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Power Quality Enhancement by Modulated Power Filter Compensator in Low Voltage Distribution Wind Turbines

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ABSTRACT: Harmonics, voltage sag/swell, persistent quasi dynamic harmonics and switching excursions can result in electric equipment failure, malfunction, hot neutral current rise, ground potential rise, fire and shock hazard. In addition it results poor power factor, inefficient utilization of electric energy manifested in increase reactive power supply to the hybrid load, and severely distorted voltage and current waveforms. The use of fixed power filters and LC compensators may not be adequate for mitigation of quasi-dynamic harmonic generated by nonlinear load switching. Hence the need for a new adaptable power filter/compensator arises. The Modulated Power Filter Compensator (MPFC) is a low cost self adjusting power filter controlled by self adjusting dynamic tri-loop error driven controller topology and pulse width modulation switching strategy. This characteristics make use as the voltage stabilization scheme for a stand-alone wind energy conversion systems using self excited squirrel-cage induction generator (SEIG) driven by a wind turbine and interfaced to Electric Load. The new Control scheme is designed not only to ensure bus voltage stabilization, but also to improve energy utilization using PWM-Switched Modulated Power Filter Compensator (MPFC) driven by a tri-loop Dynamic Error driven error scaled regulator.

KEYWORDS: Low Voltage Power Distribution System, Power Quality, Power Factor, Modulated Power Filter.

I. INTRODUCTION

Electrical power is usually generated at different grid locations and transmitted through high voltage transmission lines, and finally distributed through the low voltage distribution and utilization networks to all customers at different locations. Presently the common generation voltages are 11kV and 25kV whereas the transmission voltages can be 33kV, 66kV, 138kV, 220kV, 400kV and up to 735kV. The low voltage customer utilization grids are mainly done at 230V (single phase) and 400-600 volts (line to line) in three phase 3 wire and 4 wire system in residential, commercial and small industrial load centers. The low voltage utilization grid systems are classified as: (i) Single phase, 2 wire, 120V (ii) Single phase, 3 wire, 240/120V (iii) Three phase, 4 wire, 208/120V (iv) Three phase, 3 wire, 480V (v) Three phase, 4 wire, 480/277V (vi) Three phase, 3 wire, 600V and (vii) Three phase, 4 wire, 600/347V

To reduce the effect of any phase load imbalance, three phase 4 wire systems are widely used for commercial centers and large residential loads. The common or neutral wire is the neutral of the three phase secondary winding, which is usually solidly grounded. When the phase loads are balanced, the neutral return current is near zero. When the three phase load is severely unbalanced, the neutral current can be large and equals to the residual vector of phase currents.

M. Sharaf and RoshanChetri [2] describe power quality aspect to the industrial user. The most important aspects are the continuity of power and the integrity of the sinusoidal aspect of the voltage wave. The continuity of power is dependent upon many aspects of the system design and operation. Some of the factors affecting the continuity of power are: surge protection, fault interruption and reclosing, transmission line design, and distribution system design and operation. If a transmission or distribution

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system is properly designed to withstand lightning and other surges, the reliability of the system is increased. Likewise, with proper fault protection, fast coordinated relaying, and voltage support from a static VAR compensator (SVC), the system is more reliable. The degradation of the sine wave is a result of non-linear loads in the industrial user's processes. The most common is a static power converter that produces harmonic currents in the AC system. These harmonic currents flowing through the impedance of the system results in harmonic voltages in the utility system that distorts the voltage wave form. Understanding the above problems and the correction of them takes both the electric

utility and the industrial user cooperating together. Filtering or trapping the harmonic current from the nonlinear loads is mainly the responsibility of the industrial user that uses these loads in his processes. However, he must have the cooperation of the electric utility to obtain system characteristics and capacitor bank sizes and locations in order to get the proper harmonic filter design. The size of filters is dependent upon the reactive power requirement of the industrial user's load. The number of the filters depends upon the amount of harmonic producing loads the user has.

