Effect of Thyristor Based Modulated Power Filter Compensator on Power Quality

Laxmi Chand Sharma, Shiv Shanker Sharma, Devendra Mittal, Pushpendra Sharma

***Abstract*— The shunt capacitor and OLTC are jointly used to regulate voltage and reactive power flow at a substation which ultimately decide the stability of the power system. This paper also presents an overview of the state of the art in reactive power compensation technologies. The principles of operation, design characteristics and application examples of Var compensators implemented with thyristors and self-commutated converters are presented. Static Var generators are used to improve voltage regulation,stability, and power factor in ac transmission and distribution systems. Examples obtained from relevant applications describing the use of reactive power compensators implemented with new static Var technologies are also described.**

***Index Terms*— OLTC, Var compensators, transmission, distribution**

I. INTRODUCTION

Var compensationn is defined as the management of reactive power to improve the performance of ac power systems. The concept of Var compensation embraces a wide and diverse field of both system and customer problems, especially related with power quality issues, since most power quality problems can be attenuated or solved with an adequate control of reactive power . In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation the objectives are to increase the value of the system power factor, to balance the real power drawn from the ac supply, to compensate voltage regulation, and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads .Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line. Reactive power compensation in transmission systems also improves the stability of the ac system by increasing the maximum active power that can be transmitted. It also helps to maintain a substantially flat voltage profile at all levels of power transmission, it improves high-voltage dc (HVDC) conversion terminal performance, temporary over voltages , and can avoid disastrous blackouts .Series and shunt Var compensation are used to modify the natural electrical characteristics of ac power systems. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load . In both cases, the reactive power that flows through the system can be effectively controlled improving the performance of the overall ac power system. Traditionally, rotating synchronous condensers and fixed or mechanically switched capacitors or inductors have been used for reactive power compensation. However, in recent years, static Var compensators (SVCs) employing thyristor-switched capacitors (TSCs) and thyristor controlled reactors (TCRs) to provide or absorb the required reactive power have been developed .Also, the use of self-commutated pulse width modulation (PWM) converters with an appropriate control scheme permits the implementation of static compensators capable of generating or absorbing reactive current components with a time response faster than the fundamental power network cycle . Based on the use of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies, flexible ac transmission systems (FACTS) have been developed and represent a new concept for the operation of power transmission systems . In these systems, the use of SVCs with fast response times play an important role, allowing to increase the amount of apparent power transfer through an existing line, close to its thermal capacity, without compromising its stability limits. These opportunities arise through the ability of special SVCs to adjust the interrelated parameters that govern the operation of transmission systems, including shunt impedance, current, voltage, phase angle and the damping of oscillations. This paper presents an overview of the state of the art of static Var technologies. Static compensators implemented with thyristors and self-commutated converters are described. Their principles of operation, compensation characteristics and performance are presented and analyzed. A comparison of different Var generator compensation characteristics is also presented. New static compensators are also discussed.

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II. SINGLE-PHASE SERIES COMPENSATED NETWORK

This demonstration ilustrates frequency-domain and time-domain analysis of a series-compensated transmission system

2.1 Circuit Description

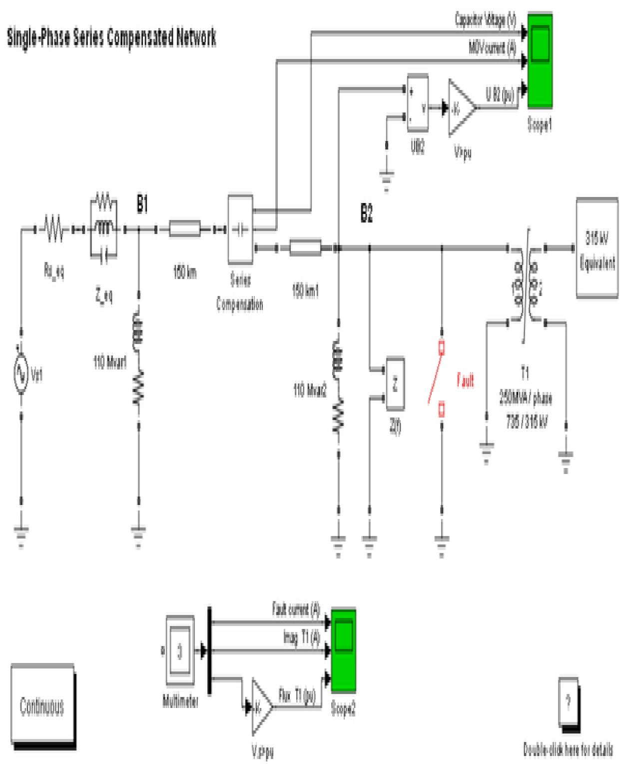


Fig.1 A 735 kV, 300 km line is used to transmit power from bus B1 (735 kV equivalent system) to bus B2 (315 kV equivalent). In order to simplify, only one phase of the system has been represented.

In order to increase the transmission capacity, the line is series compensated at its center by a capacitor representing 40% of the line reactance. The line is also shunt compensated at both ends by a 330 Mvar shunt reactance (110 Mvar /phase). Open the Series Compensation subsystem. Notice that the series capacitor is protected by a metal oxide varistor (MOV) simulated by the Surge Arrester block. The 250 MVA, 735 kV / 315 kV transformer is a Saturable Transformer block simulating one phase of the three-phase 750 MVA transformer. A Multimeter block is used to monitor the fault current as well as the flux and magnetizing current of the transformer.

