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A Novel Design of Modulated Switched Filter Compensator (MSFC) Scheme for the Power Quality Improvement of Smart Grid.

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ABSTRACT: ***The paper proposes Modulated Switched Filter Compensator (MSFC) devices for distribution system voltage and reactive power compensation by using renewable energy sources like wind energy system (WES). The Modulated Power Filter Compensator is having advantages of good power quality improvement, voltage stabilization, less harmonics, efficient operation and reduced switching devices. A novel modified PID controller with Asymmetrical Switched Pulse Width Modulation (ASPWM) for MSFC devices for enhancing of dynamic performance of power system. Wind energy system is having wide range of transient conditions including wind fluctuations. The paper presents the application of Multi Objective Particle Swarm Optimization (MOPSO) technique in online optimal modified PID controller gain adjusting that dynamically minimizes the global dynamic error. The MATLAB simulation models of the proposed MSFC scheme have been verified.***

Key words – modulated Switched filter compensator (MSFC), Particle Swarm Optimization (PSO), Wind Energy System (WES), Power Quality compensation, Smart Grid.

INTRODUCTION

The growing demand for renewable and green energy (Wind, Solar, PV, Wave, Tidal, Fuel Cell, Biogas, Hybrid ...) is motivated by economic viability and environmental concerns. The increasing reliance on fossil fuels with the accelerating rate of resource depletion is causing a strategic shift to energy conservation, clean fuel replacement and energy displacement of all or part of conventional sources to green and renewable energy sources [1-2]. By 2020, it is expected that the wind power generation will supply around 12% of the total world electricity new demands. However, integration of such wind resources into the power system grids has caused new and persisted challenges to security, control, reliability, power quality and stability of modern electric power systems. The more critical aspect is the voltage stability and power quality of the power network [3-4]. Connecting a wind turbine with an induction generator directly to the transmission network without proper compensation and control can be troublesome. Dynamic control of the wind system that generates power from a stochastically varying prime mover input such as the wind presents control and stabilization challenges. The wind speed varies from time to time due to gusts and is further disturbed by the effect of supporting tower shadow [5].

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The paper has a focus on wind power efficient utilization that meets performance and economic requirements for successful integration of large wind generation units into the power grid. A new stabilization control strategy which uses novel FACTS filter compensator devices is presented to dynamically ensure voltage regulation and energy utilization. SFC FACTS devices can provide fast active and reactive power compensations and voltage support as well as efficient utilization.

The FACTS based dynamic switched power filter compensator is expected to provide:

- Power factor improvement (at the generator and load sides).
- Reduction in transient over voltage during short circuit as well as safe neutral by eliminating hot grounds.
- Improved damping of transient conditions.
- Efficient wind energy Utilization.

Time-domain simulations using MATLAB/SIMULINK under various disturbance conditions including wind gusts and three-phase fault at the generator terminal, illustrate the effectiveness and robustness of the optimized MOPSO. The new MOPSO proposed controller offers significant improvement in terms of damping of power system oscillations in comparison with the conventional controller previously designed using fixed gains. MOPSO search and gain optimization techniques are used to adjust the control gains and settings to minimize each controller total absolute error. This control scheme is extremely effective in ensuring voltage stabilization and enhancing power/energy utilization under severe load and wind prime mover/wind velocity excursion. The proposed switched dynamic power filter compensator with the self regulating dynamic error driven controller is an attractive and viable solution for dynamic voltage stabilization, power factor correction, power quality enhancement , efficient-utilization, and loss reduction for distribution and utilization electric grid feeders.

WIND-FACTS SCHEME

The typical circuit diagram of FACTS controller interfaced with wind energy conversion system is shown in figure 1. A suirrel-cage permanent magnet synchronus machine is connected to rotor. Switched filter compensated FACTS device is having different schemes. The objectives of filter schemes are as follows:

- Harmonic reduction and power quality enhancement;
- Electric power/energy savings and
- Dynamic reactive compensation for the wind system.