A.M. Sharaf and Khaled Abo-Al-Ez [3] describe that Harmonics, voltage sags/swells, persistent quasi-steady state harmonics, and dynamic switching excursions can result in electric equipment failure, malfunction, hot neutral, ground potential rise problem, fire and shock hazard, as well as in poor power factor and inefficient utilization of electric energy. These manifest in increase reactive power supply to the hybrid load, poor power factor and severely distorted voltage and current waveforms. Nonlinear industrial/commercial schemes are now mushrooming as they represent a composite load family comprising lightning, motorized, computers, arc type, and low power factor industrial processes, such as rectifiers, power supplies and inrush type loads. Such composite load often cause voltage flicking, power quality quasi-static waveform distortion and harmonic interference, which in turn cause automatic data processing component failure and computer data. The nonlinear volt-ampere characteristics are introduced by analogue or switching type nonlinearity results in dynamic, quasi-static harmonics and inter-harmonics. Harmonics can propagate through the AC utilization/distribution system causing multiple problems and power quality concerns. The use of fixed power filters and LC compensators may not be adequate for quasi-dynamic harmonics generated by nonlinear load switching devices; hence, the need for a new adaptable power filter/compensator. It is applicable in low voltage (below 1KV) distribution systems. It is mainly used in residential, commercial applications and small industrial nonlinear type loads with substantial mix of nonlinear hybrid arc type, converter type loads.

A.M. Sharaf, Hassan A. Mahasneh and YevgenBiletskiy [4] explain that, Electric utility power quality problems are classified as any abnormal occurrence manifested in voltage/current waveforms or frequency deviations that result in supply failure or any mis-operation of electronic equipment. It is a growing concern for electric utilities, equipment manufacturers and major electricity users. Utilities have a shared responsibility in addressing and solving these power quality problems. Power Quality problems are increasing due to world-wide proliferation of nonlinear loads and increasing use of sensitive power electronic equipment in process control and automation. Voltage sags, swells, and momentary power supply interruptions are also persistent problems in large electric power grid systems. These shortfalls in supply power quality can be very expensive in terms of sensitive industrial process shutdowns as well as electronic equipment malfunctions. Generally speaking, there are three fundamental changes in the nature of customer loads and power systems which drive the engineering power quality problems and concerns. A. M. Sharaf and Guang Sheng Wang [5] describe that, Harmonics and power quality problems are byproducts of solid state converters, industrial rectifiers, switching mode power supplies and arc type load such as lightning and arc furnaces. Electric utility supply power quality problems including harmonics, dynamic and quasi-static waveform distortion are now top priority issue for equipment manufacturers, users, and electric utilities. Nonlinear loads are causing dynamic, quasi-static and transient type harmonics of integral, sub-, super- and inter-harmonic content[6]. Other non-integer modulating type frequency signals are introduced by load nonlinearities. These peculiar frequencies are generated by periodic and temporal load variations along with the nonlinearity in the load, whether analogue or switching-type nonlinearity. Voltage drop calculations, reactive power compensations and power factor correction become complex issues in presence of three non-common, non-sinusoidal feeder voltage and current waveforms.

A.M.Sharaf and Liang Zhao [6] describe, the term harmonics referred to Power quality in ideal world would mean how pure the voltage is, how pure the current waveform is in its sinusoidal form. Power quality is very important to commercial and industrial power system designs. Ideally, the electrical supply should be a perfect sinusoidal waveform

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without any kind of distortion. If the current or voltage waveforms are distorted from its ideal form it will be termed as harmonic distortion. This harmonic distortion could result because of many reasons. In today's world, prime importance is given by the engineers to derive a method to reduce the harmonic distortion. Harmonic distortion was very less in the past when the designs of power systems were very simple and conservative. But, nowadays with the use of complex designs in the industry harmonic distortion has increased as well.

II. SYSTEM DESCRIPTION

The investigated Low Voltage distribution /utilization system uses 3 phase 4 wire system which is widely used for large residential building and commercial load centers. The main purpose of using the novel MPFC Scheme is to decrease the large current flowing to the ground to an acceptable value which will not be dangerous to people and equipment. The model of distribution system to be investigated is shown in Fig 4.1. The major parameters of the system are shown in Table 4.1.