2.2 Demonstration

To study the transient performance of this circuit when a 6-cycle fault is applied at node B2, Fault is simulated by the Breaker block. Switching times are defined in the Breaker block menu (closing at t = 3 cycles and opening at t = 9 cycles).

2.3 Frequency Analysis

In order to understand the transient behavior of this series-compensated network, a frequency analysis is first preformed by measuring the Impedance at node B2. This measurement is performed by the Impedance Measurement block connected at node B2. Open the Powergui and in the Tools menu select 'Impedance vs Frequency Mesurement'. Click on Display to compute and display the impedance for the 0 - 500 Hz range. The impedance curves show two main parallel resonances (impedance maxima and phase inversion), corresponding to 15 Hz and 300 Hz modes. The 15 Hz mode is due to a parallel resonance of the series capacitance and the two shunt reactances. The 300 Hz mode is mainly due to resonance of shunt line capacitance and series reactance of the transmission system. These two modes are likely to be excited at fault clearing.

2.4 Time Domain Simulation - Fault at Bus B2

Start the simulatiom and observe waveforms on the two Scopes. At t = 3 cycles, a line-to-ground fault is applied and the fault current reaches 10 kA (trace 1 of Scope2). During the fault, the MOV conducts at every half cycle (trace 2 of Scope1) and the voltage across the capacitor (trace 1 of Scope1) is limited to 263 kV. At t = 9 cycles, the fault is cleared. The 15 Hz mode is clearly seen on the capacitor voltage (trace 1 of Scope1) and bus B2 voltage (trace 3 of Scope1). During fault the flux in the transformer is trapped to around 1 pu. At fault clearing the flux offset and 15 Hz component cause transformer saturation (flux > 1.2 pu, trace 3 of Scope2), producing magnetizing current pulses (trace 2 of Scope2).

III. Three-Phase Series Compensated Network

This demonstration ilustrates use of three-phase blocks to study transients on a series-compensated 735-kV transmission system

3.1 Circuit Description

A three-phase, 60 Hz, 735 kV power system transmitting power from a power plant consisting of six 350 MVA generators to an equivalent network through a 600 km transmission line. The transmission line is split in two 300 km lines connected between buses B1,B2, and B3. In order to increase the transmission capacity, each line is series compensated by capacitors representing 40% of the line reactance. Both lines are also shunt compensated by a 330 Mvar shunt reactance. The shunt and series compensation equipments are located at the B2 substation where a 300 MVA 735/230 kV transformer with a 25 kV tertiary winding feeds a 230 kV, 250 MW load. The series compensation subsystems are identical for the two lines. For each line, each phase of the series compensation module contains the series capacitor , a metal oxide varistor (MOV) protecting the capacitor, and a parallel gap protecting the MOV. When the energy dissipated in the MOV exceeds a threshold level of 30 MJ, the gap simulated by a circuit breaker is fired. CB1 and CB2 are the two line circuit breakers .

The generators are simulated with a Simplified Synchronous Machine block. Universal transformer blocks (two-windings and three-windings) are used to model the two transformers. Saturation is implemented on the transformer connected at bus B2. Voltages and currents are measured in B1, B2, and B3 blocks. These blocks are Three-phase V-I Measurement blocks where voltage and current signals are sent to the Data Acquisition block through Goto blocks.

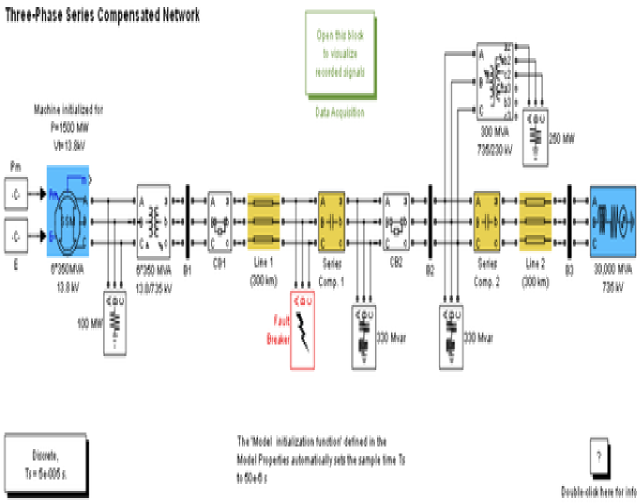


Fig. 2 Single Line Diagram of Radial Utilization System

3.2 Fault and Line Switching

To study the transient performance of this circuit when a line-to-ground and three-phase-to-ground faults are applied on line 1, The fault and the two line circuit breakers CB1 and CB2 are simulated with blocks from the three-phase library. Open the dialog boxes of CB1 and CB2. See how the initial breaker status and switching times are specified. A line-to-ground fault is applied on phase A at t = 1cycle. The two circuit breakers which are initially closed are then open at t = 5 cycles, simulating a fault detection and opening time of 4 cycles. The fault is eliminated at t = 6 cycles, one cycle after line opening.

