# Reduction of line losses, Voltage stabilization, Power Factor improvement and power Quality enhancement in a Radial distribution feeder by using low cost FACTS device modulated power filter compensator (MPFC)

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*Abstract*— This paper presents a switched power filter compensator FACTS device for voltage stabilization, power factor improvement, line loss reduction and power quality enhancement in a long distribution feeder feeding nonlinear arc type or temporal inrush type loads The FACTS based device is controlled by novel tri-loop proportional plus integral (PI) dynamic error driven controller developed by the First Author. The dynamic controller improves voltage stabilization at the load bus and enhances feeder utilization via enhanced voltage regulation and reduced active and reactive feeder power losses. Power quality and improved power factor are the added bonus of this dynamic GTO-switched FACTS filter device. Digital validation is conducted for different cases of load, excursions and fault conditions using the Matlab/Simulink/SimPower software environment.

*Key Words*— Power quality, FACTS, Modulated power filter compensator, Dynamic Controller

## INTRODUCTION

Secure and efficient electric transmission and distribution grid networks are big challenges in the current competitive de-regulation market and growing demand for a reliable electric service.

Power quality is an important additional concern of new competitive selection criteria that covers energy reliability, performance and security. Since transmission connection services are now provided under contract, limits on voltage and current distortion, voltage sags, flickering and fluctuations are coming into force at a scale hitherto unseen in many countries. Light flicker in work places as well as industrial loads where energy outages due to poor power quality of electrical grid can cost millions of dollars in lost productivity is no longer acceptable. The traditional approaches to overcome these growing problems become insufficient and provide an elegant entrance to Flexible AC Transmission Systems FACTS technology [1-6] as a tool to bolster transmission capacity, dynamic voltage stability, security and efficient operation.

The economic transfer of available FACTS technology to distribution and utilization grid networks requires cost effective measures and new devices. From technical, economical and environmental points of view the most efficient way to introduce low cost FACTS technology as either a temporary stop-gap or permanent solution to enhance power flow and converter topologies and control strategies to increase power flow capacity, reduce losses, improve power factor and adhere to emission control and environmental standards.

## SYSTEM MODELS

The sample study distribution system model is shown in Fig. 1. And the proposed low cost modulated power filter compensator (MPFC) is shown in Fig. 2. Fig. 3 depicts the dynamic error driven tri-loop controller developed by the first Author. System and control parameters are given in Appendix.

Since all non-linear and motorized type loads are both sources of dynamic, quasi-static and transient type harmonics of inter, sub and super as well as inter harmonic spectra content, the capacitor banks can be used only to improve the power quality for quasi-state steady state operation. Fast controllable FACTS devices on the other hand can perform well in both cases of quasi-state as well as in dynamic conditions. The real challenge in this paper is to develop novel dynamic and flexible control strategies with multi-loop time scale decoupling.

This paper presents a novel, low cost switched IGBT capacitor filter (MPFC). The FACTS device (MPFC) is installed at load bus for voltage stabilization, improving power quality, power factor and reducing transmission losses and equipped with a tri loop (PI) dynamic controller as shown in fig. 3.

