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Power quality improvement using FACTS power filter compensation scheme
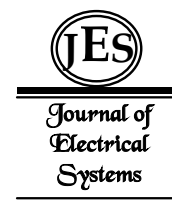
This paper presents a novel modulated power filter compensator (MPFC) scheme for the smart grid stabilization and efficient utilization. The MPFC is controlled by a novel tri-loop dynamic error driven inter coupled modified VSC controller. The Matlab digital simulation models of the proposed MPFC scheme has been fully validated for effective power quality (PQ) improvement, voltage stabilization, power factor correction and transmission line loss reduction. The proposed FACTS based scheme can be extended to distributed/dispersed renewable energy interface and utilization systems and can be easily modified for other specific stabilization, compensation requirements, voltage regulation and efficient utilization.

Keywords: FACTS, Power Quality, Dynamic Voltage Compensation, Stabilization; Efficient Utilization.

1. INTRODUCTION

A power quality problem is defined as any variation in voltage, current or frequency that may lead to an equipment failure or malfunction. In a modern electrical distribution system, there has been a sudden increase of nonlinear loads, such as power supplies, rectifier equipment used in telecommunication networks, domestic appliances, adjustable speed drives, etc. These power-electronic-based loads offer highly nonlinear characteristics. Due to their non-linearity, the loads are simultaneously the major causes and the major victims of power quality problems [1].

Harmonics, voltage sag/swell and persistent quasi steady state harmonics and dynamic switching excursions can result in electric equipment failure, malfunction, hot neutral, ground potential use, fire and shock hazard in addition to poor power factor and inefficient utilization of electric energy manifested in increase reactive power supply to the hybrid load, poor power factor and severely distorted voltage and current waveforms. To improve the efficiency, capacitors are employed which also leads to the improvement of power factor of the mains [2].

Passive filters are traditionally used to absorb harmonic currents because of low cost and simple robust structure. But they provide fixed compensation and create system resonance [3, 4]. The filtering characteristics of passive filters are determined by the impedance ratio of the supply and the passive filter and are often difficult to design. The shunt active filters are used for providing compensation of harmonics, reactive power and/or neutral current in ac networks, regulation of terminal voltage, suppression of the voltage flicker, and to improve voltage balance in three-phase system [5, 6]. They have the capability of damping harmonic resonance between an existing passive filter and the supply impedance, but they require a large current rating with high current bandwidth and do not constitute a cost-effective harmonic filtering solution for nonlinear loads.

Hybrid filters effectively mitigate the problems of both passive filters and pure active filter solutions and provide cost effective and practical harmonic compensation approach, particularly for high power nonlinear loads. The combination of low cost passive filters and control capability of small rating active filter effectively improve the compensation

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characteristics of passive filters and hence reduce the rating of the active filters, compared to pure shunt or series active filter solutions [7- 9]. Many power filter compensation configurations are proposed in literature to enhance power quality and to improve power factor [10-14].

The paper validated a novel modulated power filter compensator (MPFC) scheme to improve the power quality and utilization in smart grid application. The proposed FACTS based system utilizes the tri-loop dynamic error-driven modified VSC controller to control the MPFC. The proposed scheme proved success in improving the power quality, enhancing power factor, reduce transmission losses and limit transient over voltage and inrush current conditions.

2. Modified Power Filter Compensator (MPFC)

The low cost modulated dynamic series-shunt power filter and compensator is a switched type filter, used to provide measured filtering in addition to reactive compensation. The modulated power filter and compensator is controlled by the on-off timing sequence of the pulse width modulation (PWM) switching pulses that are generated by the dynamic tri loop error driven dynamic modified VSC controller. The modified VSC controller is equipped with a supplementary error-sequenced compensation loop for fast effective dynamic response in addition to conventional VSC activation.

This scheme of MPFC structure comprises a series fixed capacitor bank and two shunt fixed capacitor banks are connected to a modulated PWM switched tuned arm filter through six pulse uncontrolled rectifier. The matlab model of this scheme structure is shown in Fig. 1
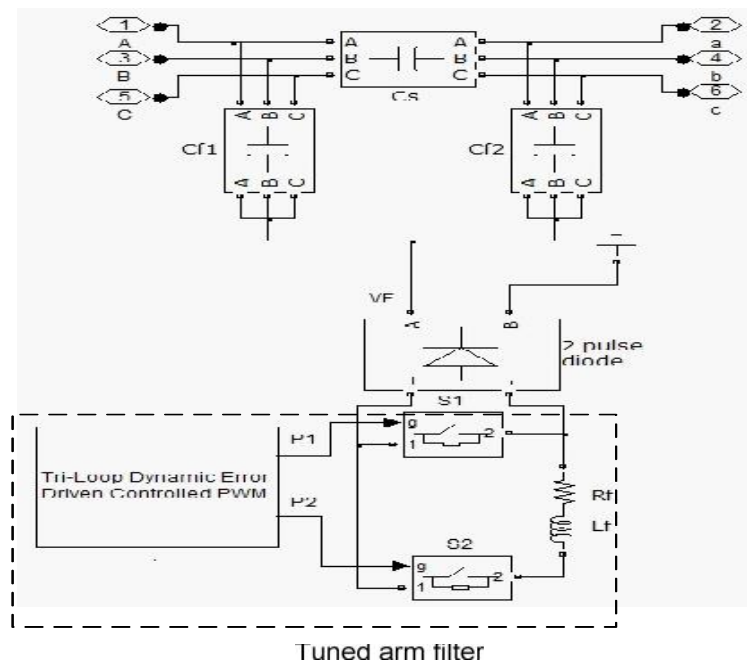