3.3 Demonstration

Notice that this system contains the Powergui block. In addition, when you start the system the 'power_3phseriescomp' model, the sampling time Ts = 50e-6 is automatically set in your workspace. The system is therefore be discretized using a 50 microseconds sample time.

3.4 Line-to-Ground Fault

Double click the Data Acquisition block and open the three scopes. Start the simulation. As the system has already been initialized (1500 MW generation at the 13.8 kV bus) with the Lod Flow utility of the Powergui, the simulation starts in steady state. At t = 1 cycle a line-to-ground fault is applied and the fault current reaches 10 kA . During the fault, the MOV conducts at every half cycle and the energy dissipated in the MOV builds up to 13 MJ. At t = 5 cycles the line protection relays (not simulated) open breakers CB1 and CB2 and the energy stays constant at 13 MJ. As the maximum energy does not exceed the 30 MJ threshold level, the gap is not fired. After breaker opening the fault current drops to a small value and the line and series capacitance start to discharge through the fault and the shunt reactance. The fault current extinguishes at the first zero crossing after the opening order given to the fault breaker (t = 6 cycles). Then, the series capacitor stops discharging and its voltage oscillates around 220 kV .

3.5 Three-Phase-to-Ground Fault

Change the fault type to a three-phase-to-ground fault by checking Phases A, B, and C in the Fault Breaker block. Restart the simulation. Notice that during the fault the energy dissipated in the MOV builds up faster that in the case of a line-to-ground fault. The energy reaches the 30 MJ threshold level after 3 cycles, one cycle before opening of the line breakers. As a result, the gap is fired and the capacitor voltage quickly discharges to zero through the damping circuit.

IV. Simulation Models

Grid electricity is generally distributed as three phase balanced voltage waveforms forming the common 3-phase sinusoidal AC system. One of the characteristics of the AC system is its sinusoidal voltage waveforms, which must always remain as close as possible to that of a pure sine-wave. If it is distorted beyond certain acceptable limits, as is often the case on power source networks comprising nonlinear type loads, the supply waveform must be cleaned and corrected. The distorted waveform is usually composed of a number of dominant sine waves of different harmonic frequencies, including the fundamental one at the 60 Hz. power frequency, referred as the fundamental frequency, and the rest is referred to as the "integral harmonic ripple component" with frequencies which are multiple of that of the fundamental. Harmonic effective quantities are generally expressed in terms of their RMS-value since the heating or loss effect depends on this total sum squared value of the distorted waveform.

V. System Models

Figure depicts the single line diagram of radial utilization system feeding a nonlinear type load. The load bus is connected to the switched/modulated Smart Power Filter (SMPF). SMPF can be used to improve electric supply power quality by reducing harmonic content in supply current by minimizing waveform distortion, notching and voltage fluctuations (swell, sag). Rs and Ls represent the equivalent source transformer feeder resistance and inductance. and represent the supply and load voltage respectively.

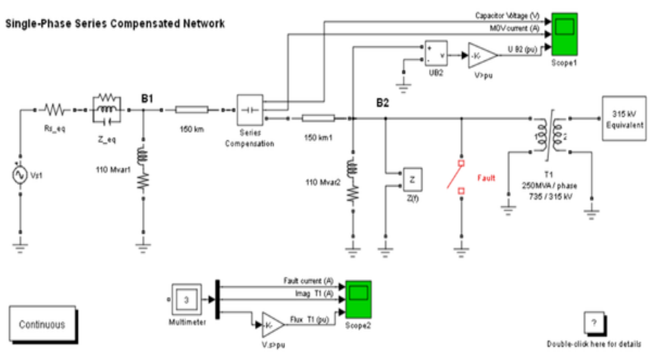


Fig. 3 Single Line Diagram of Radial Utilization System

When Load Is Linear

This case addresses the power quality enhancement scheme using modulated power filter compensator. The use of the switched modulated power filter compensator is to enhance power quality in low voltage distribution systems under unbalanced and fault conditions. The simulation results are shown and are done with and without the modulated power compensating filter. The software used in this case is the Matlab/Simulink.

The Modulated power filter is controlled by a dynamic tri-loop controller. The purpose of this dynamic controller is to minimize switching transients, maximize power/energy utilization and to improve power factor under unbalanced load and fault conditions. The major components of the AC system are: Three phase-four wire AC power supplies; Novel Modulated power Filter; Tri -loop dynamic error driven error controller and Single phase load.