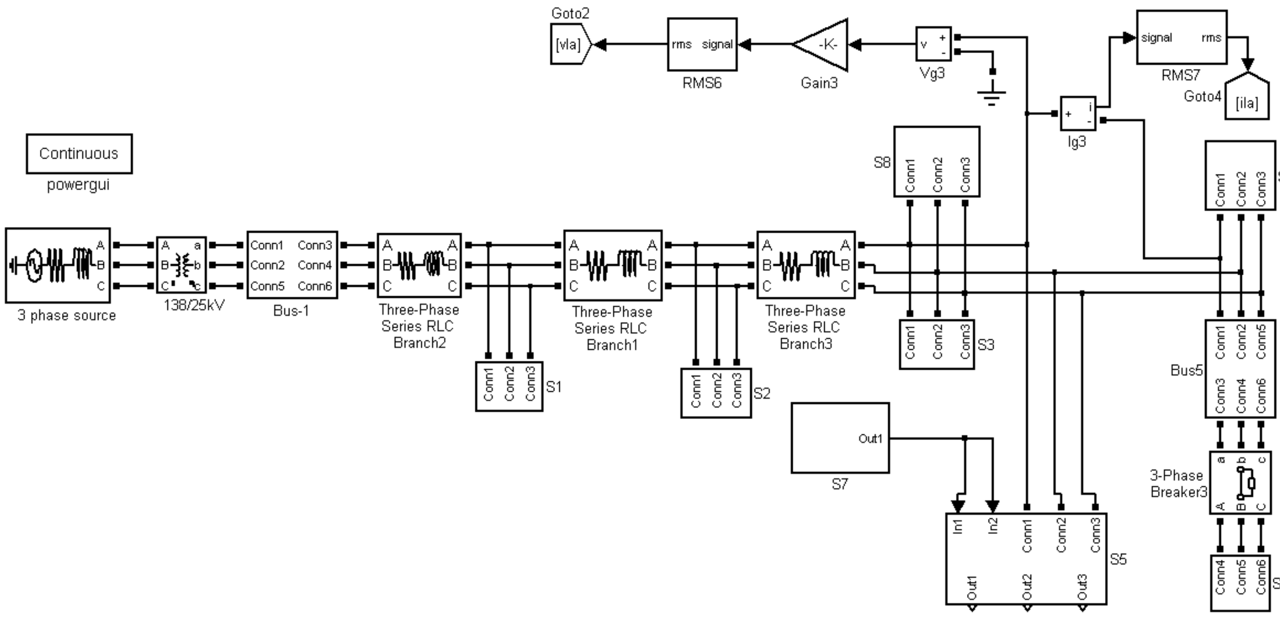


Fig. 1. Matlab/Simulink functional block model for the sample study radial AC distribution Feeder with linear load.

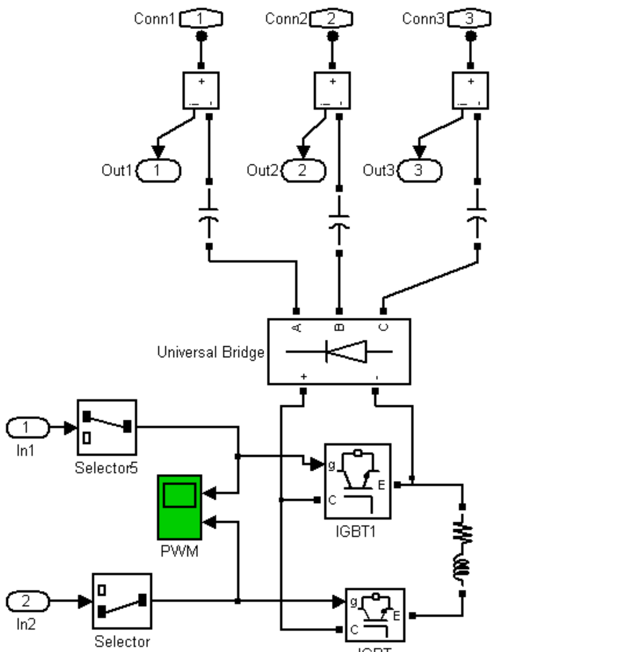


Fig. 2. MATLAB/Simpower system block model of the novel FACTS ( MPFC)

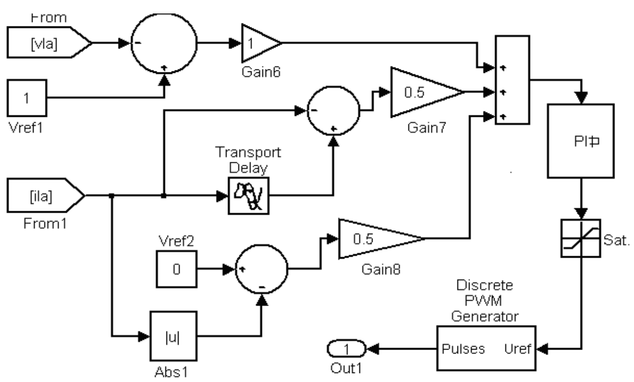


Fig. 3. MATLAB/Simulink/Simpower system block diagram of the tri loop dynamic error driven PI Controller.

