(ASD's),furnaces, computer power supplies, HVDC(High voltage DC),systems. Due to inherent non linearity the power electronic devices draw harmonic and reactive power from the supply in three phase systems they could also unbalance and draw excessive neutral currents the injected harmonics, reactive power burden, unbalance and excessive neutral currents cause low system efficiency and poor power factor. Isolated power systems are commonly found in rural and remote areas of the world. Isolated power systems are characterized by limiting generating capacity. The sensitive loads which are present in the isolated power systems are much more affected by the power quality problems. Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Power quality problems encompass a wide range of disturbances such as voltage sags/swells, flickers, harmonics distortion, impulse transient, and interruptions.

Non-linear loads result in harmonic or distortion current and create reactive power problems .Traditionally passive filters have been used to compensate harmonics and reactive power; but passive filters are large in size, aging and tuning problems exist and can resonate with the supply impedance. Recently active power line conditioners (APLC) or active power filters (APF) are designed for compensating the current-harmonics and reactive power simultaneously. In the proposed system the compensation process is based on sensing load currents only, which require current harmonics and reactive power elimination due to the loads. The cascaded H-bridge active filter has been applied for power quality applications due to increase the number of voltage levels, low switching losses and higher order of harmonic elimination. The main objective of the proposed system is to suppress the harmonics by using shunt active power filter designing based on SRF controller in electrical power system with non linear loads in order to improve the power quality in the distribution system. In this paper the concept of design of SRF controller for shunt APLC system and the basics of power quality were discussed i.e. power quality standards, need for improvement of power quality, sources of power quality problems and simple prevention techniques. Simulink and Matlab provide an ideal integrated environment for developing models, performing dynamic system simulations, and designing and testing new ideas. The enhancement of power quality in isolated power systems is studied by using with and without shunt compensators. The corresponding simulation results are presented and compared.

2. IMPLEMENTATION OF ACTIVE FILTERS

The voltage source inverter used in the active filter makes the harmonic control possible. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal that will cancel the harmonics from the nonlinear load.The active filter does not need to provide any real power to cancel harmonic currents from the load. The harmonic currents to be cancelled show up as reactive power. Reduction in the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore, the dc capacitors and the filter components must be rated based on the reactive power associated with the harmonics to be cancelled and on the actual current waveform (rms and peak current magnitude) that must be generated to achieve the cancellation.

The current wave form for cancelling harmonics is achieved with the voltage source inverter in the current controlled mode and an interfacing filter. The filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistors (IGBT's) in the inverter.

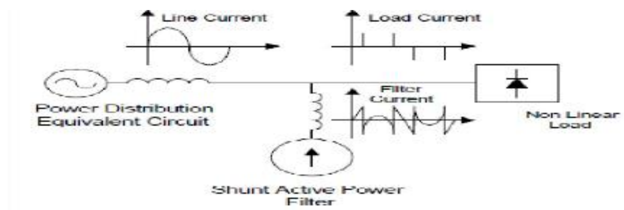

Fig1.Need for shunt Active Filter

Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance .A large inductor is better for isolation from the power system and protection from transient disturbances. However, the larger inductor limits the ability of the active filter to cancel higher order harmonics. The inverter in the Shunt Active Power filter is a bilateral converter and it is controlled in the current Regulated mode i.e. the switching of the inverter is done in such a way that it delivers a current which is equal to the set value of current in the current control loop.

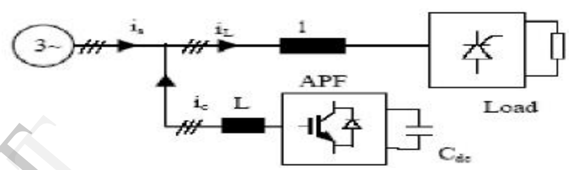

Fig 2 Shunt Active Power Filter

The basic principle of Shunt Active Filter is that it generates a current equal and opposite to the harmonic current drawn by the load and injects it to the point of coupling there by forcing the source current to be pure sinusoidal. This type of Shunt Active Pow er Filter is called the Current Injection Type APF.

2.1 Harmonic compensation

2.1.1 Current Harmonic Compensation

Current harmonics are greatly reduced by the compensation of voltage harmonics at the consumer's point of common coupling. The reduction in current harmonics is not only important for reasons such as device heating and reduction in life of devices but also in design of power system equipment. One of the major design criteria covers the magnitude of the current and its waveform. This is to reduce cable and feeder losses. Since the root mean square (RMS) of the load current incorporates the sum of squares of individual harmonics, true current. Harmonic compensation will aid system designers for better approached power rating equipment.