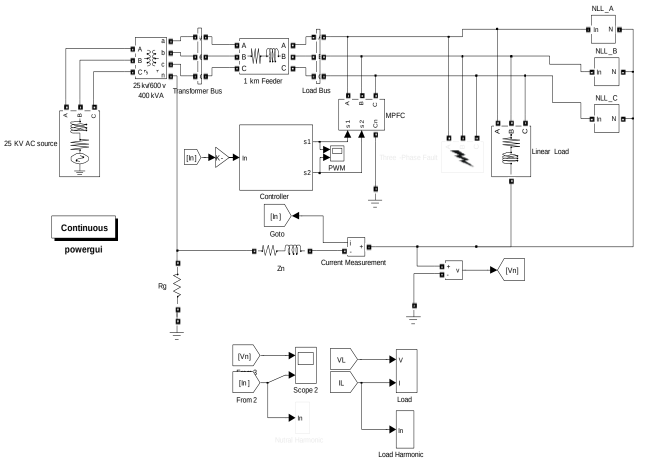


Fig. 4 Matlab- Simulink functional model of the 3Phase-4 Wire Model

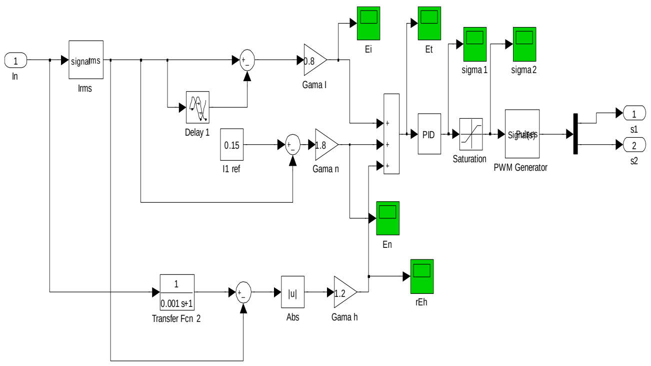


Fig. 5 Tri loop dynamic Variable structure-sliding mode control Scheme

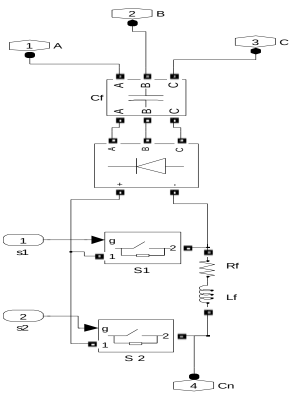


Fig. 6 Modulated Power Filter Compensator Scheme

Without Filter Compensation

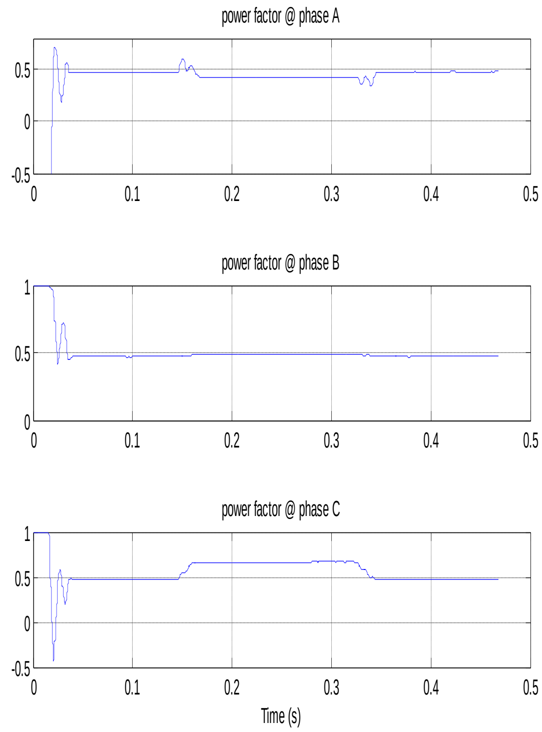


Fig 7 Load Power Factor without compensation

With Filter Compensation

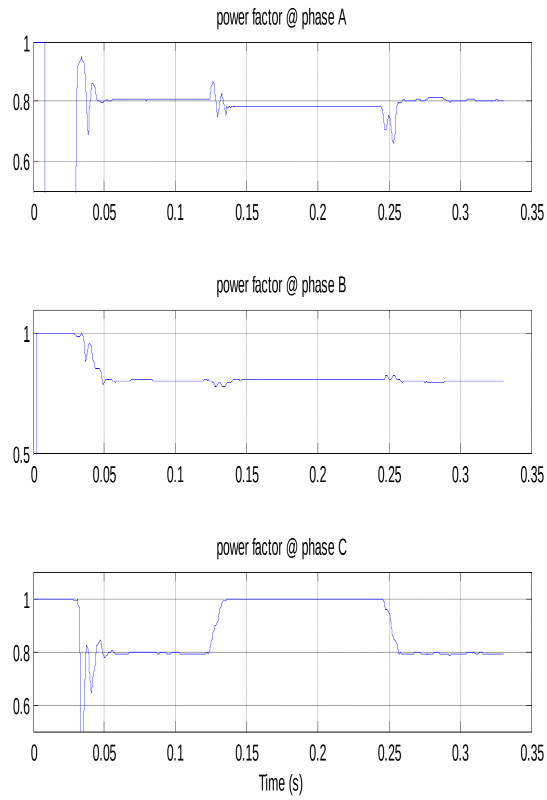


Fig 8 Load Power Factor with compensation

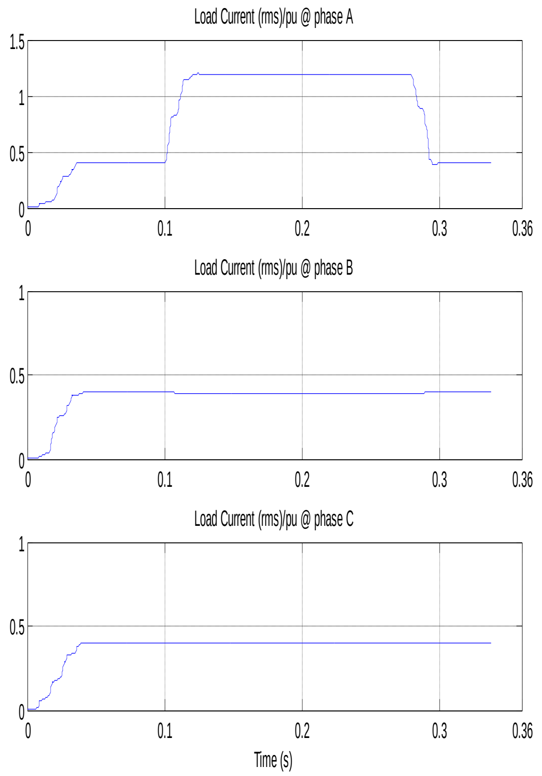


Fig 9 Load current without compensation