## DYNAMIC TRI LOOP ERROR DRIVEN PI CONTROLLER

The tri loop dynamic error driven PI controller is used to generate the required sequence of pulses for a PWM switching device and stabilize the voltage at the load bus by regulating pulse width switching pattern of two complementary switched GTO devices as shown in the Fig. 4. This controller comprises three basic regulating loops for RMS load voltage, dynamic load current and minimum current-ripple loops. These three weighted and dynamically acting loops play an important role in effective dynamic voltage stabilization and reactive power compensation. The scaling and time delay selection of these key loops is done using an offline guided trial and error method to ensure fast response and minimize the total error.

*Loop 1* – The main loop for the dynamic voltage error using the RMS voltage at the load bus. This loop is to maintain the voltage at the load bus at a reference value by modulating the admittance of the compensator.

*Loop 2* - The RMS dynamic load current is used in his loop as an auxiliary signal to compensate for any sudden electrical load excursions.

*Loop 3* **-** The third Current-Ripple loop is added to minimize the total harmonic ripple content in the load current

## DIGITAL SIMULATION RESULTS

To validate the proposed low cost FACTS device (MPFC) scheme, A Matlab/Simpower unified system model is developed and used with the proposed AC distribution system. The study system was simulated with and without the novel MPFC and the results is compared for performance evaluation under linear and nonlinear load operating conditions.

Simulation results without the MPFC are given in Figs. 4 (a-d) for the sending end quantities of power, voltage, current, and power factor. Simulation results with the MPFC are given in Fig. 5 (a-d) for the same quantities of the sending end. Both simulation results with and without the MPFC are placed side by side for better comparison. As it can easily be seen, considerable improvements in all four quantities; power, voltage, current, and power factor are obtained by using the novel MPFC.

Simulation results without the MPFC are given in Figs. 6 (a-d) for the receiving end quantities of power, voltage, current, and power factor. Simulation results with the MPFC are given in Fig. 7 (a-d) for the same quantities of the sending end. Both simulation results with and without the MPFC are placed side by side for better comparison. As it can easily be seen, considerable improvements in all four quantities; power, voltage, current, and power factor are obtained by using the novel MPFC.

## CONCLUSION

The paper presents a novel low cost FACT based dynamically modulated power filter compensator (MPFC) for radial grid networks. The new FACTS device is used mainly for voltage stabilization and reactive power compensation. Other benefits of better voltage regulation include enhanced power factor, reduced active and reactive power losses and feeder utilization due to released capacity.

The novel tri loop dynamic controller is using a pulse width modulating strategy to switch the dynamic Filter device from Capacitive-Compensator to Modulated Power Tuned Arm Filter and vice-versa.

The digital simulation results validated the low cost (MPFC) scheme as an effective tool in voltage regulation and power quality enhancement with added power utilization and reduced losses load excursions and fault conditions under load excursions and fault conditions.

**APPENDIX**

**System Parameters**

1. *Constant voltage source:*
   50MVA, 138 KV (L- L) RMS voltage X/R: 10
2. *Step down transformer*:
   Base power 10MVA and Voltage 138KV/25 kV L-L
3. *10 km Distribution Feeder:*
   R:.25 Ω/km, L:997 mH/km
4. *Linear Loads:* P: 7.5MW, Q: 2.5MVAR,
5. *Non linear loads*: P: 1.5MW
6. *Triloop Dynamic controller:*
   KP: 10, KI: 1, Kd;1 $\gamma_v$=1, $\gamma$i: 0.5, $\gamma_p$: 0.5
7. *PWM switching Block*=1 arm- two bridge pulses
8. TS/W:1/fs/W; 2000HZ (selected).
9. FACTS (MPFC): 6 pulse diode rectifier
10. *Capacitor/Phase*: 28 micro farads RF:.05, Lf: 0.23mH
11. Two Ideal switches: Ron: 001 Ω, Lon: 1e-6H
12. Snubber resistance=1e-5 Ω, Snubber capacitance= ∞