Fig.4.1 System model The major components of the sample study systems include: 1. Three phase-four wire AC power supply. 2. Modulated Power Filter Compensator (MPFC) Filter 3. Tri -loop dynamic error driven error scaled-SPWM controller 4. Loads: balanced nonlinear RL load, unbalanced nonlinear RL type and nonlinear converter type load. **Modulated Power Filter Compensator (MPFC)** The MPFC is controlled by a Tri Loop error driven error scaled dynamic controller. The controller will take the neutral current input and will calculate the harmonic present by separating the fundamental component. Finally error will be generated that will be used to vary the admittance by S1 and S2

The proposed Modulated Power Filter Compensator (MPFC) is a member of FACTS based devices and compensators. Figure 4.2 displays the functional model of the proposed MPFC. The MPFC is composed of a capacitor, an inductor, a resistor, two PWM controlled IGBT switches and a three phase diode bridge. The two IGBT switches are controlled by two complementary pulses. The topology of the MPFC circuit and hence the equivalent admittance can be changed with different states of the complementary pulses. If S1 is open and S2 is closed, the resistor and inductor will be connected into the circuit. If S1 is closed and S2 is open, the resistor and inductor will be shorted, and disconnected from the circuit. The three phase diode bridge is used to avoid the reverse flow of voltage and current.