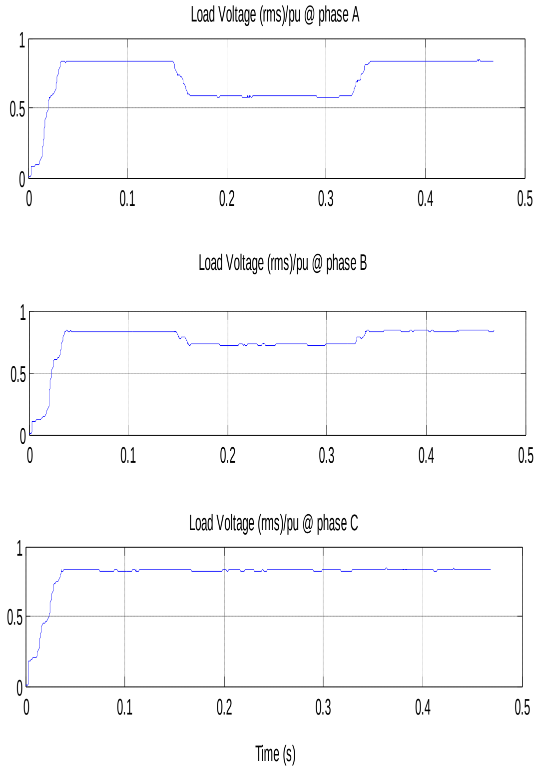


Fig 11 Load voltage without compensation

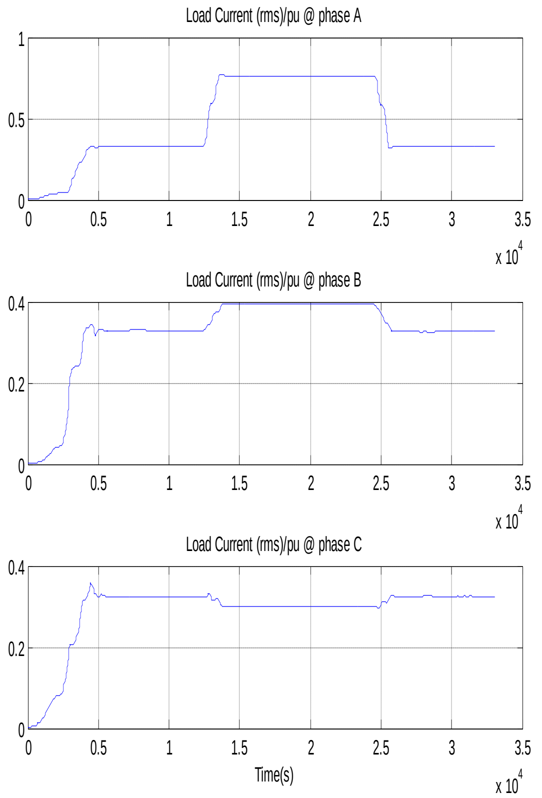


Fig 10 Load current with compensation

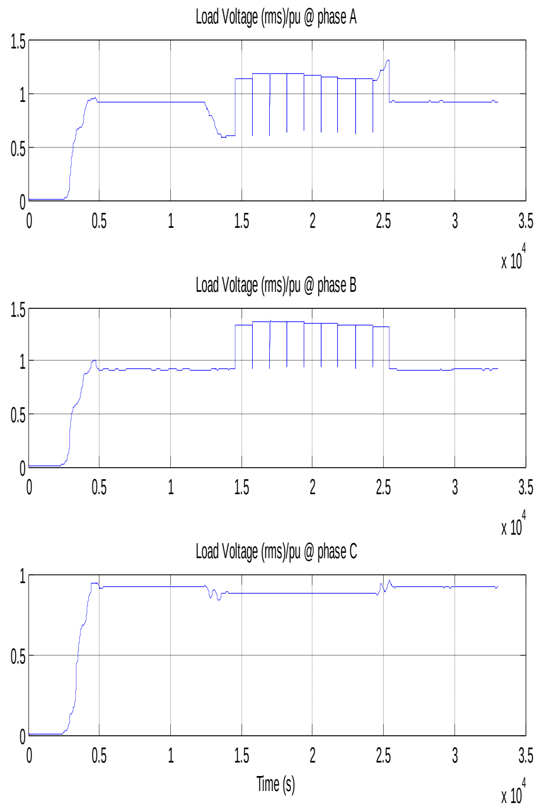


Fig 11 Load voltage with compensation

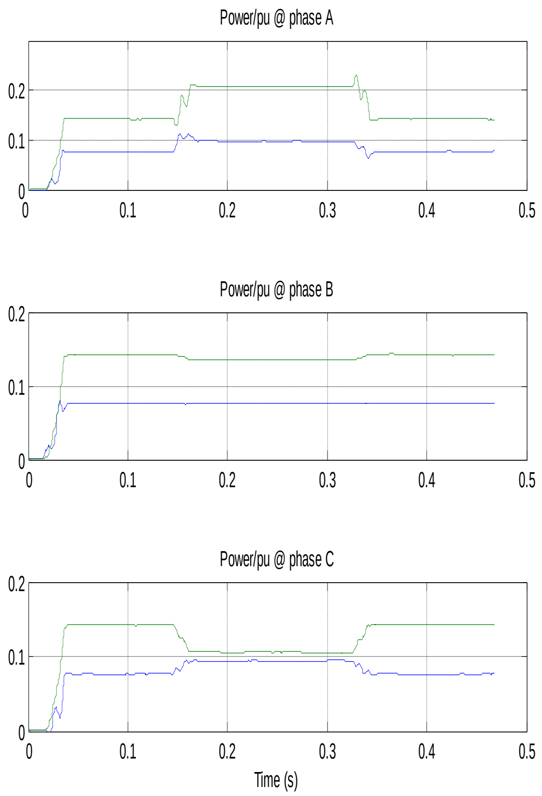


Fig 11 Load power without compensation

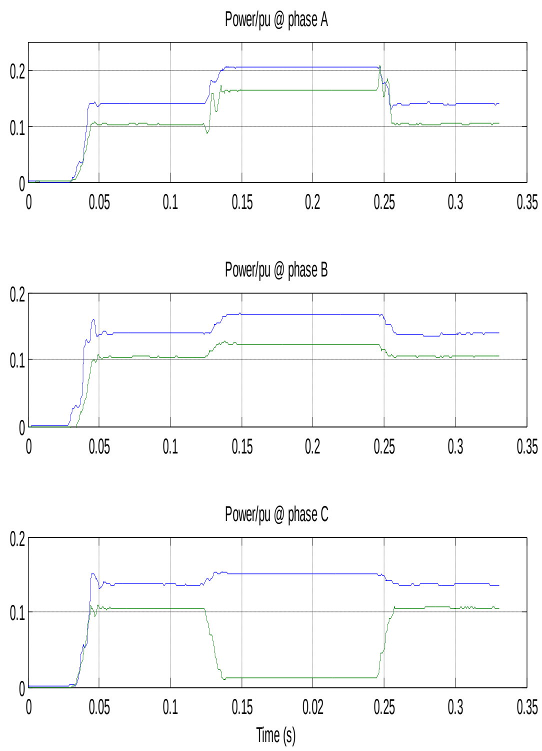


Fig 12 Load power with compensation

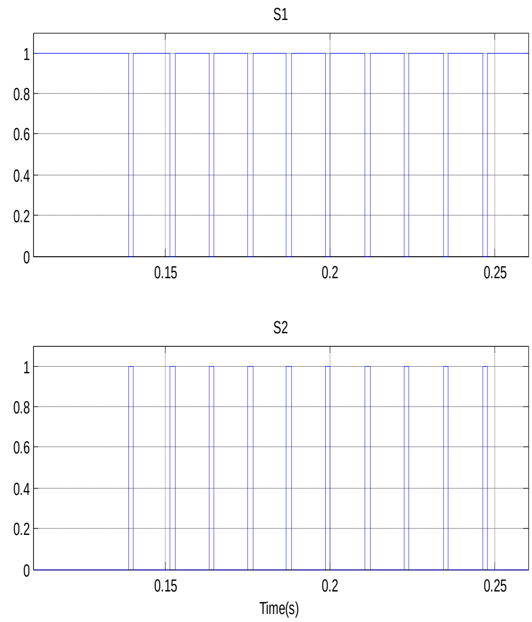


Fig 13 Compensator S1 and S2

VI. When Load Is Not Linear

This case addresses another power quality enhancement scheme also using modulated power filter compensator. This case presents a novel dynamic voltage regulator Power filter and capacitor correction compensator scheme to enhance power utilization and improve power quality in low voltage distribution systems under the nonlinear load conditions. The modulated power filter is controlled by a dynamic tri-loop error driven PID controller. The purpose of this dynamic hybrid Tri-functional compensator is to minimize feeder switching transients, maximize power/energy utilization and to improve power factor under unbalanced load and fault conditions. The functional MATLAB/SIMULINK model of a radial distribution system with the proposed dynamic hybrid reactive power compensation scheme is presented.