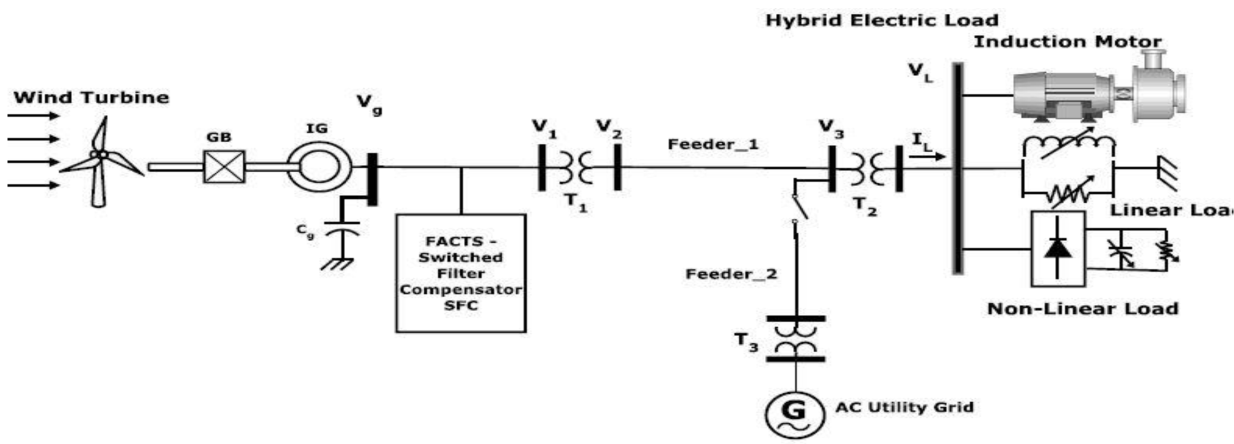

Figure 1: The proposed (Wind-FACTS) energy utilization system

The proposed tri-loop dynamic tracking controller to provide Better voltage stabilization, improved power quality, Interface security, efficient utilization, minimum harmonics levels and energy loss minimization of electricity networks. The proposed Modulated Switched Filter Compensator (MSFC) scheme is shown in figure 2. The proposed tri-loop controller block diagram is shown in figure 3.

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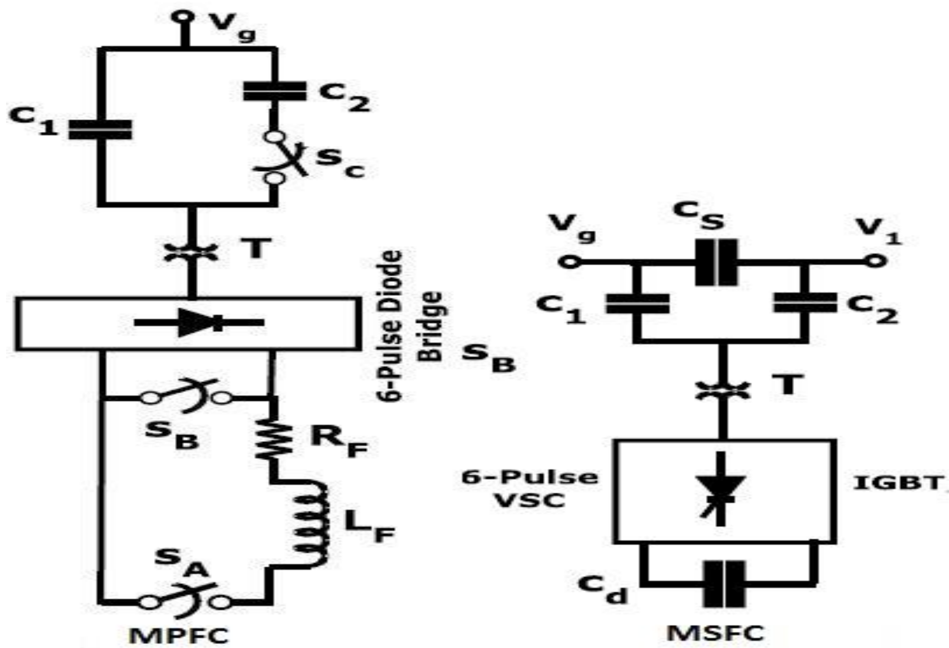
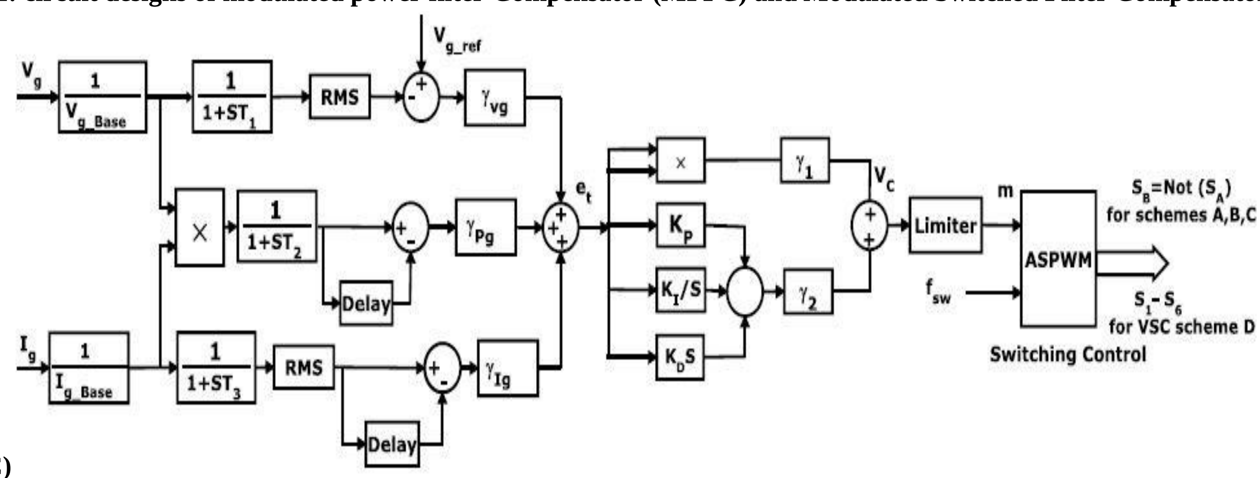