Figure 1: Modified Power Filter Compensator structure

3. Tri Loop Error Driven Modified VSC Controller

The tri-loop error-driven dynamic controller is a novel dual action control used to modulate the power filter compensator [15, 17]. The global error signal is an input to the modified VSC controller to regulate the modulating control signal to the PWM switching block as shown in Figs. 2(a) & 2(b). The modified VSC includes an error sequential activation supplementary loop to ensure fast dynamic response and affective damping of large excursion, in addition to conventional VSC structure.
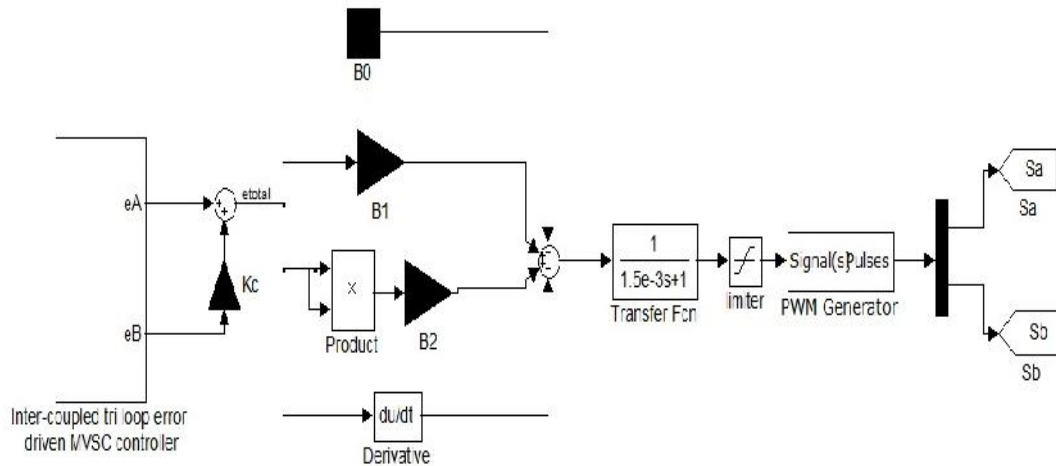
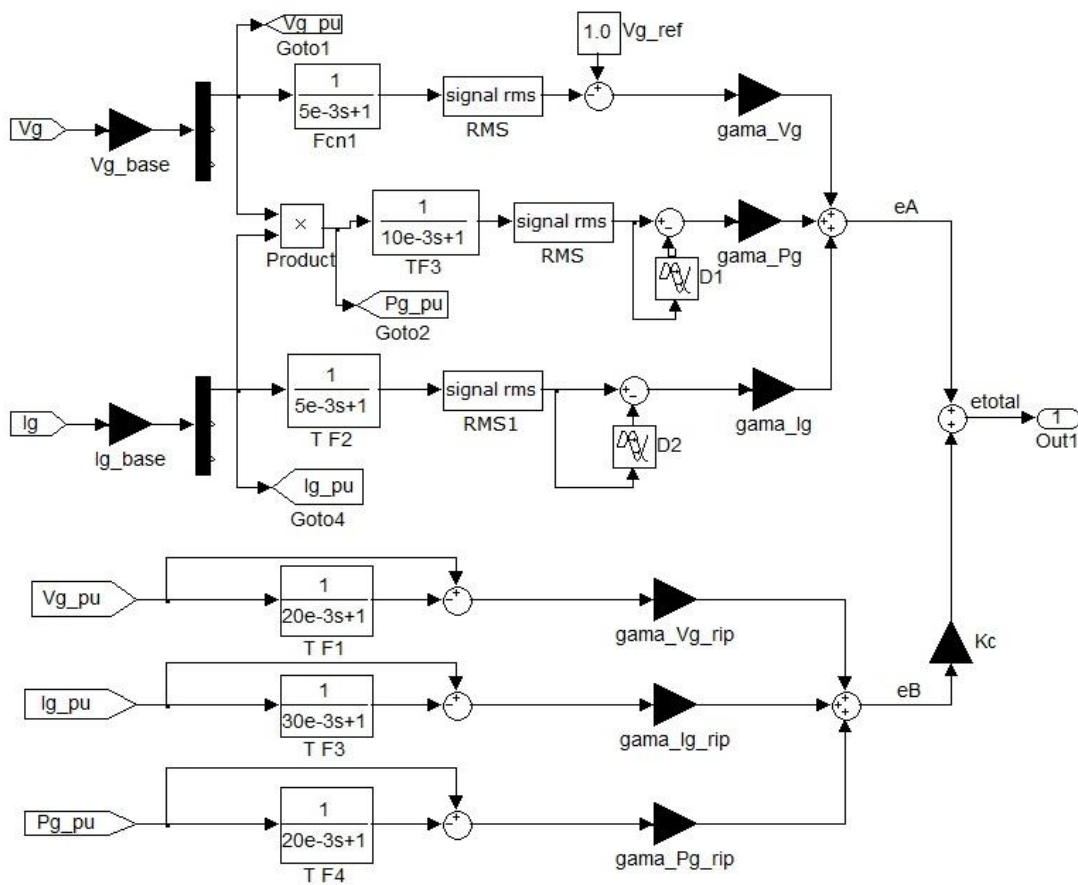Figure 2(a): The modified VSC controller

Figure 2(b): Matlab functional model of the Inter-coupled tri loop error driven modified VSC controller

4. AC Study System

The sample study AC grid network is shown in Fig. 3. It comprises a synchronous generator (driven by steam turbine) delivers the power to a local hybrid load (linear, non-linear and induction motor load) and is connected to an infinite bus through 300 km transmission line. The system, compensator and controller parameters are given in the Appendix.
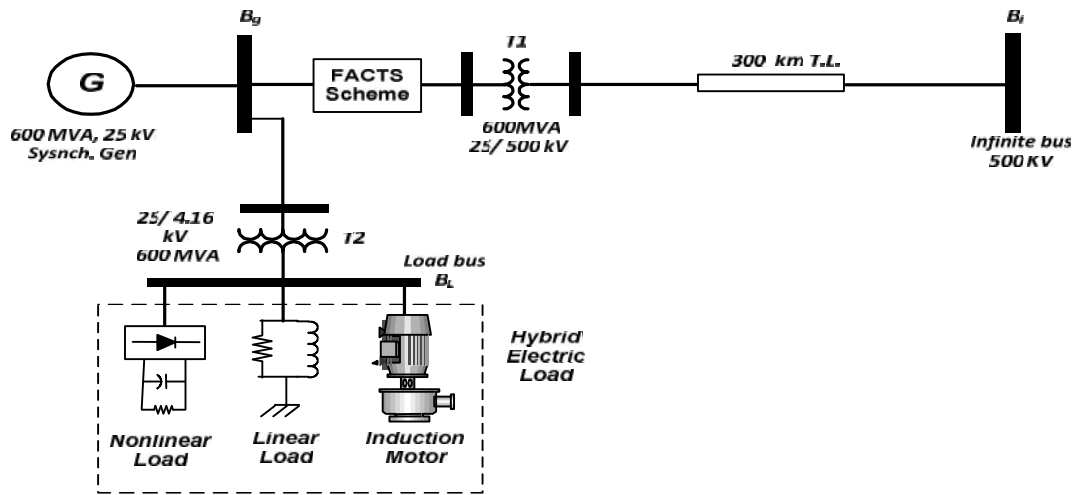
Figure 3: the single line diagram of the Full study AC system