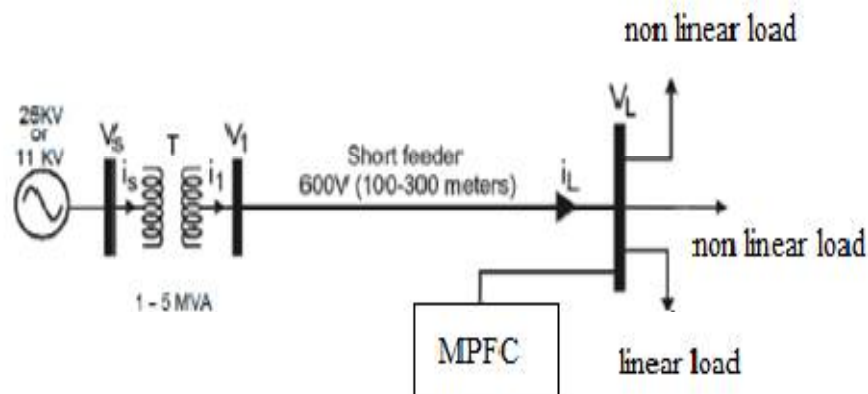


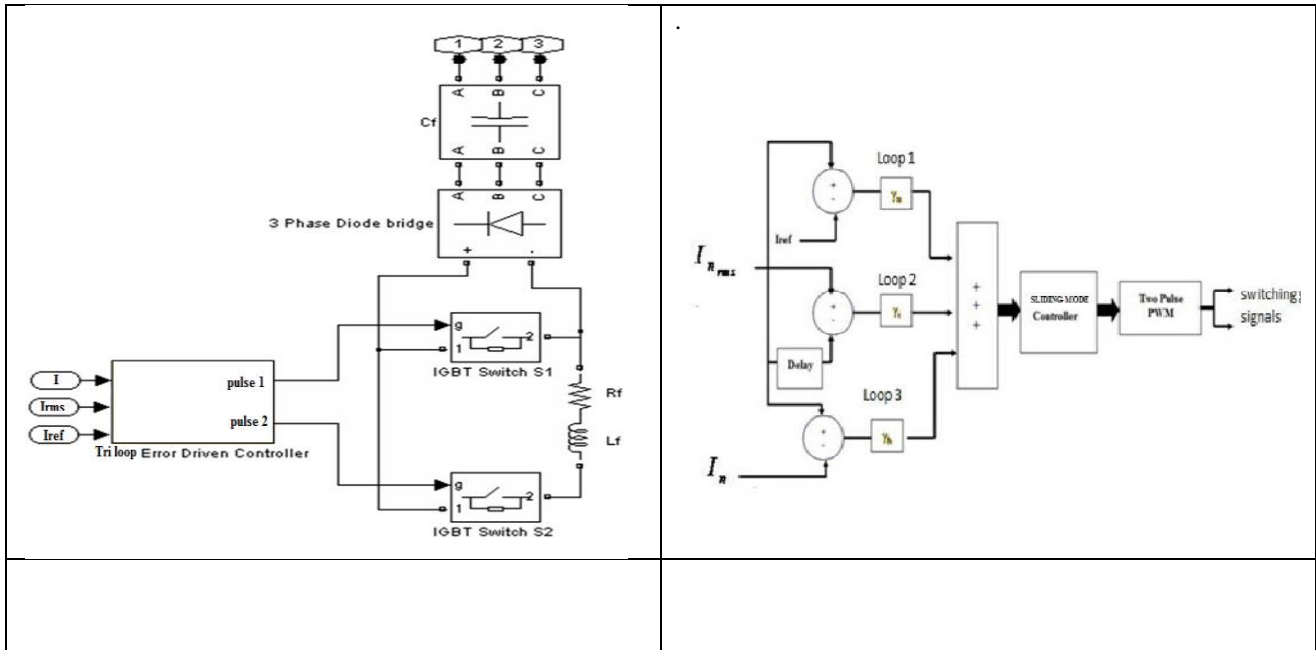
Fig. 4.2 Modulated Power Filter Compensator MPFC is a kind of Switched/Modulated Capacitor Compensator or switched passive capacitor filter. Generally capacitor injects the same harmonic current in the negative direction so the actual harmonic current in the line will get nullified. The IGBT Switches S1 and S2 are placed in the circuit to connect and disconnect RL circuit. The Equivalent circuit is like R, L, and C component in series. So by operating the switches S1 and S2 the effective admittance on the line will vary.).

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Tri loop error driven sliding mode control

The novel tri-loop dynamic controller shown in fig 4.3. it uses a variable structure Bang Bang slide mode control scheme driven by three dynamic error regulating loops: (rms neutral current, minimum neutral rms current, harmonic current ripple) error-tracking loops. The purpose of this three multi-loop dynamic controller structure is to minimize switching transients, maximize power/energy utilization and to improve power factor under unbalanced load conditions. The total error signal () is the sum of the three basic dynamic loop errors. The loop weighing factors is assigned to ensure loop time [3]. The novel dynamic tri loop error driven Bang-Bang Slide Mode Controller comprises the following three basic regulating loops

1. The minimum neutral rms current ($I_{ref} = 0.15$ pu) reference tracking loop.
2. The main rms neutral current (I_n) tracking loop is to minimize neutral return current or residual current.
3. The low neutral current- harmonic ripple loop is to enhance power quality.

The novel tri-loop dynamic controller is governed by the equation (1) and (2):

$$\sigma = \zeta e_t + \frac{de_t}{dt}$$

$$\zeta = \zeta_0 + K_e \zeta_1$$

Where σ is sliding surface slope

The dynamic global error magnitude is defined as follows K_e

$$K_e = \sqrt{(\gamma_i e_i)^2 + (\gamma_n e_n)^2 + (\gamma_h e_h)^2}$$

$$\sigma = [(\zeta_0 + K_e \zeta_1)] e_t + \frac{de_t}{dt}$$

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$$\sigma = \left[\left(\zeta_0 + \left[\sqrt{(\gamma_i e_i)^2 + (\gamma_n e_n)^2 + (\gamma_h e_h)^2} \right] \zeta_1 \right) \right]$$

$$(\gamma_i e_i + \gamma_n e_n + \gamma_h e_h) + \frac{d(\gamma_i e_i + \gamma_n e_n + \gamma_h e_h)}{d}$$

The Sliding surface parameters are usually selected by Trial and Error and usually in the optimum range at = 0.1 – 0.25; = 0.3 – 0.5. The switching signals are determined by the dynamic Sigma –Sign (negative or positive). If > 0, Switch S1 will be on and S2 in off state If < 0,

III. SIMULATION AND RESULTS

Matlab-Simulink software is used in the simulation of distribution system. There are two cases investigated: (1) Low voltage distribution system with unbalanced non-linear load with and without MPFC
(2) Low voltage distribution system with balanced non-linear load with single phase to ground fault on phase A with an without MPFC