2.1.2 Harmonic detection and extraction

A shunt active filter acts as a controllable harmonic current source. In principle, harmonic compensation is achieved when the current source is commanded to inject harmonic currents of the same magnitude but opposite phase to the load harmonic currents. Before the inverter can subtly inject opposing harmonic currents into the power system, appropriate harmonic detection strategies must be implemented to efficiently sense and determine the harmonic current from the nonlinear load.Types of harmonic detection strategies.To determine the current reference for the active filters 3 different types of harmonic detection strategies used. These are:

- Measuring the load harmonic current to be compensated and using this as a reference command.
- Measuring source harmonic current and controlling the filter to minimize it.
- Measuring harmonic voltage at the active filter point of common coupling (PCC) and controlling the filter to minimize the voltage distortion.

So out of these harmonic detection strategies in this system we are using first method i.e., measuring the load current.

2.1.3 Load current sensing

This method involves measurement of the load current and subsequent extraction of its harmonic content using a high pass filter scheme. The harmonic components, so extracted, are adjusted for polarity and used as reference commands for the current controller. This is explained with the help of below equation and figure.4 denoting the harmonic components of the load current by, describing the equation for this strategy is

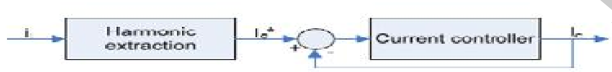

Fig.3 Load Current sensing compensation

2.1.4 Source current sensing

In this strategy, the source current is measured and its harmonic component extracted. This is scaled by a suitable controller, generally of the proportional type. The output of the proportional controller is provided as a reference to the current controller. This is schematically represented in figure and analytically expressed by equation. Denoting the harmonic components of the source current by shi, the describing equation for this strategy is

$$i^*_c(t) = -K_{sh} \times i_{sh}(t)$$

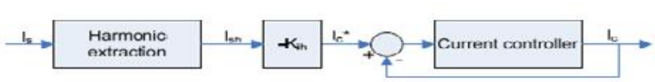

Fig 4 Source current sensing compensation

2.2 Point of Common Coupling (PCC) voltage sensing

This method requires measurement of the harmonic component of the Point of Common Coupling (PCC) voltage, e(t). The harmonic component is then used to generate the current reference, after passing it through a proportional controller. Schematically, it is represented in figure 5 and analytically expressed by the below equation ,denoting the harmonic components of the PCC voltage by, the describing equation for this strategy is

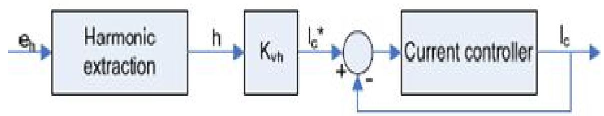

Fig .5 PCC Voltage sensing compensation

Load current sensing and supply current sensing are suitable for shunt active filters installed in the vicinity of one or more harmonic producing loads by individual high-powered consumers. PCC voltage sensing is suitable for shunt active filters, which will be installed on distribution systems by utilities. Supply current detection is the most basic harmonic detection method for series active filters acting as a voltage source.

3. CONTROL STRATEGY

SIMULINK model of a Discrete Virtual PLL, abc to dq0 and dqo to abc, Triangular carrier current controller, SRF controller, Shunt converter controller, Non Linear Load.

3.1 Discrete Virtual PLL

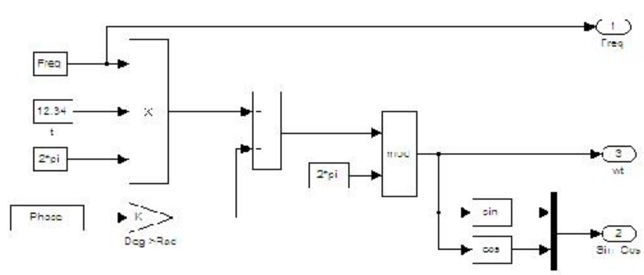

Fig 6 Simulink model of Discrete Virtual PLL

3.2 ABC Axis to DQ0 Axis

The fig 7 shows the conversion of simulink model of abc to dqo, the input is taken from source current and discrete virtual PLL block. By using parks transformation equations as early said , construct abc to dq0 simulink model, the output this transformation block is fed to MUX