5. Digital Simulation Results

The Matlab digital simulation results using MATLAB/SIMULINK/Sim-Power Software Environment for the proposed MPFC scheme under three different study cases are:

5.1. Case 1: Normal Loading Operation

The modulated tuned power filter switching signals that are generated by the dynamic tri loop error driven dynamic modified VSC controller are shown in Fig. 4. The stable voltage signal of synchronous generator power system stabilization (PSS) is depicted in Fig. 5. The RMS of voltage and current waveforms of the MPFC are shown in Fig. 6 and Fig. 7, respectively. The dynamic responses of voltage, current, reactive power, power factor, and frequency spectra at generator bus (V_g), load bus (V_L) and infinite bus (V_b) under normal loading operation are shown Figs. 8 - 17. The Transmission line losses are shown in Table 1.
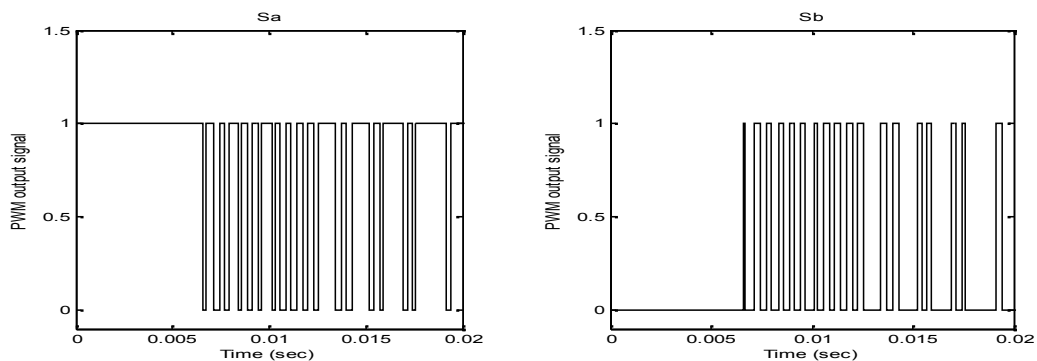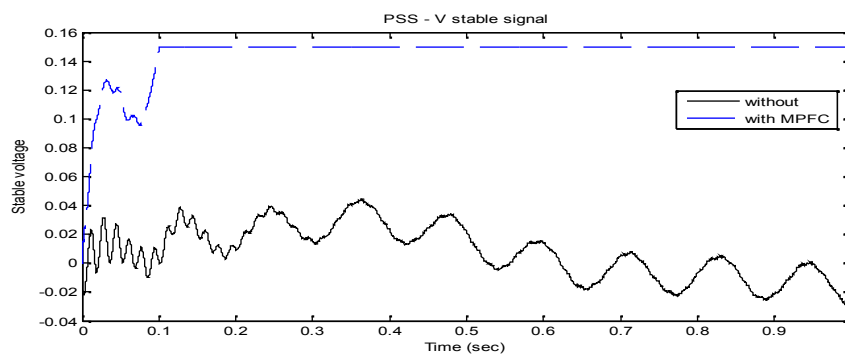

Figure 4: Sa and Sb pulsing signals

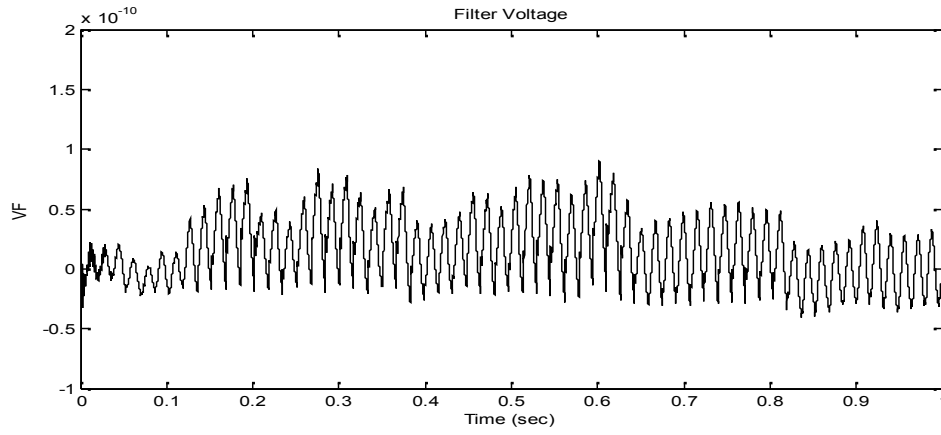Figure 5: PSS stable voltage signal
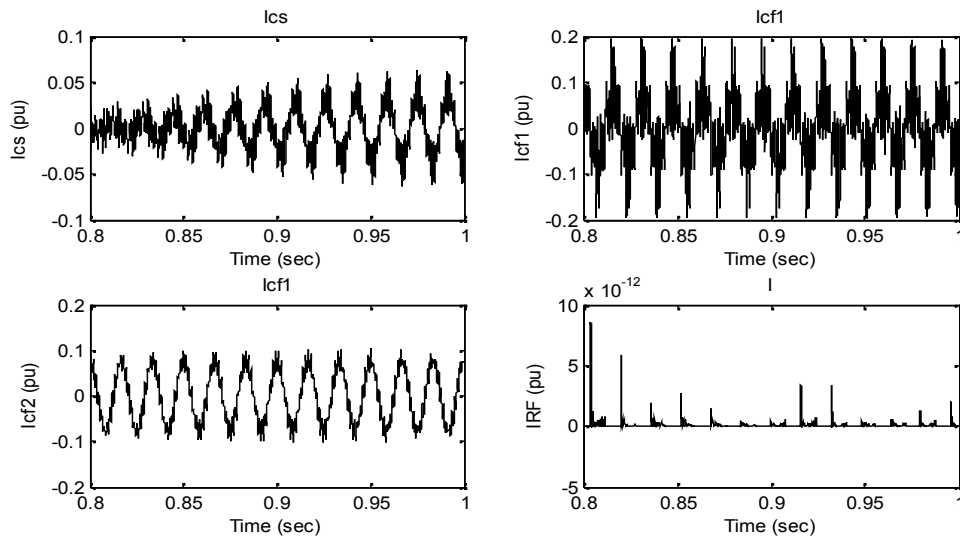
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Figure 6: The voltage waveform of the MPFC