5.1 Simulation of low voltage distribution system under unbalanced non-linear load with and without MPFC

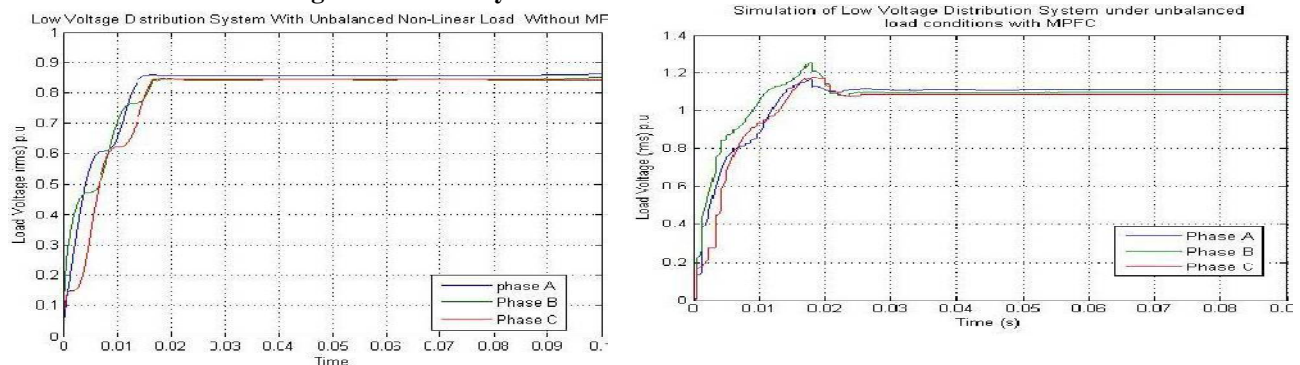


Fig 5.2 Voltage- Time characteristics without and with MPFC

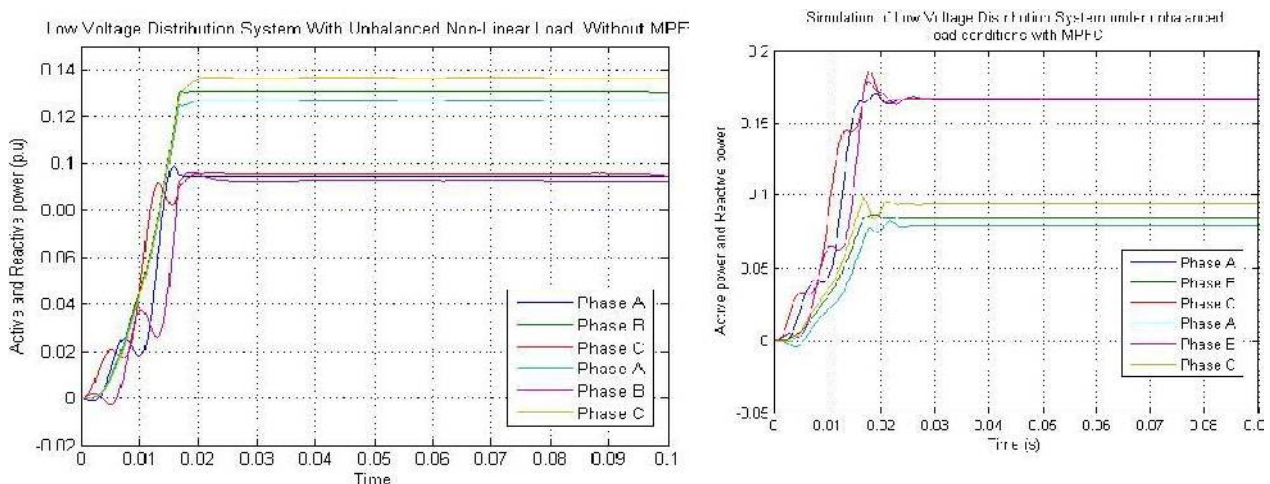