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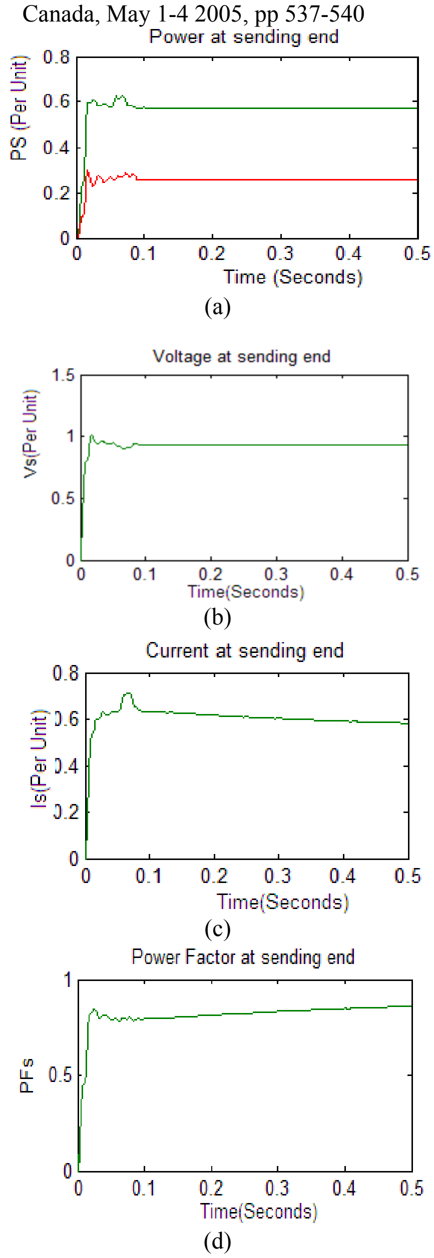


Fig. 4. Unified system dynamic response for normal full load operation without modulated power filter compensator (MPFC) at the sending end.

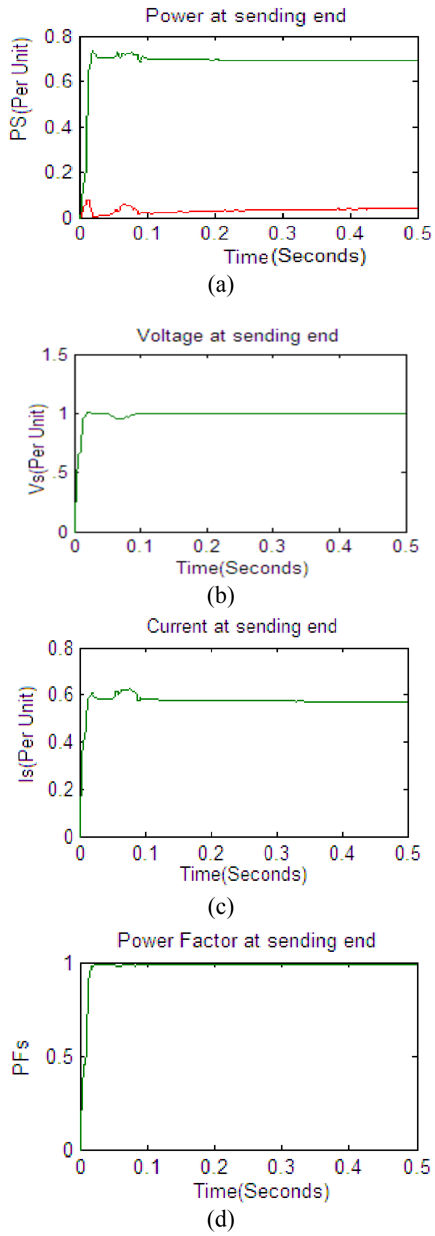


Fig. 5. Unified system dynamic response for normal full load operation with modulated power filter compensator (MPFC) at the sending end.