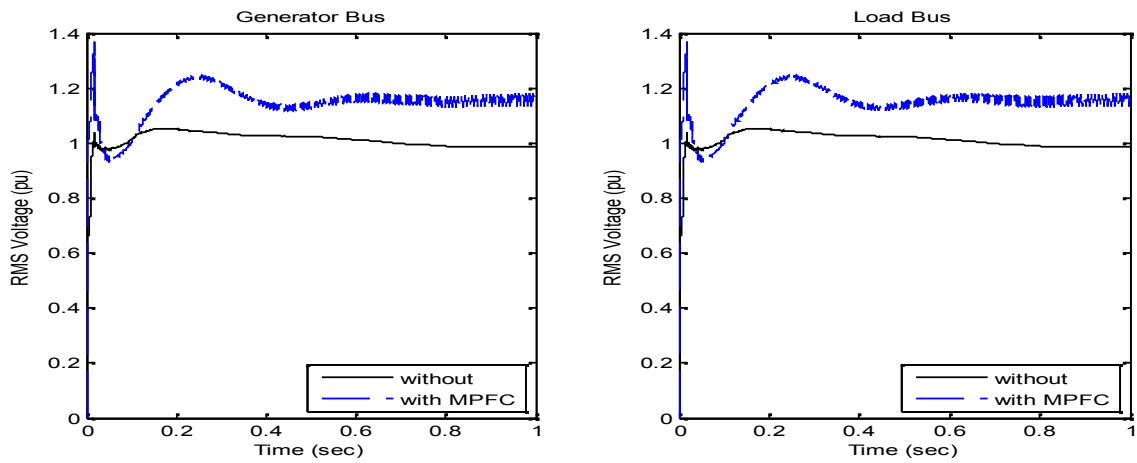Figure 7: The current waveforms of the MPFC

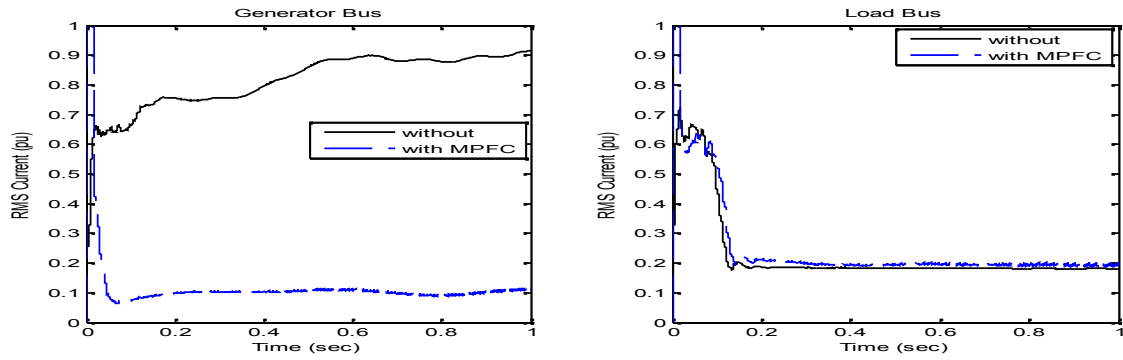Figure 8: The rms voltage at AC buses under normal operation

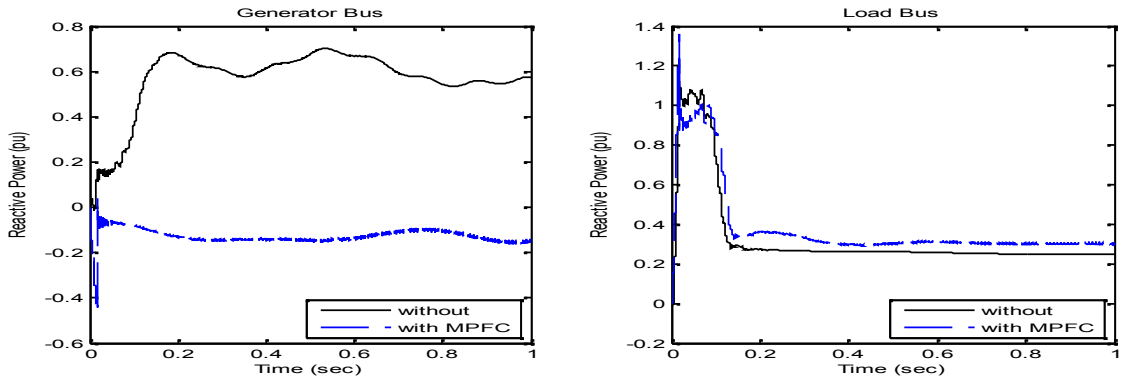Figure 9: The rms current at AC buses under normal operation

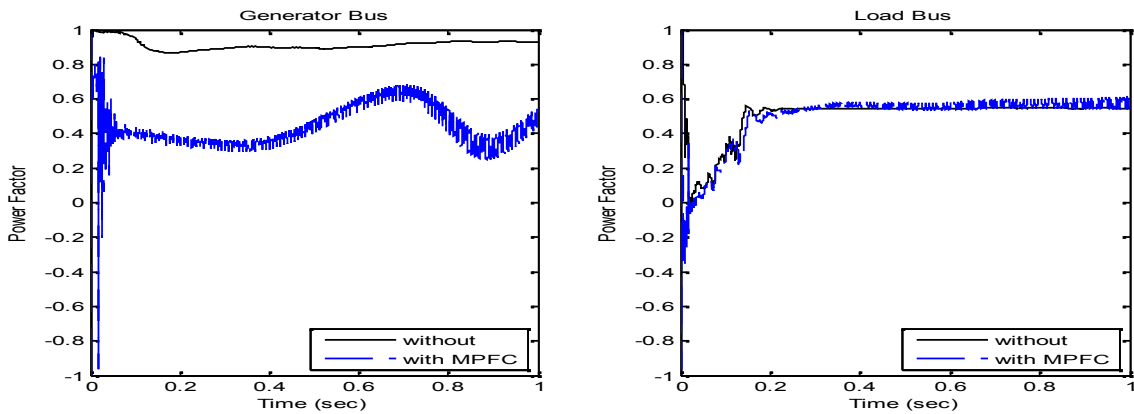Figure 10: The reactive power at AC buses under normal operation