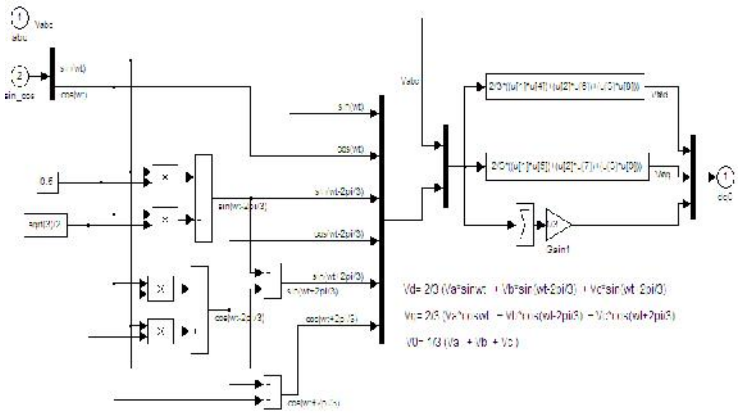

fig 7 Simulink model of abc to dqo

3.3 DQ0 axis to ABC Axis

The fig 8 shows simulink model of dq0 to abc, the input is taken from filters and discrete virtual PLL, by using equations of dq0 to abc as early said in construct simulink model of dq0 to abc. The output from this transformation block is fed to the PWM hysteresis current control.

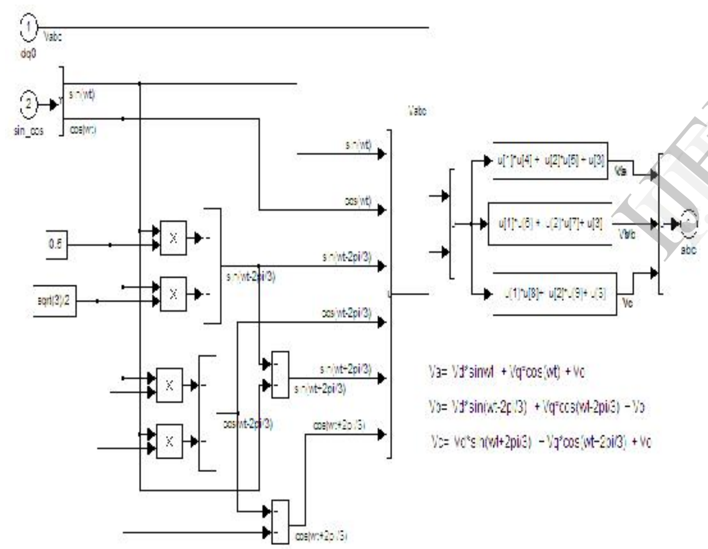

Fig.8 Simulink model of dq0 to abc

3.4 Triangular carrier current Controller

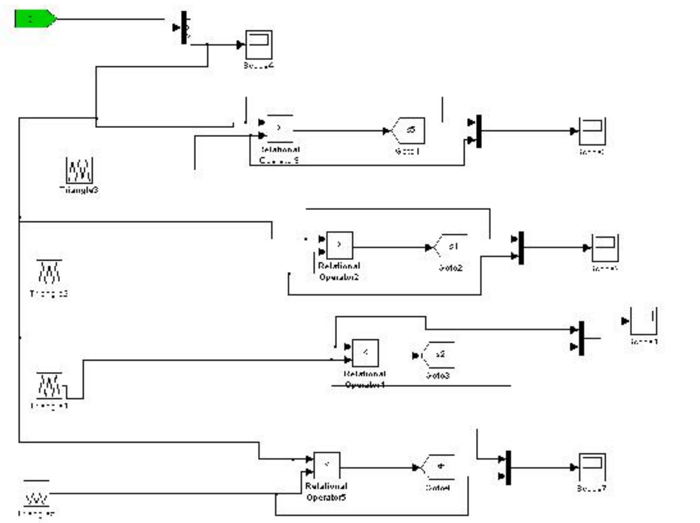

Fig 9 Simulink model of Periodical carrier current controller

Here current controller directly generates the switching signal of the three A, B, C phases. The A-phase actual source current represented as isa and reference current represent as isa*.Similarly derived the B and C phase currents. To determine the switching frequency by means the error current [desired reference current compared with the actual source current] multiplied the proportional gain (Kp) and compared with triangular periodical signal. The four triangular signals are generated same frequency with different amplitude for cascaded inverter.