Figure 2: circuit designs of modulated power filter Compensator (MPFC) and Modulated Switched Filter Compensator



(MSFC)

Figure 3: proposed tri-loop controller with global signal generator

The novel PSO and GA self tuned multi regulators and coordinated controller are used. The global error is the summation of the three loop individual errors including voltage stability, current limiting and synthesize dynamic power loops. The multi loop dynamic control scheme is used to reduce a global error based on a tri-loop dynamic error summation signal in addition to other supplementary motor current limiting and dynamic power loops are used as auxiliary loops to generate a dynamic global total error signal that consists of not only the main loop speed error but also the current ripple, over current limit and dynamic over load power conditions.

To compare the global performances of all controllers, the Normalized Mean Square Error (NMSE) deviations between output plant variables and desired values (in this paper the

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generated voltage Vg is the output variable and Vg-ref is the desired generated voltage), and NMSE_Vg is defined as:

$$NMSE\_V_g = \frac{\sum (V_g - V_{g-ref})^2}{\sum (V_{g-ref})^2} \qquad - (1)$$

A number of conflicting objective functions are selected to optimize using the MOGA/MOPSO algorithms. These functions are defined by the following:

J1 = Minimize the Total Harmonic Distortion of the Load current (THD_i) - (2)

J2 = Minimize the Total Harmonic Distortion of the Load Voltage (THDv) - (3)

J3 = Maximize the electric energy efficiency - (4)

J4 = Maximize the Power factor - (5)

J5 = Minimize the NMSE_Vg of the generated voltage - (6)

Basically, the PID controller having three control actions. They gives better performance and easy to develop. The tuning of the PID controller gains are complex because of iterative nature. First, it is necessary to tune the "Proportional" mode, then the "Integral", and then add the "Derivative" mode to stabilize the overshoot, then add more "Proportional", and so on. The proposed modified weighted PID controller has the following form in the time domain:

$$u(t) = \gamma_1 \left[K_P e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt}\right] + \gamma_2 [e(t)]^2 \qquad - (7)$$

Here e(t) is the system error, u(t) the control variable, K_P the proportional gain, K_I the integral gain, and K_D is the derivative gain. Each coefficient of the PID controller adds some special characteristics to the output response of the system.

MULTI –OBJECTIVE OPTIMIZATION

The general MO problem requiring the optimization of N objectives may be formulated as follows [6-7].

Chromosome Representation

The search and gain optimization techniques are used to adjust the control gains and settings to ensure voltage stabilization and enhancing power/energy utilization under severe load and wind prime mover/wind velocity excursion. It is important to select appropriate optimal variables for optimization process and WECS optimal performance. We select ten variables for genetic algorithm optimization, which correlate closely with the fundamental WECS operation. Five variables define the gains of the proposed modified weighted PID controller (KP, KI, KD, g1, g2). Other five variables define the selected objective functions (J1, J2, J3, J4, and J5). The first work to operate the genetic algorithm for WECS optimization problem is to choose the appropriate chromosome representation, which represents the potential solution to control strategy. Chromosome representation describes each individual of the population in genetic algorithm. Based on the selected objective functions and optimization variables, we define the chromosome with the following genes. According to the multi objective genetic algorithm, the computational procedure to optimize the specific cycles is listed as follows:

a) Initialization: Set the initial values of six parameters for genetic algorithm, including

- The maximal number of generations,
- The population size,
- The generation number,
- The crossover probability,
- The mutation probability,
- The constraint parameters.

b) Evaluation of fitness function. Compute the fitness value for each chromosome in each generation. After validating by the constraints, record and modify the 'best" chromosome to the next generation, update the archive vector of Pareto optimal solutions.

c) Reproduction: Compute the reproduction probability and the cumulative probability. Generate a random number r in [0, 1] according to uniform distribution. Operating the reproduction process will produce a new generation.

d) Crossover: For each selected pair, apply a crossover operation to generate two new strings. Generate a random number in [0, 1] according to uniform distribution in turn. Set up a parent chromosome population. Select two chromosomes in the parent chromosome population and a breakpoint for each chromosome in random. Crossover the two chromosomes, save the new chromosome and delete the parents from the population.