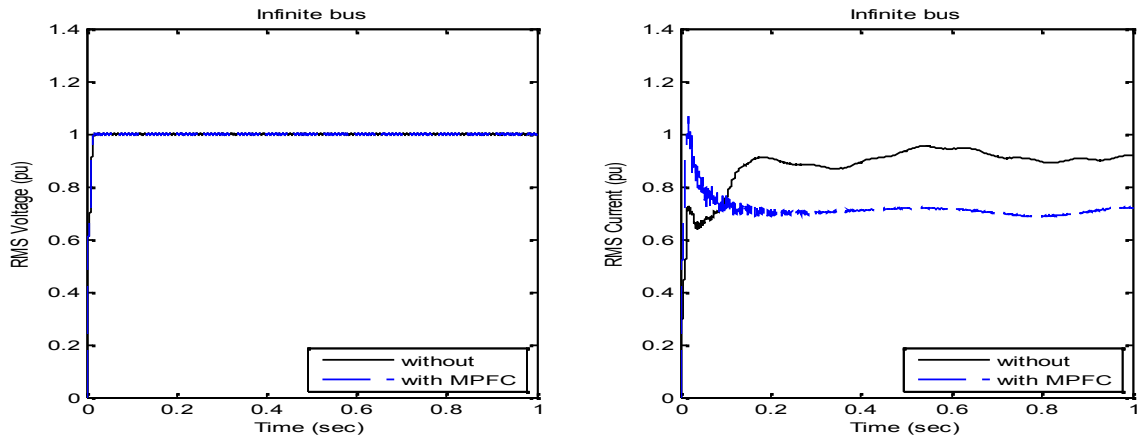Figure 11: The power factor at AC buses under normal operation

Figure 12: The rms voltage and current at infinite bus under normal operation
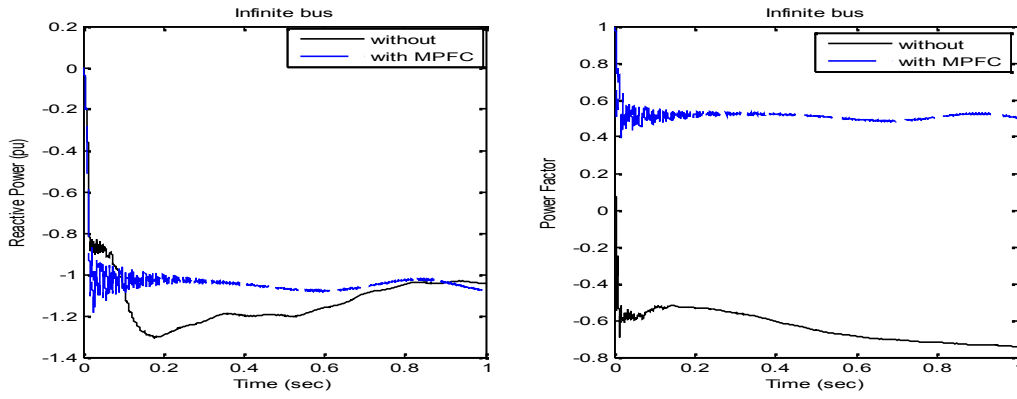
Figure 13: The reactive power and power fator at the infinite bus under normal operation
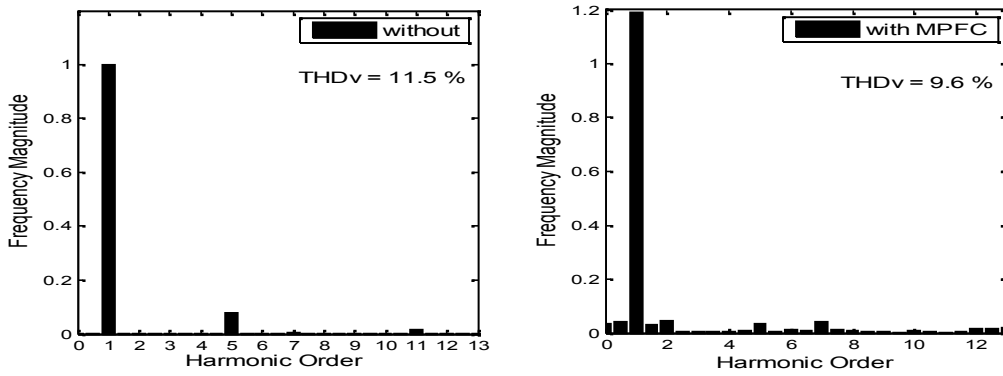

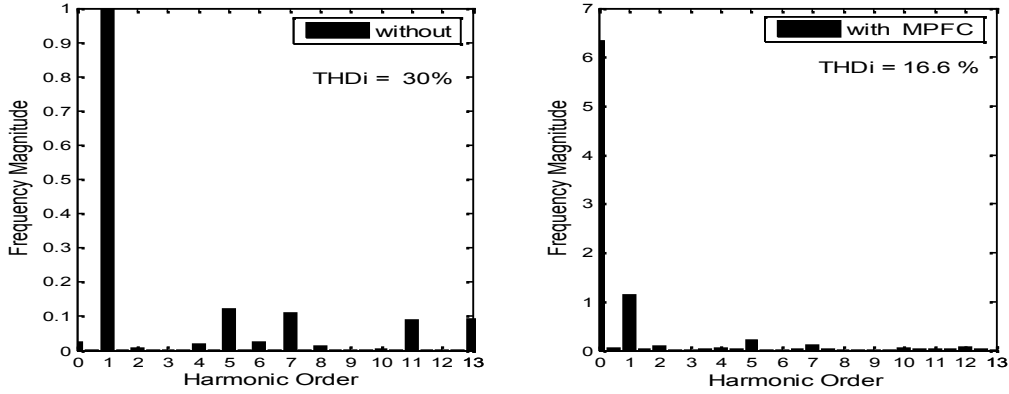Figure 14: The frequency spectrum and THD of voltage waveforms at the load bus