3.5 SRFController

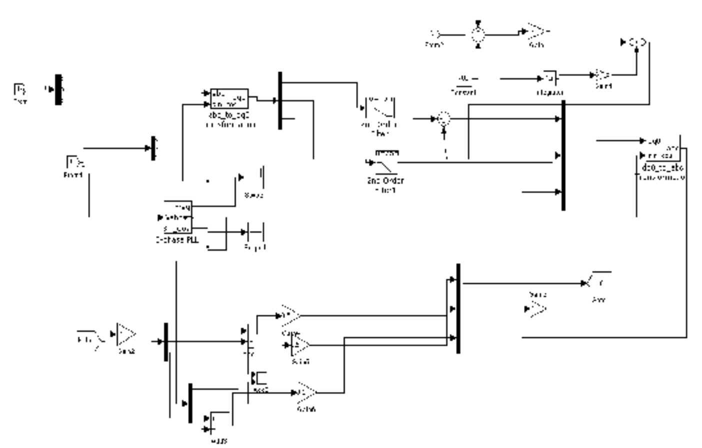

Fig 10 Simu;ink model of SRF Controller

3.6 Non Linear Load

The non linear load is simulated as a bridge load with selected power electronic devices

Fig 11 Simulink model of Non Linear Load

Simulink models of a Discerte Virtual PLL, ABC to dq0 and dqo to ABC, Periodical carrier current controller, SRF controller, Non Linear Load are implemented.

4. SIMULATION AND EXPERIMENTAL RESULTS

In this study power circuit is modelled as a three phase three wire system with a non linear load comprising of RL load which is connected to source through three phase Diode Bridge. Circuit parameters used in simulation are shown in Table 1.

Table 1 Circuit Parameters

Parameters	Values
Source Line Voltage (RMS)	440V, 50Hz
DC Link Voltage	700V
Source impedance L_S	1mH
Filter impedance(R_C,L_C)	0.1Ω,1mH
Dc side Capacitance	2100 µF

4.1 MATLAB/SIMULINK Model without SHUNT APLC

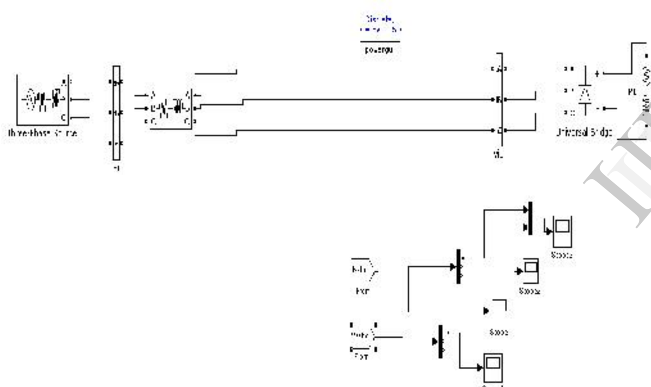

Fig.12 Simulink model for without SHUNT APLC System

Fig 12 show simulink model without SHUNT APLC, it consists of three phase AC source and Non-linear load. The source is directly connected to the load, observe the wave forms of three phase AC source input voltage and current , Non-linear load current and voltage, load power factor wave forms also observed.