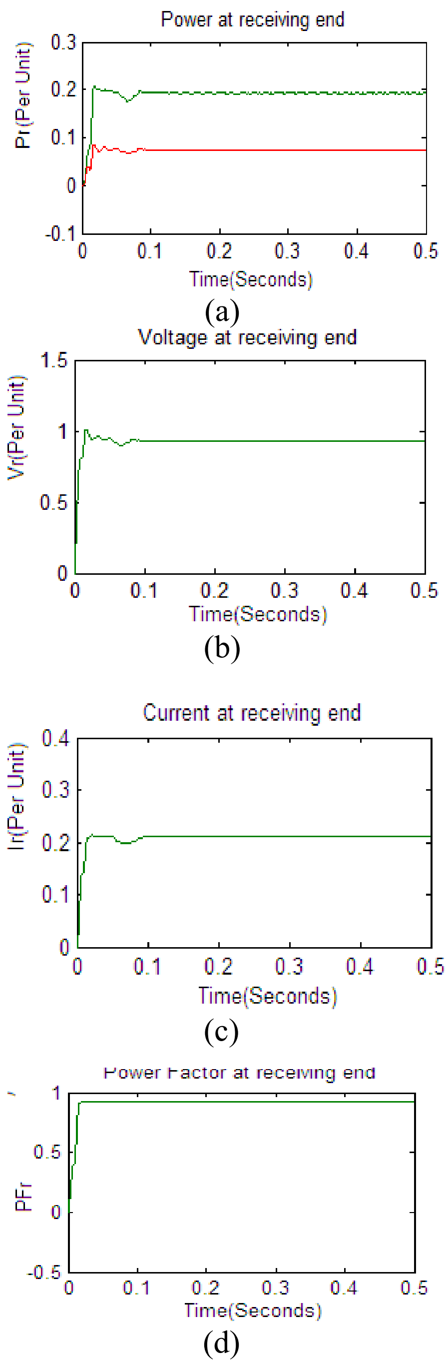


Fig. 6 Unified system dynamic response for normal full load operation without modulated power filter compensator (MPFC) at the receiving end.

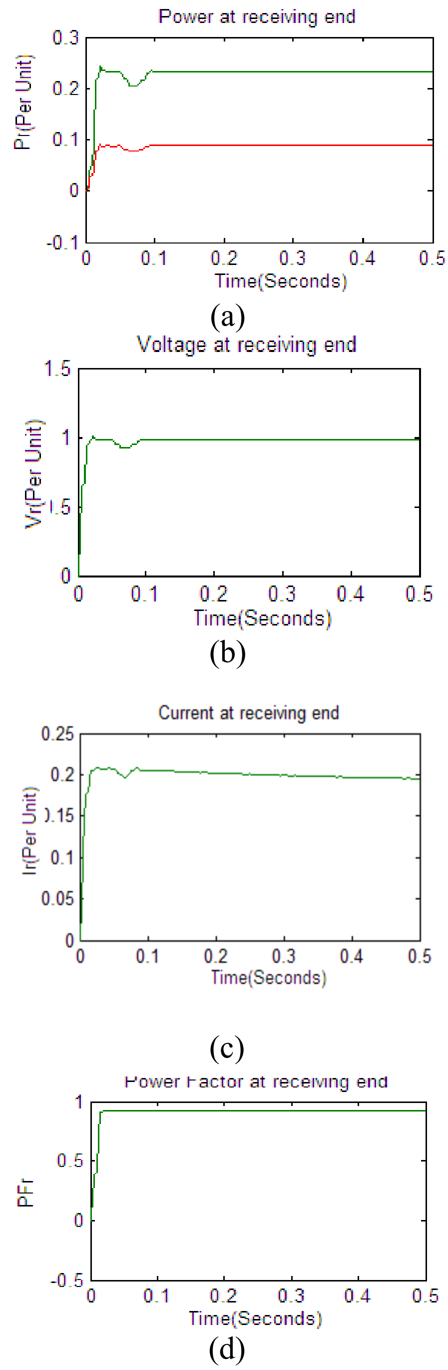


Fig. 7 Unified system dynamic response for normal full load operation with modulated power filter compensator (MPFC) at the receiving end.