Figure 15: The frequency spectrum and THD of current waveforms at the load bus
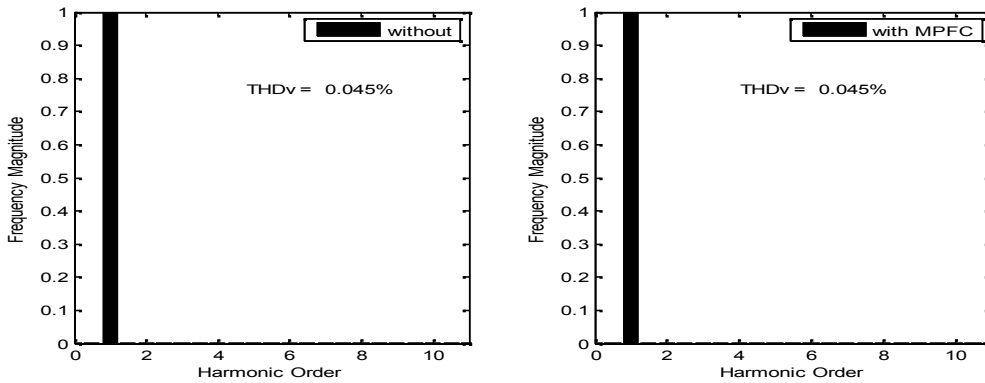

Figure 16: The frequency spectrum and THD of voltage waveforms at the infinite bus
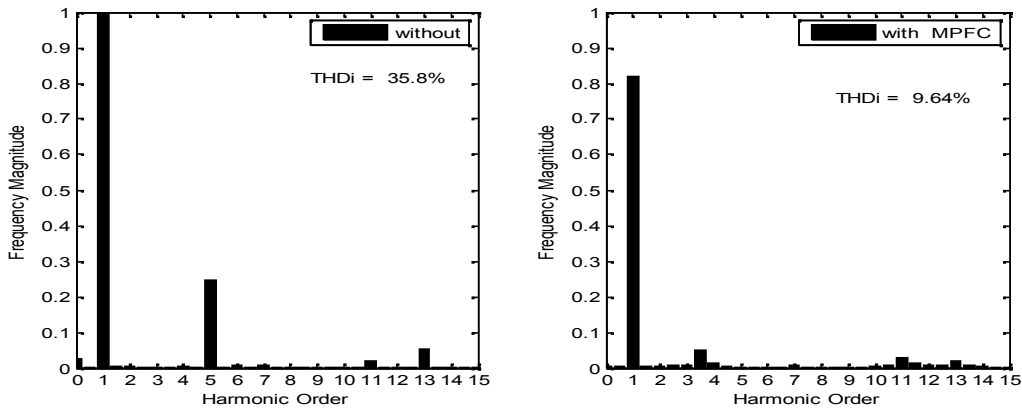
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Figure 17: The frequency spectrum and THD of current waveforms at the infinite bus

The previous figures confirm the compansation effeteveness as well as the harmonic filtering of the proposed MPFC.

5.2. Case 2: Short Circuit Fault Condition

A three phase short circuit (SC) fault is occurred at bus V_s, as shown in Fig. 3, for a duration of 0.1sec, from t = 0.2 sec to t= 0.3 sec. The RMS of voltage and current waveforms at generator and load buses are depicted in Figs. 18 & 19.

As shown in Figs. 18 & 19, with using the proposed MPFC scheme, the remote short circuit fault has not any effect on the values of RMS voltage and RMS current of generator and load buses, so these schemes can be considered a good power quality mitigation method.
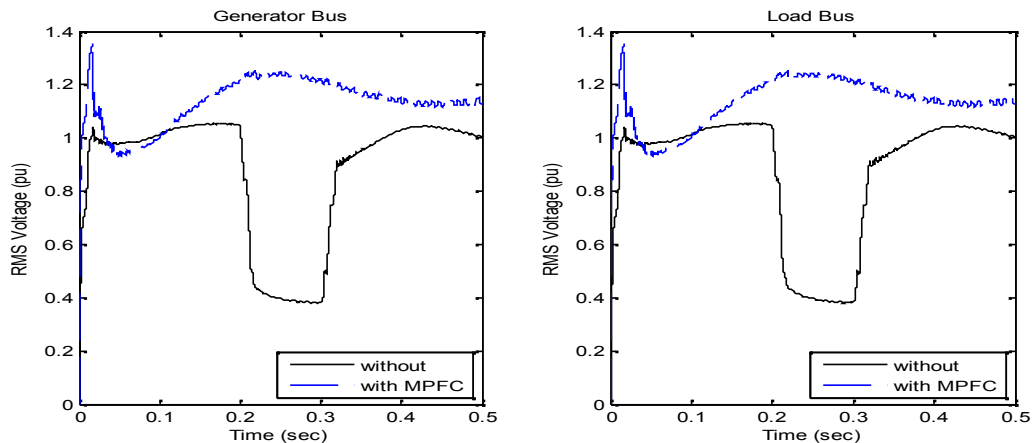

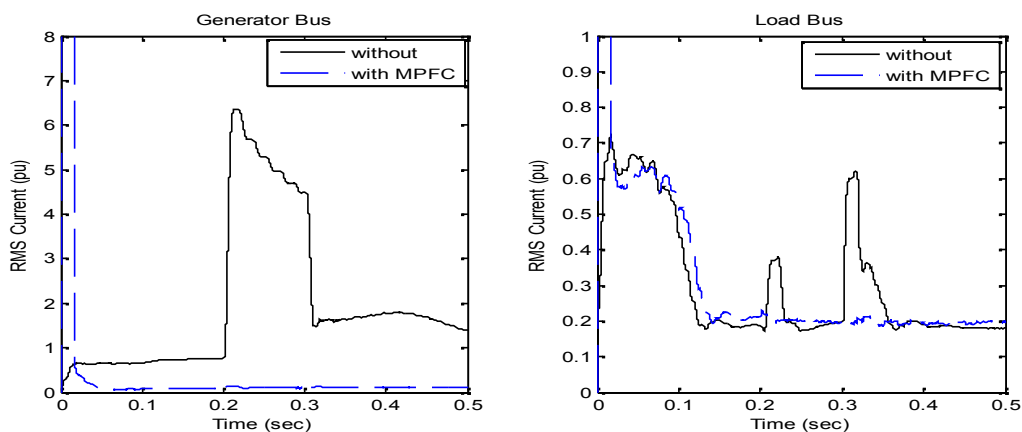Figure 18: The rms voltage at generator and load buses under SC fault condition

Figure 19: The rms current at generator and load buses under SC fault condition

5.3. Case 3: Local Hybrid Load Excursions

The real time dynamic responses of the system for a load excursion are obtained for the following time sequences.

- At t = 0.1 sec, linear load is disconnected for a duration of 0.05 sec.
- At t = 0.2 sec, nonlinear load is disconected for a duration of 0.05 sec.
- At t = 0.3 sec, the induction motor torque is decreased by 50% for a duration 0.05 sec.
- At t = 0.4 sec, the induction motor torque is increased by 50% for a duration 0.05 sec.