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Operate the crossover process until all of parent chromosomes are computed with crossover.

e) Mutation: Mutation increases the diversity of the population by introducing random variation to the population.

f) Finish Condition If the present generation number equals to the maximal number of generations, optimization processes of genetic algorithm finish and the optimal operation parameters come into being.

Multi-Objective Particle Swarm Optimization

The system initially has a population of random selective solutions. Each potential solution is called a particle. Each particle is given a random velocity and is flown through the problem space. The particles have memory and each particle keeps track of its previous best position (called the Pid) and its corresponding fitness. There exist a number of Pid for the respective particles in the swarm and the particle with greatest fitness is called the global best (Pgd) of the swarm. The basic concept of the PSO technique lies in accelerating each particle towards its Pid and Pgd locations, with a random weighted acceleration at each time step. In MOPSO [8], a set of particles are initialized in the decision space at random. For each particle i, a position xi in the decision space and a velocity vi are assigned. The particles change their positions and move towards the so far best-found solutions. The non-dominated solutions from the last generations are kept in the archive. The archive is an external population, in which the so far found non-dominated solutions are kept.

MODIFIED PID CONTROLLER

The tri-loop error-driven dynamic controller is a novel dual action control used to modulate the power filter compensator. The input of the PID controller is global error signal and is generates modulating control signal for PWM switching generator. Simulation circuits of the global error signal generator and Tri-loop PID controller is shown in figure 4.

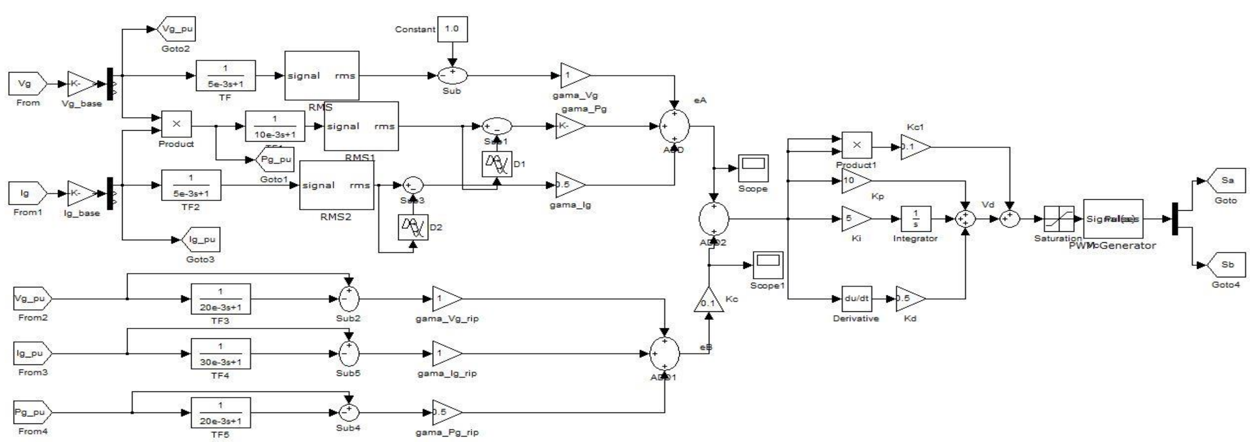

Figure4: simulation diagram for global error signal generator with PID controller

SIMULATION RESULTS

The proposed FACTS devices performance is compared for two cases; Matlab-Simulink Software was used to design, test, and validate the effectiveness of the FACTS devices to minimize network losses while satisfying the grid code connection requirement for reactive power control. The control system comprises a dynamic multi loop error driven regulator is coordinated to minimize the selected objective functions.