Fig5.4 Power- Time characteristics without and with MPFC

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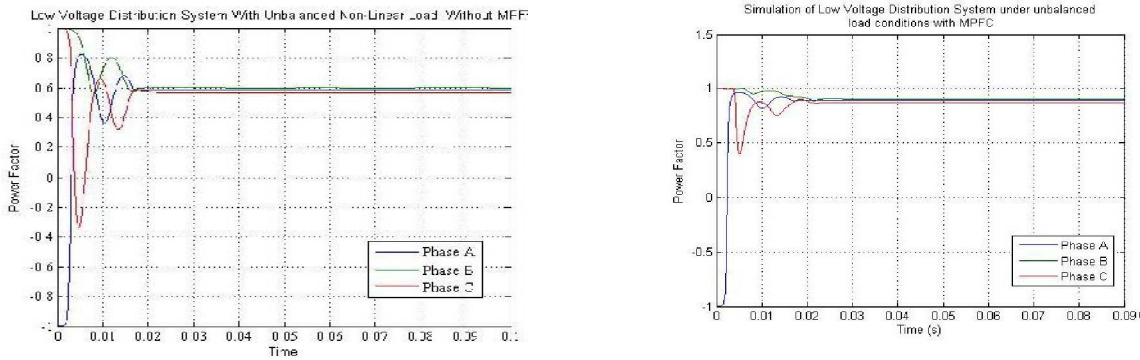


Fig.5.5 Power Factor characteristics without and with MPFC

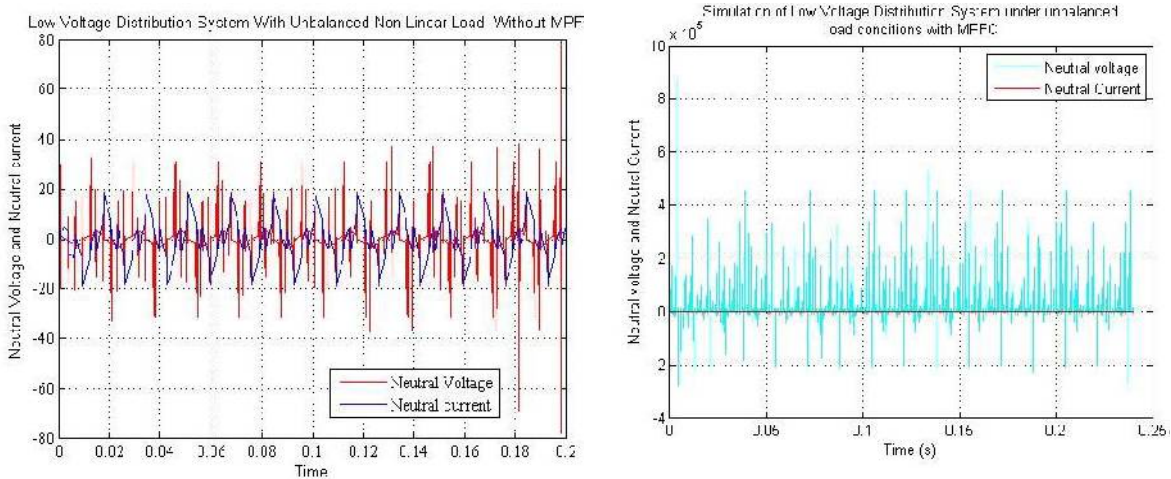
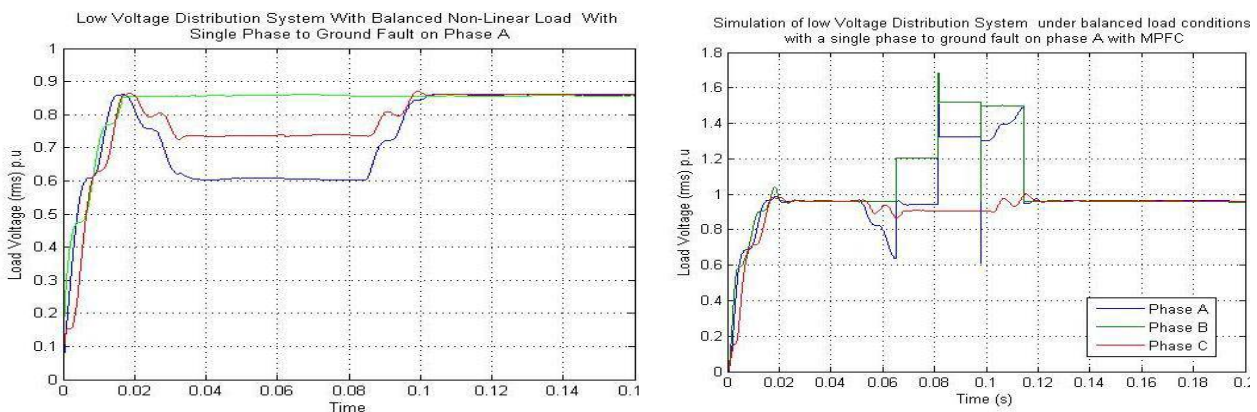