The rms values of voltage and current waveforms at generator and load buses under load excursions are depicted in Figs. 20 & 21. The linear and nonlinear load RMS current waveforms are shown in Fig. 22 and the speed-torque relationship of induction motor (IM) is shown in Fig. 23.
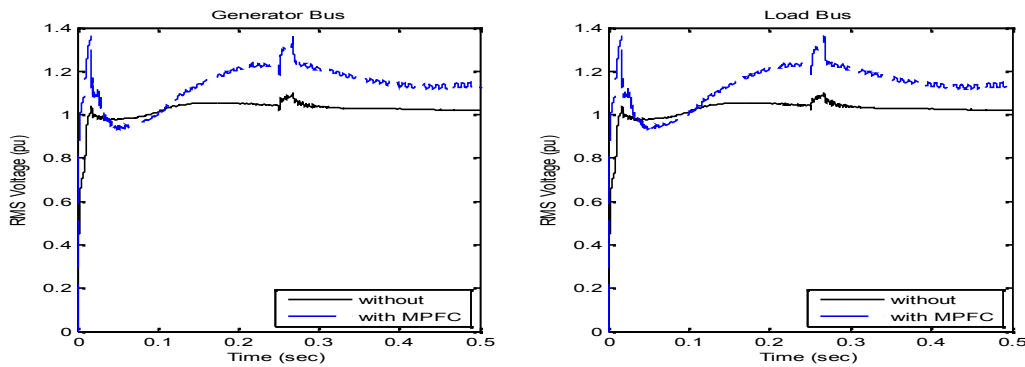

Figure 20: The rms voltage waveform at generator and load buses under load excurtions
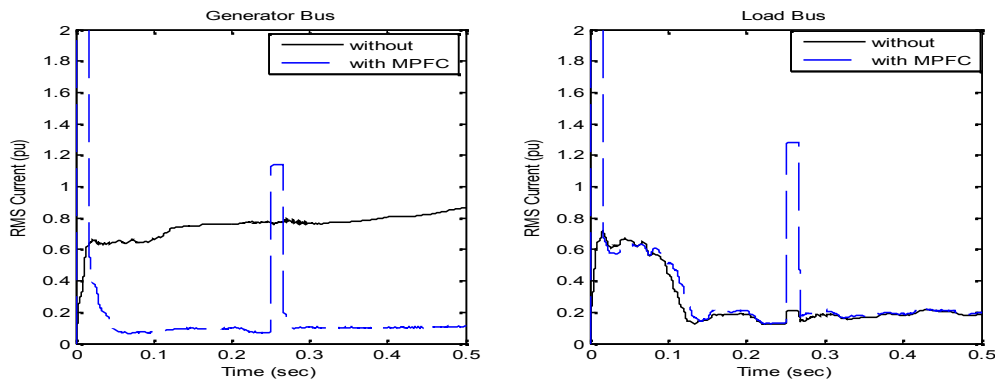

Figure 21: The rms current waveform at generator and load buses under load excurtions
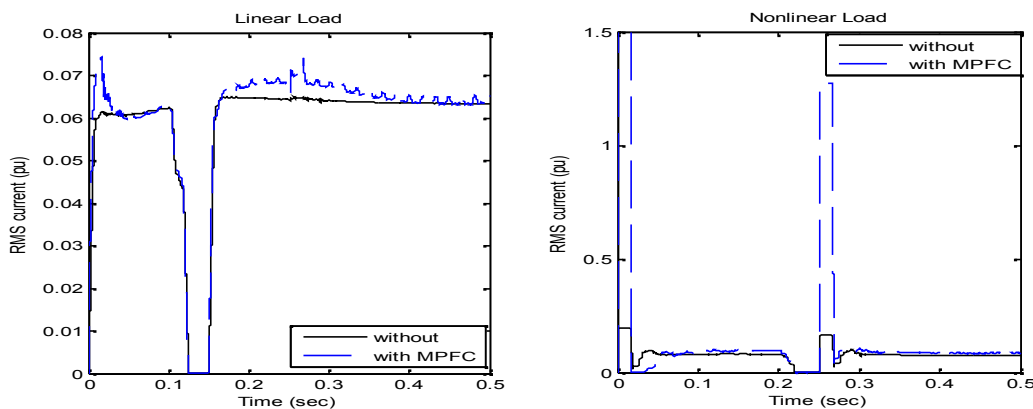

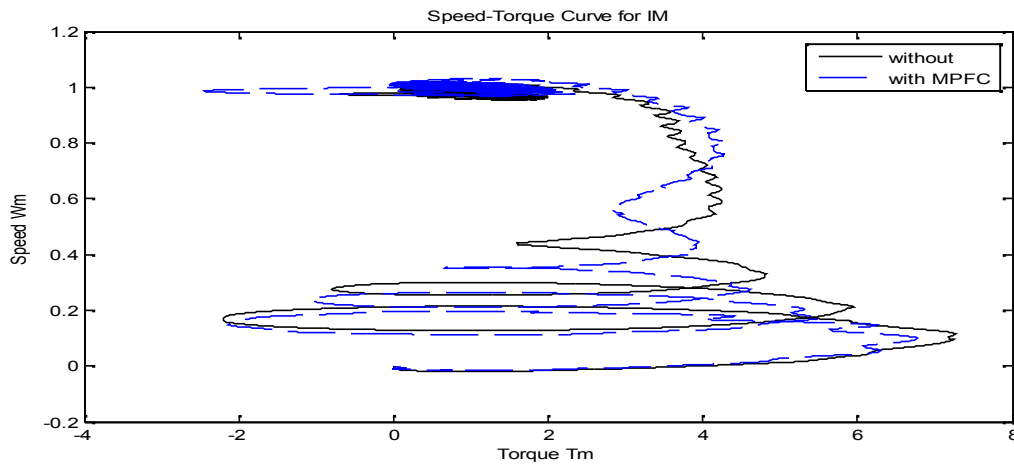Figure 22: The linear and nonlinear load rms current waveforms

Figure 23: The speed-torque relationship of the induction motor

Table 1: The transmission line losses

		P Loss (pu)	Q loss (pu)	S loss (pu)
Case 1	Without MPFC	0.073	0.1369	0.1422
	With MPFC	0.001	0.007	0.0071
Case 2	Without MPFC	0.1953	0.3464	0.443
	With MPFC	0.0012	0.007	0.0071
Case 3	Without MPFC	0.0739	0.1385	0.157
	With MPFC	0.0009	0.007	0.0071

Comparing the dynamic response results without and with using the proposed MPFC under three study cases; normal operation, short circuit fault conditions and hybrid load excursions, it is quite apperent that the proposed MPFC enhanced the power quality, improved power factor, compansated the reactive power, stabilized the buses voltage and reduced the transmission line losses.