Case 1 (Normal Loading Operation):

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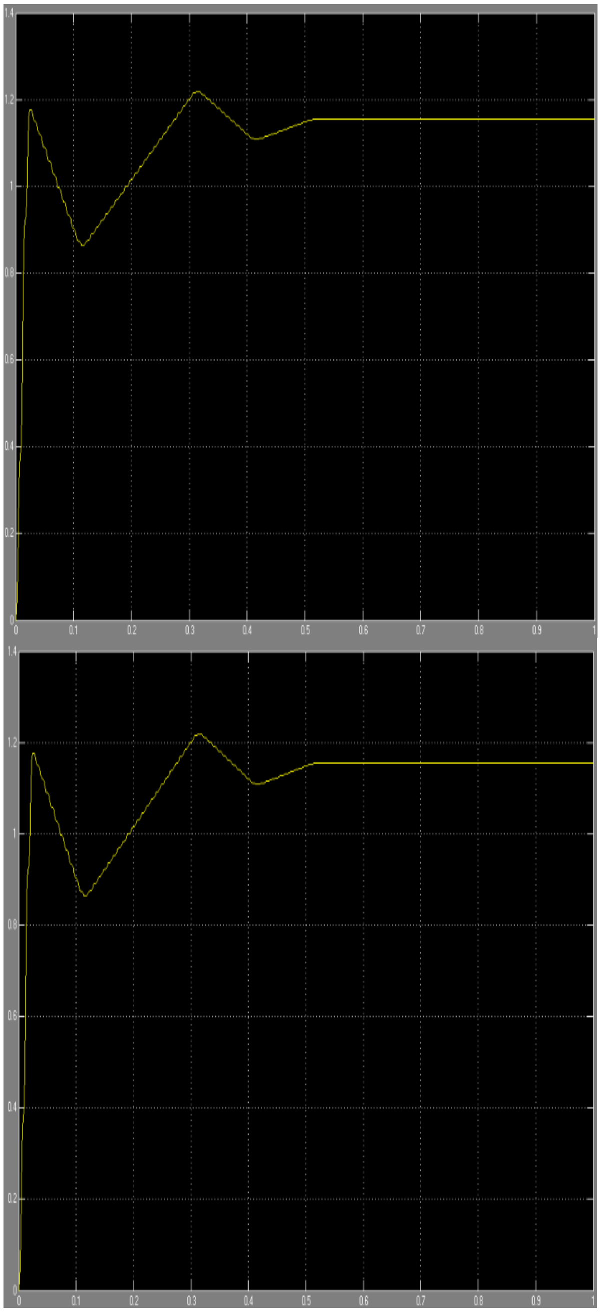

Figure: The RMS voltage at AC buses (generator and load) under normal operation.