4.1.1 Simulation Results without SHUNT APLC

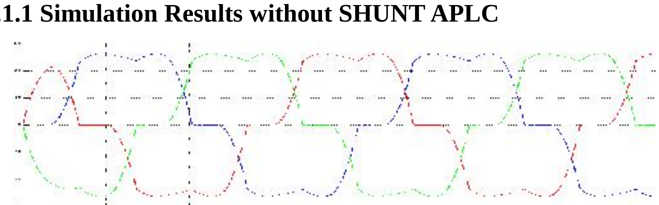

Fig 13 Three phase input source current without SHUNT APLC

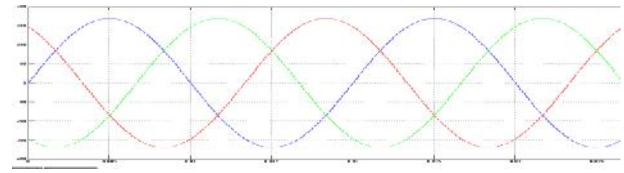

Fig 14 Three phase input source voltage without SHUNT APLC

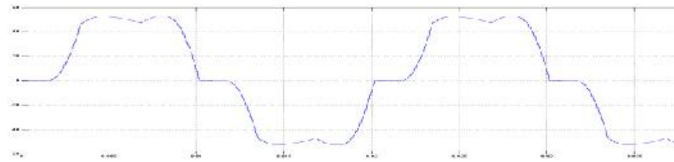

Fig 15 Non- linear load current without SHUNT APLC

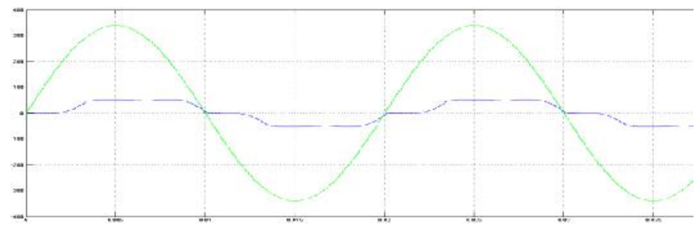

Fig 16 . P.F OF the system without SHUNT APLC

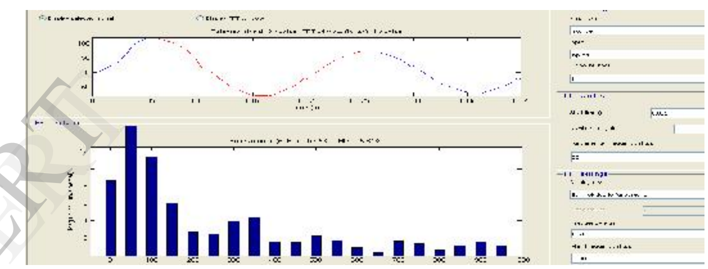

Fig 17 THD Without SHUNT APLC

Fig 17 shows THD without UPQC,THD graph plot between magnitudeversus frequency, for considering 50Hz frequency,selected six cycles in that cosider one cycle FFT window, then THD value is 15.81% of the fundamental frequency without UPQC which is shown in the fig 16.

4.2 MATLAB/SIMULINK Model of SHUNT APLC

Fig.18 shows the block diagram of SHUNT APLC system is simulated in MATLAB/SIMULINK. Three Phase Voltage source is connected to non linear load which is a RL Load which is connected through Diode Bridge. Cascaded active filter for power line conditioning system is connected in the distribution network at the PCC through filter inductances and operates in a closed loop . SHUNT APLC System consists of discrete virtual PLL, abc to dq0, dq0 to abc, PI controller and Periodical carrier current controller. The capacitor voltage is maintained constant using PI-controller and the output voltage is *Vdc* .