6. Conclusions

This paper presents a novel modulated switched power filter compensator (MPFC) scheme. The MPFC is controlled by a dynamic tri-loop dynamic error driven modified VSC controller. The digital simulation model of the proposed MPFC scheme has been validated for effective power quality improvement, voltage stabilization, power factor correction and transmission line loss reduction. The proposed FACTS based scheme can be extended to other distributed/dispersed renewable energy interface and utilization systems and can be easily modified for other specific compensation requirements, voltage stabilization and efficient utilization. Topology variations and flexible dynamic control techniques can be utilized in renewable energy smart grid interface.

References

[1] J. Arrillaga, D. A. Bradley, P. S. Bodge, "Power System Harmonics", Wiley, 1985.

[2] D. Daniel Sabin and Ashok Sundaram, "Quality Enhances", IEEE Spectrum, 1996, No. 2, PP. 34-38.

[3] A.M. Sharaf, Hong Huang, Liuchen Chang," Power quality and nonlinear load voltage stabilization using error-driven switched passive power filter", Proc of the IEEE Inter. Symp. on Industrial Electronics, 1995, pp 616-621

[4] M. Rastogi, N. Mohan, and A.-A. Edris, "Hybrid-active filtering of harmonic currents in power systems," IEEE Trans. Power Delivery, vol. 10, no. 4, pp. 1994–2000, Oct. 1995.

[5] H. Fujita and H. Akagi, "Apractical approach to harmonic compensation in power system-series connection of passive, active filters," IEEE Trans. Ind. Applicat., vol. 27, no. 6, pp. 1020–1025, Nov./Dec. 1991.

[6] A. M. Sharaf, Caixia Guo and Hong Huang,"Distribution/Utilization system voltage stabilization and power quality enhancement using intelligent smart filter", UPEC'95, England, UK, 1995.

[7] M. Aredes, K. Heumann, and E. H. Watanabe, "An universal active power line conditioner," IEEE Trans. Power Delivery, vol. 13, no. 2, pp. 545–557, Apr. 1998.

[8] M. Rastogi, N. Mohan, and A.-A. Edris, "Hybrid-active filtering of harmonic currents in power systems," IEEE Trans. Power Delivery, vol. 10, no. 4, pp. 1994–2000, Oct. 1995.

[9] H. Fujita and H. Akagi , "A hybrid active filter for damping of harmonic resonance in industrial power system," IEEE Trans. Power Electron., vol. 15, no. 2, pp. 215–222, Mar. 2000.

[10] A. M. Sharaf, and G. Wang, "Wind Energy System Voltage and Energy Enhancement using Low Cost Dynamic Capacitor Compensation Scheme." Proceedings of the IEEE International Conference on Electrical, Electronic and Computer Engineering. pp. 804-807, 5-7 Sept. 2004.

[11] A.M. Sharaf and Khaled Abo-Al-Ez, "A FACTS Based Dynamic Capacitor Scheme for Voltage Compensation and Power Quality Enhancement", Proceedings of the IEEEISIE 2006 Conference, Montreal, Quebec Canada, July 2006.

[12] A. Sharaf, R. Chhetri, "A novel dynamic capacitor compensator/green plug scheme for 3-phase 4-wire utilization loads", Proceeding IEEE-CCECE conference, Ottawa, Ontario, Canada 2006.

[13] A.M. Sharaf, Hassan A. Mahasneh and Yevgen Biletskiy,"Energy Efficient Enhancement in AC Utilization Systems" The 2007 IEEE Canadian Conference on Electrical and Computer Engineering CCECE 07, Vancouver Canada, April 2007.

[14] A.M. Sharaf, W. Wang, and I.H. Altas, "A Novel Modulated Power Filter Compensator for Distribution Networks with Distributed Wind Energy." International Journal of Emerging Electric Power Systems. Vol. 8, Issue 3, Article 6, Aug. 2007.

[15] A. M. Sharaf, A. A. Abdelsalam, "A novel switched filter compensation scheme for power quality enhancement and loss reduction" International Symposium on Innovations in Intelligent Systems and Applications ,INISTA 2011, Turkey, pp 398- 403.

[16] A. M. Sharaf, A. A. Abdelsalam, "Power quality enhancement in wind-grid interface based on switched filter compensator" International Symposium on Innovations in Intelligent Systems and Applications ,INISTA 2011, Turkey, pp 404- 409.

[17] A. M. Sharaf, A. A. Abdelsalam, A. A. Eldesouky, A.A. Sallam, "a novel FACTS based modulated power filter compensation scheme for smart electric grid stabilization and efficient utilization", International Journal of Distributed Energy Resources, vol. 7, no. 4, pp 311-327, 2011.

Appendix

1. Steam turbine
   P_{out} = 600 MW, speed = 3600 rpm.
2. Synchronous generator
   3 phase, 1 pair of poles, V_g = 25 kV (L-L), S_g = 600 MVA, X_d=1.79, X_d'=0.169, X_d''=0.135, X_q=1.71, X_q'=0.228, X_q''=0.2, X_l=0.13.
3. Local Hybrid AC Load (90 MVA)
   linear load: 30 MVA, 0.85 lag pf.
   non-linear load: P= 20 kw, Q=22.4 MVAR.
   induction motor: 3phase, 30 MVA, no of poles=4,
   Stator resistance and leakage inductance (pu)
   R_s =0.01965, L_s=0.0397
   Rtator resistance and leakage inductance (pu)
   R_r = 0.01909, L_r=0.0397
   Mutual inductance L_m (pu) =1.354
4. Transmission Line
   V_{L-L} = 500 kV, 300 km length, R/km=0.01273   , L/km=0.9337 mH
5. Infinte Bus: V_{L-L} = 500 kV
6. MPFC: C_s = 30μF, C_{f1} = C_{f2} =125μF, R_f= 0.25   and L_f = 3mH
7. Controller gains (figure 2): vg=1, ig=0.5, pg=0.25, vg-rip=1, ig-rip=1, pg-rip=0.5, B_0=0.2, B_1=10, B_2=0.1 and PWM frequency f_s=1750 Hz