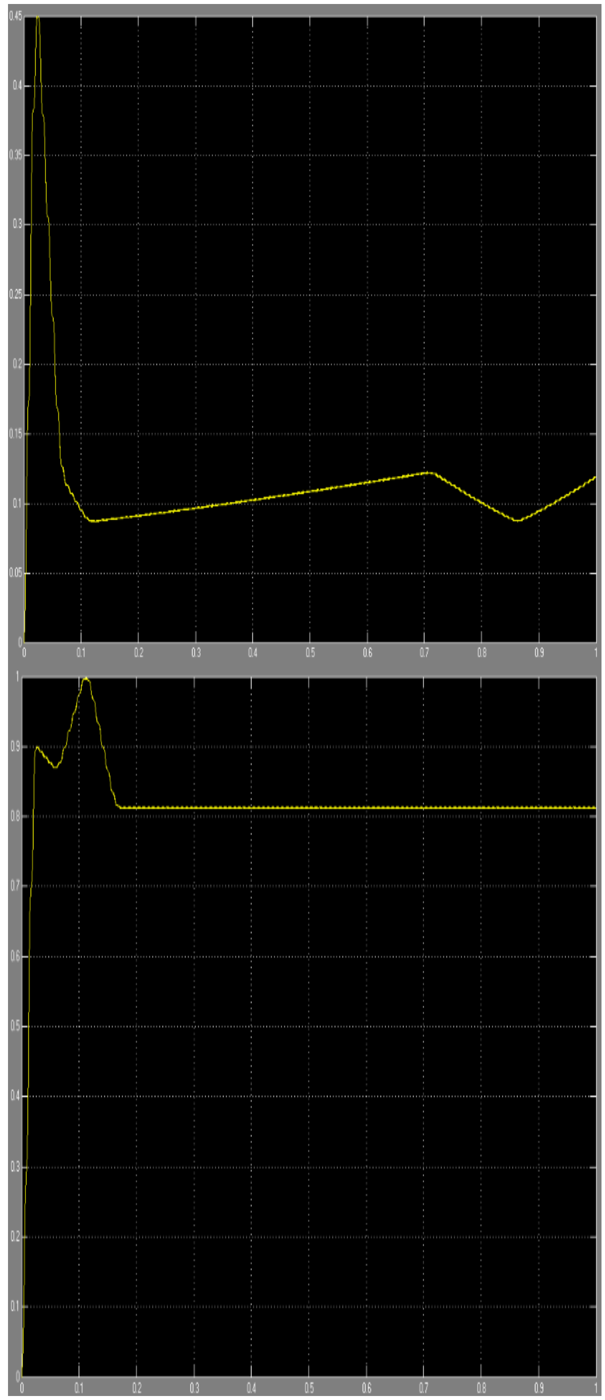

Figure: The RMS current at AC buses (generator and load) under normal operation

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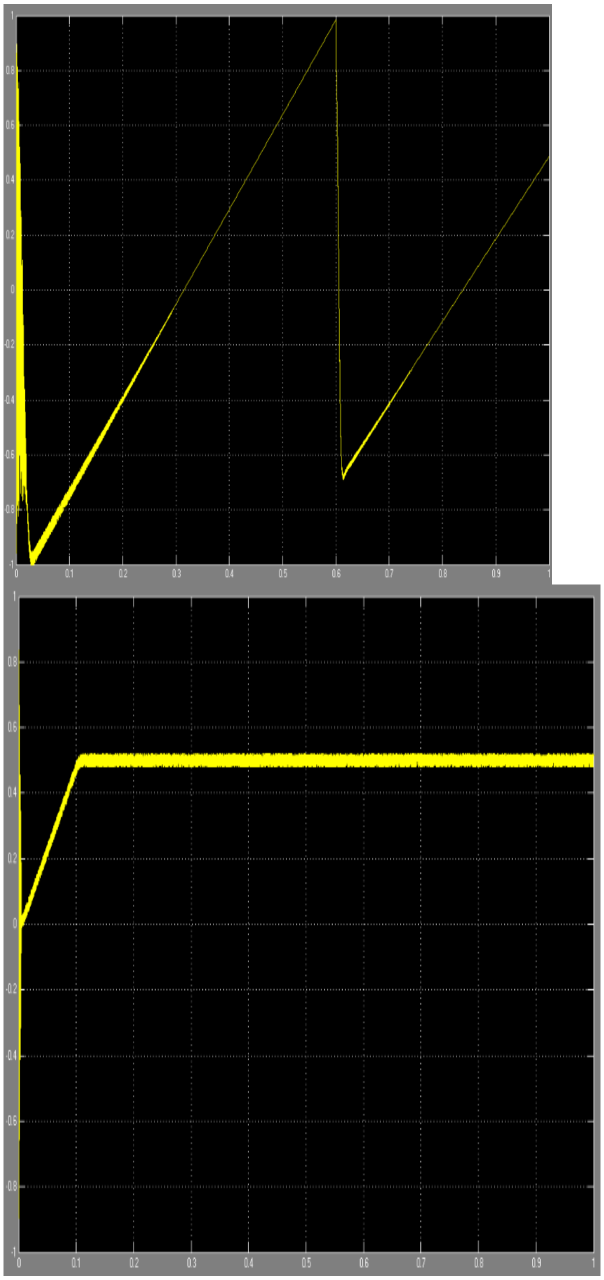

Figure: The reactive power at AC buses (generator and load) under normal operation

Case 2 (Short Circuit Fault Condition):

A three phase short circuit (SC) fault is occurred at bus Vs for a duration of 0.1sec, from t = 0.2 sec to t= 0.3 sec.