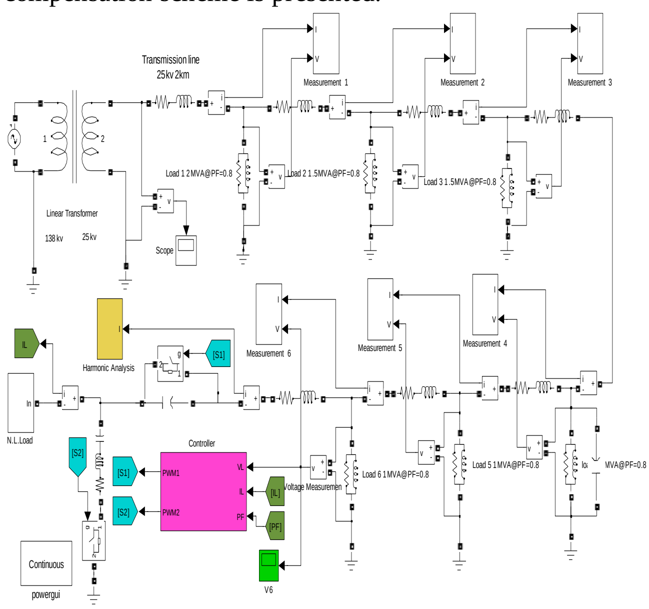


Fig 14 Simulink model of the radial distribution system with the non- linear load

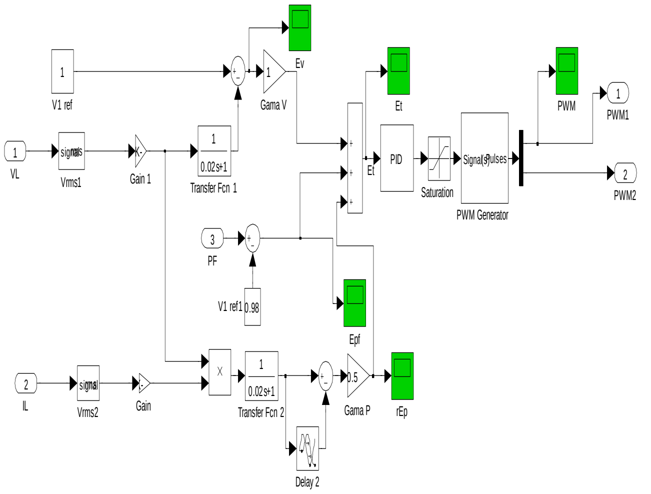
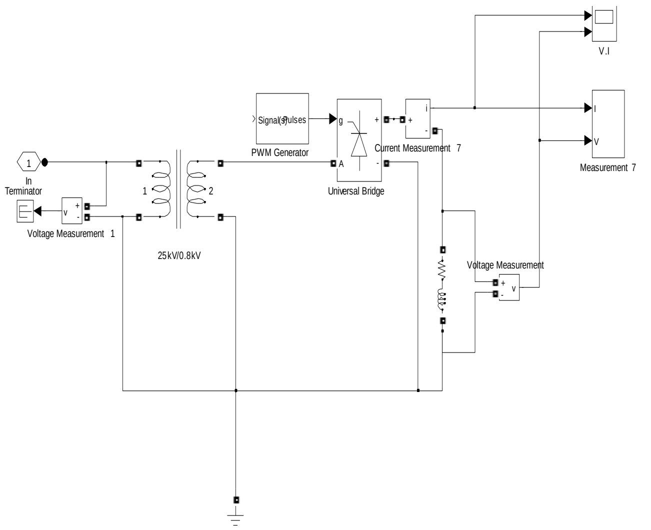


Fig 15 Dynamic Tri-loop error driven PID controller



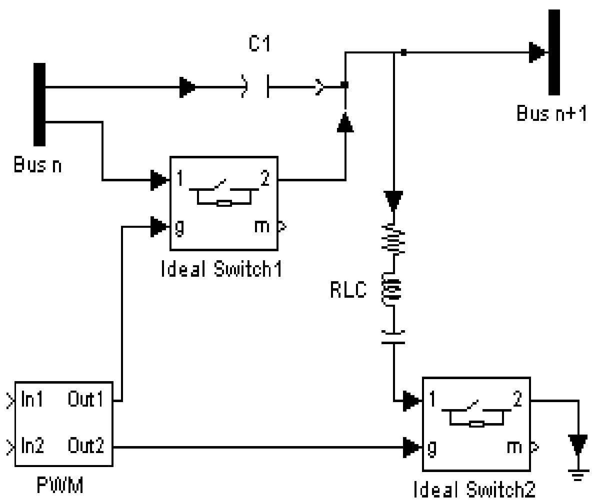
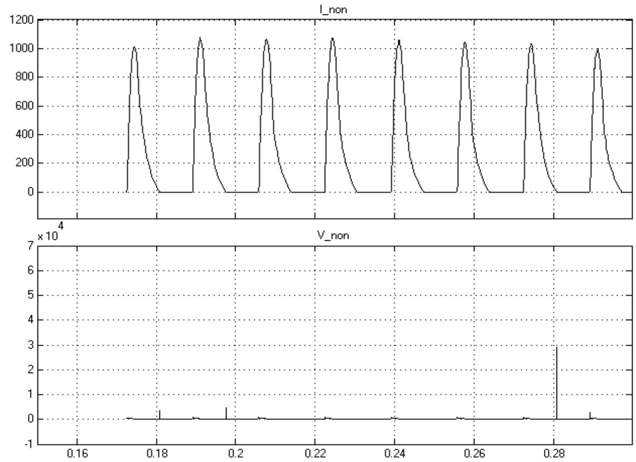
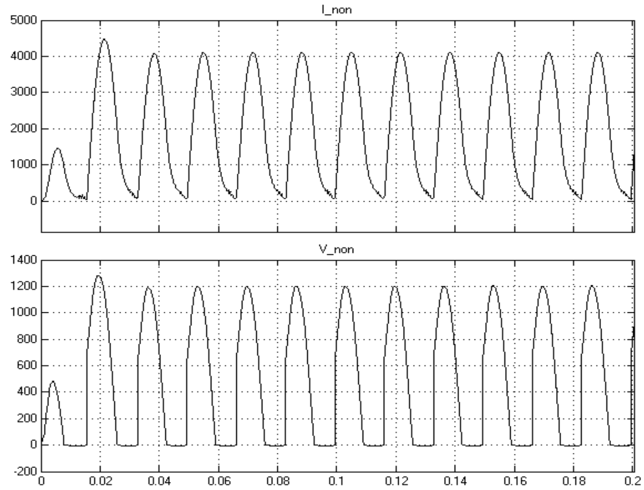