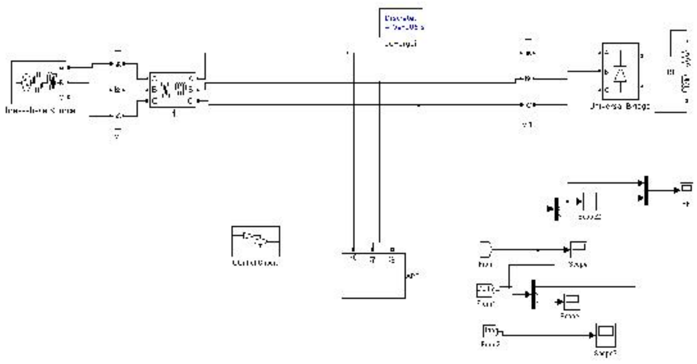

Fig 18 MATLAB/SIMULINK Model of SHUNT APLC System

4.2.1 Simulation Results With SHUNT APLC:

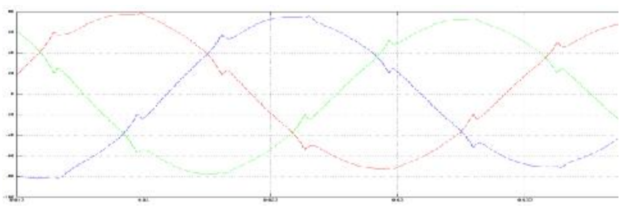

Fig 19 Three phase source current with SHUNT APLC

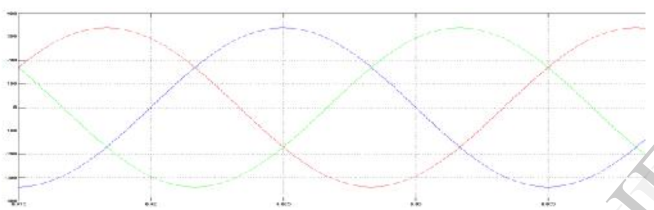

Fig 20 Three phase input source voltage with SHUNT APL

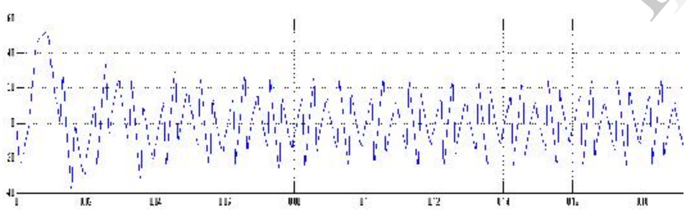

Fig 21 Compensation current at the point of common coupling for PhaseA

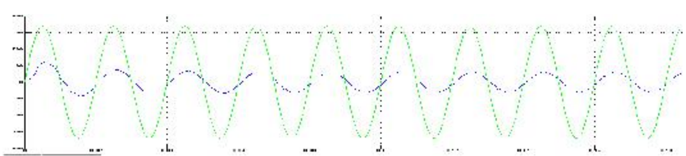

Fig 22 Power factor of the system with SHUNT APLC

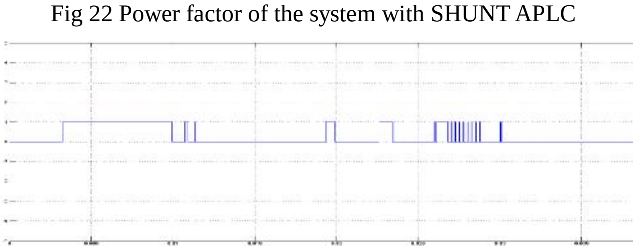

Fig 23 Gate pulses for Inverter in SHUNT APLC

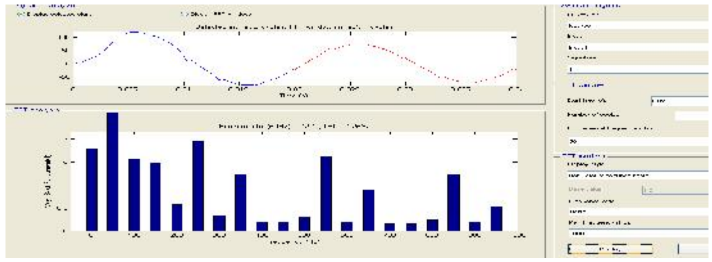

Fig 24 THD WithSHUNT APLC

THD graph plot between magnitudeversus frequency, for considering 60Hz frequency,selected nine cycles in that cosider one cycle FFT window, then THD value is 4.25% of the fundamental frequency with SHUNT APLC is shown in the fig 24.The total harmonic distortion (THD) measured at the source(current) on the distribution system and the various parameters measured without APF and with APF are presented in Table 2

Table 2: Measurement of various parameters for SRF based APF with and without compensation

parameter	Source current (Isa) with out APF	Source current(Isa) with APF
Power factor	0.707	0.9659
Real power	9.8KW	16KW
Reactive volt Ampers	6.3KVAR	5.8KVAR
THD	15.81%	4.25%

Simulation results of input source voltage and current, non-linear load voltage and current, load power factor, total harmonic distortion of with and without SHUNT APLC are presented. THD value of system with SHUNT APLC System is 4.25% is better than THD value of without SHUNT APLC is 15.81%. The input source current wave form of without SRF based SHUNT APLC is distorted waveform but with SHUNT APLC System is sinusoidal waveform.

5. CONCLUSION

Power quality improvement in an isolated power system through series compensation has been investigated. It is observed that the power system contains significant proportion of fluctuating non-linear load and high level of harmonic distortions. A method to control the injection of currents by the shunt compensators (SC) so that it can mitigate the effects of the harmonics has been proposed. The cascaded inverter provides lower cost, higher performance and higher efficiency than the traditional PWM-inverter for power line conditioning applications. The cascaded inverter switching signals are derived from the proposed triangular-periodical current modulator that provides good dynamic performance under both transient and steady state operating conditions. Here a new controlling technique is applied i.e SRF is employed to extract the fundamental component from the nonlinear load currents. This controller is developed by sensing load currents only. This approach is fairly simple to implement and is different from conventional methods. The extensive simulation results demonstrate the performance of the APF under different non-linear load conditions. Simulations have confirmed the effectiveness of the proposed method, as it is applied by the SRF based shunt APF to achieve improved quality of supply in the power system.

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