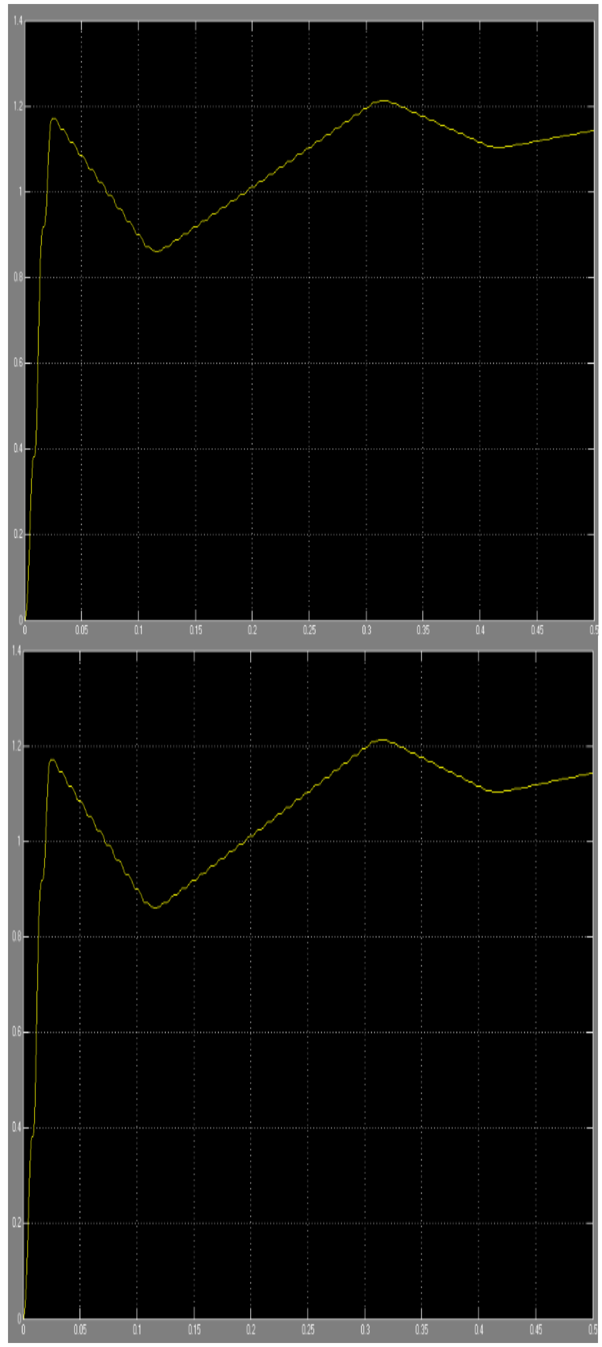

Figure: The RMS voltage at generator and load buses under short circuit (SC) fault condition at bus Vs.

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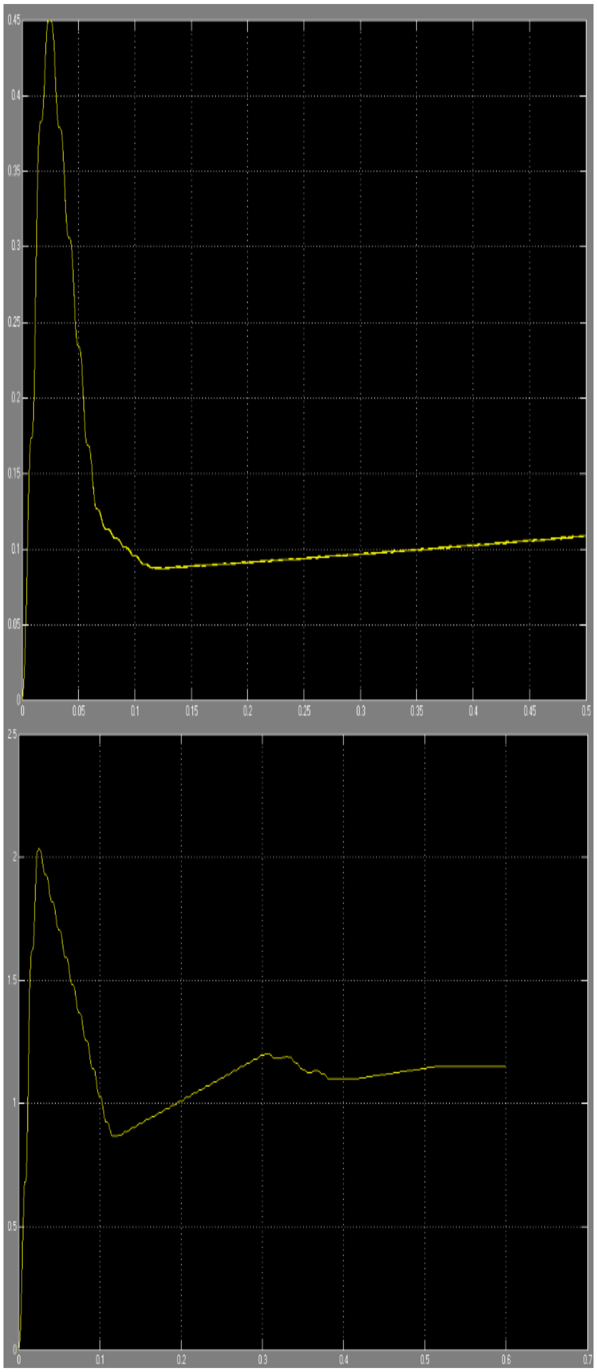


Figure : The RMS current at generator and load buses under short circuit (SC) fault condition at bus Vs.