Fig 16 Compensation Switching

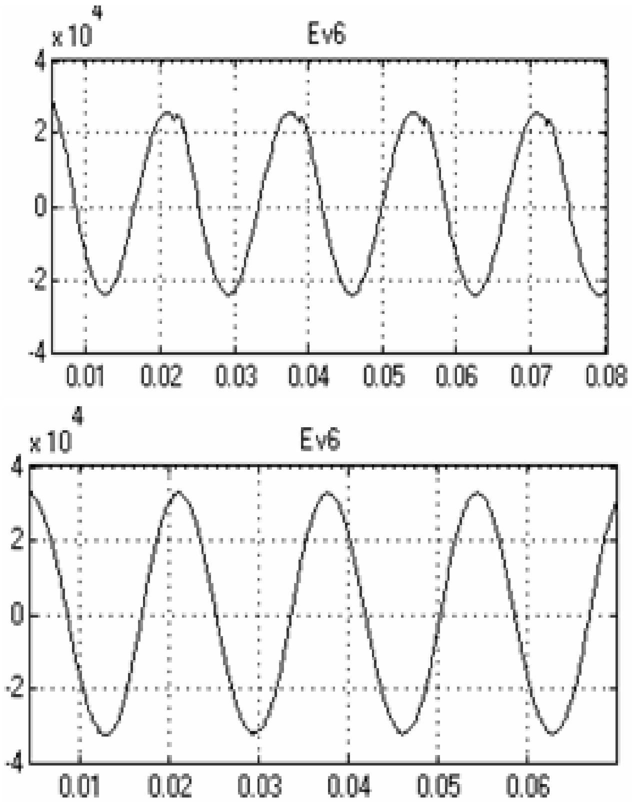
Without Filter Compensation and With Filter Compensation



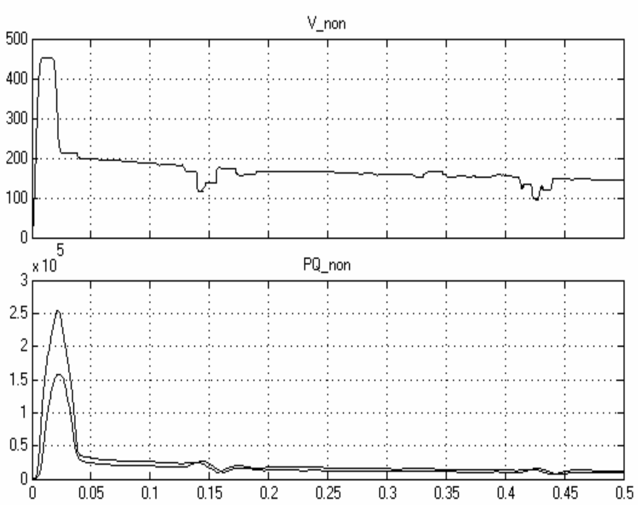
Current and voltage waveforms of the nonlinear load without compensation



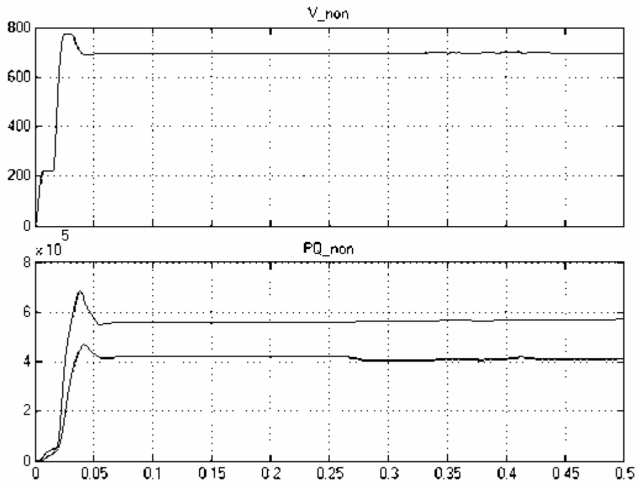
Current and voltage waveforms of the nonlinear load with compensation



Voltage waveforms of the linear load without compensation



Voltage waveforms of the linear load with compensation



Voltage waveforms and P-Q profile without and with compensation

VII. CONCLUSION

Reactive power compensation is shown in this paper using a single phase equivalent diagram and a three phase equivalent network diagram with a series compensator. Simulation is also done for linear and non linear loads and the outcomes of power, voltage and current is shown with the help of simulated waveforms in Matlab . Power quality is enhanced with the use of modulated power filter compensator.

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