Fig.5.6 Neutral voltage and Neutral Current - Time characteristics

5.2 Simulation of low voltage distribution system with balanced non linear load with single phase to ground fault on phase A fault with and without MPFC



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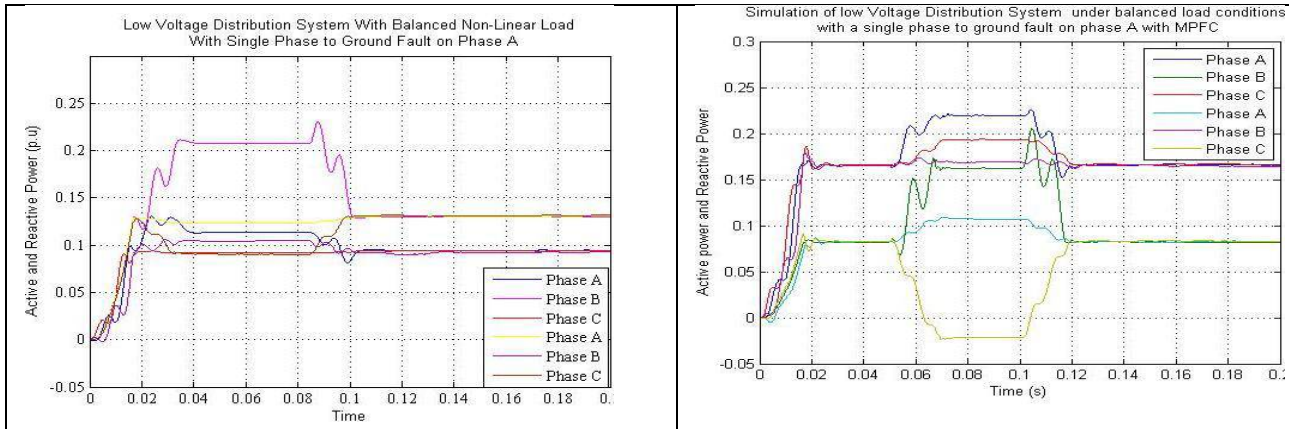