Case 3 (Hybrid Local Load Excursions):

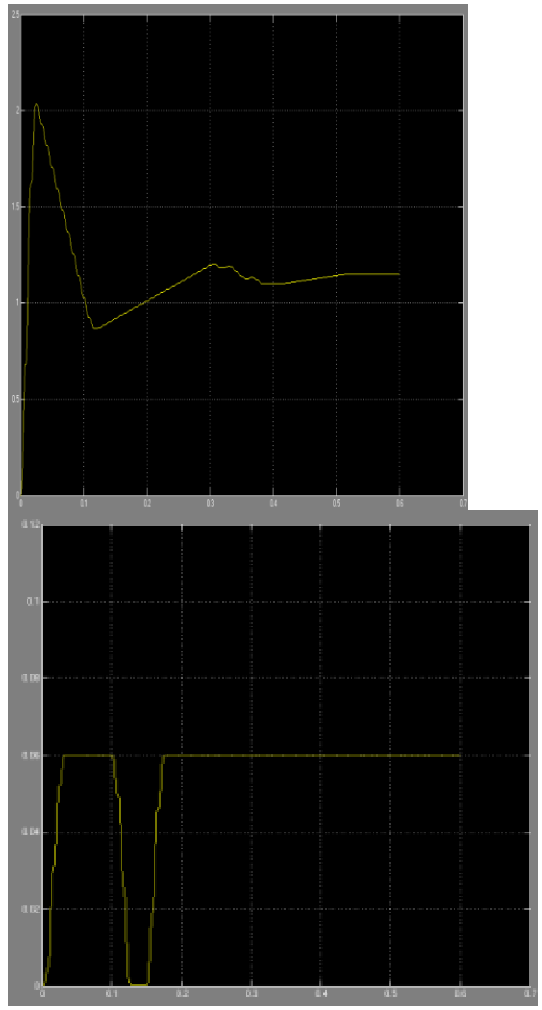
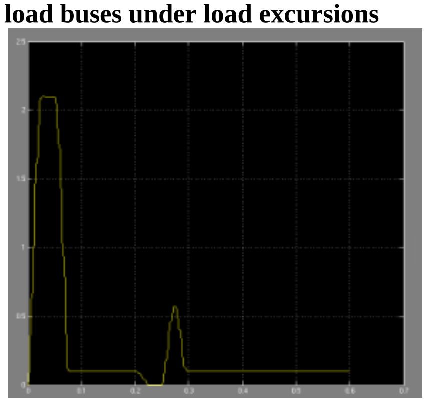


Figure: The RMS voltage waveform at the generator and load buses under load excursions



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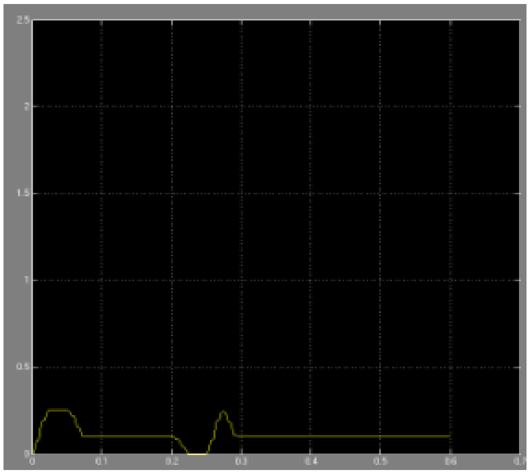

Figure: The RMS current waveform at the generator and load buses under load excursions

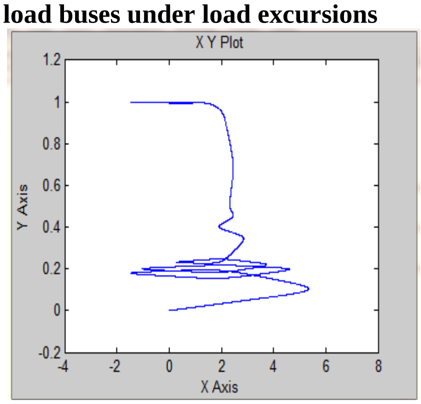

Figure: The speed-torque relationship of the induction motor

CONCLUSION

In this paper a modified switched filter compensator (MSFC) is proposed and an advanced controlling of tri-loop dynamic error driven by modified PID controller is applied for switching pulses generation. The filter is the special type FACTS controller designed with using only capacitor-banks. The control scheme is easier to develop and implement. MSFC scheme is effective for power quality improvement, stabilization of voltage levels, power factor correction and reducing of transmission losses. MSFC is verified by two schemes and the total system is validated with three different operating conditions. The dynamic performance of the proposed system is verified by MATLAB/Sim Power System Tool, and performance characteristics are observed in the section simulation results.

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