Fig.5.8 Power- Time characteristics without and with MPFC

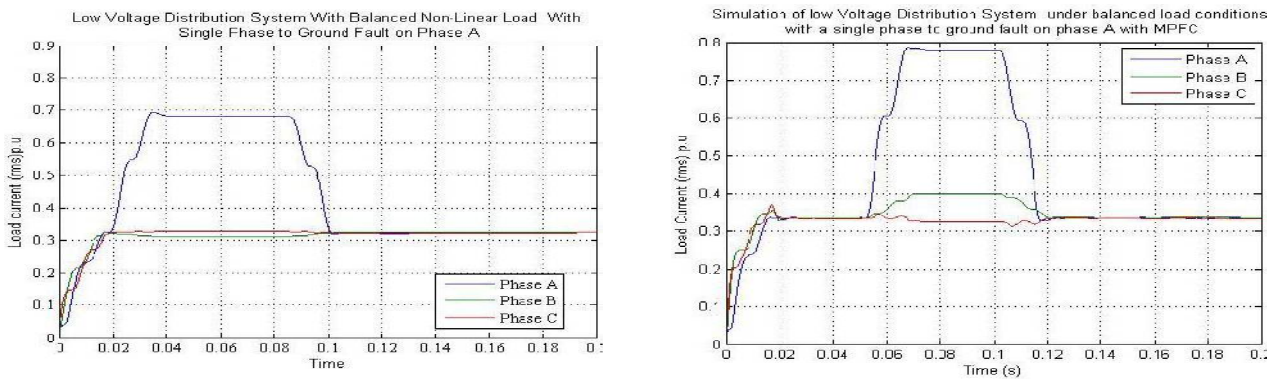


Fig.5.9 Current- Time characteristics without and with MPFC

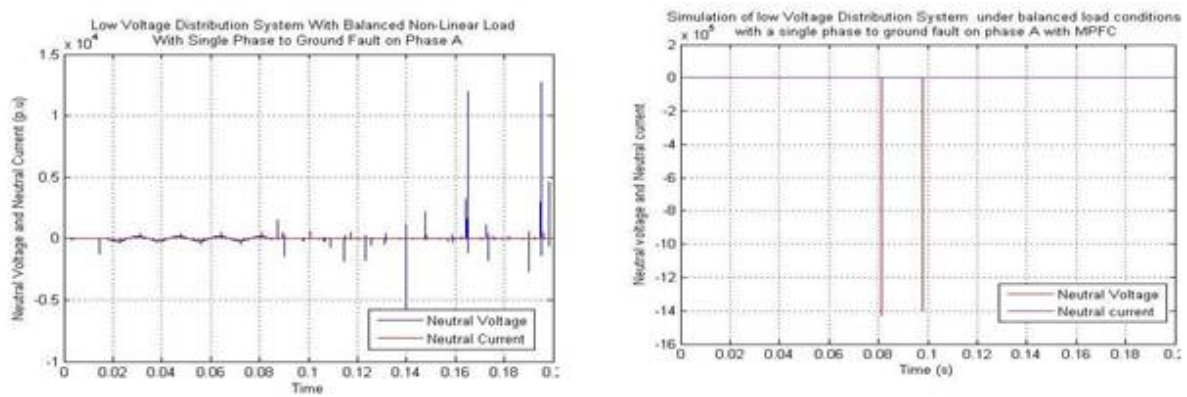


Fig.5.10 Neutral voltage and Neutral Current - Time characteristics without and with MPFC

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IV. CONCLUSIONS

The Modulated Power Filter (MPFC) device for voltage compensation of Low Voltage distribution systems under balanced / unbalanced, normal and fault conditions. This compensation device is regulated by a dynamic error driven tri-loop Slide mode Controller to reduce the effect of switching transients, faults and load disturbances in any existing commercial and large residential load centers. The simulation results show that the power factor can be effectively improved (from 0.5 to 0.9) In addition, the phase voltage can maintained around 1pu and the transient over-voltages and surge type inrush currents are also damped. For the balanced nonlinear load fault case, voltage sag caused by phase short circuited can also be compensated by this MPF. It is observed that the power factor is also increased from 0.5 to 0.8. MPF device with the Slide mode- controller developed is low cost and efficient Voltage stabilization and power factor correction device that also improve power quality and efficient-utilization of three phase –four wire Residential and Commercial Loads.

The performance of low voltage distribution system with unbalanced non-linear load with and without MPFC and low voltage distribution system with balanced non-linear load with single phase to ground fault on phase A with and without MPFC will be investigated and a compare study will be carried out. Thus it is implemented for bus voltage stabilization and effective energy utilization for standalone wind energy driven squirrel cage induction generator system..The controller is designed to ensure voltage stabilization and improve power utilization and power factor. The Modulated Power Filter Compensator (MPFC) and a Tri loop error driven sliding mode controller to achieve both stabilization and an improved power factor.simulation tests areperformed under different load conditions and satisfactory results are obtained showing the validity of the stabilization scheme for supplying electricity to remote areas such as isolated villages, heating, water pumping, ventilation and air conditioning.

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