Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

7th International Conference
on Electrical Engineering
ICEENG 2010

A Dynamic Filter Compensator Scheme for Voltage Stabilization and Efficient Utilization of Wind-Grid Interface Systems

By

Mohamed A. El-Sayed* Adel Sharaf *

Abstract:

Energy shortage and global warming issues are among key world challenges in the 21st Century. Wind energy is a renewable clean source, which can reduce carbon dioxide emission. Economical electric energy generation using wind energy production has been rapidly growing for the last two decades. However, the integration of large wind scheme can pose inherent security and power quality problems. The paper presents dynamic simulation of a novel stabilization scheme using a coordinated tri loop error driven controller. The Wind Energy Scheme comprises three key parts. The wind farm, induction generator, Modulated Power Filter compensator MPFC and hybrid System Load. The distribution grid-wind integrated AC system feeding the hybrid load is to be stable and efficient.

The integrated wind-grid scheme with all subsystems has been digitally simulated using the Matlab Simulink/Sim-Power software environment. The modulated filter compensator scheme with the coordinated dynamic error driven hybrid controller was fully validated.

Keywords:

Renewable Wind Energy, Novel Filter Schemes, Voltage Stabilization and Efficient Utilization of wind Energy.

---

* Energy Research Centre, University of Trinidad and Tobago

1. Introduction:

Wind energy becomes one of the most competitive renewable sources of economical alternative energy. Wind energy has been used to convert wind kinetic energy to mechanical energy for more than one thousand years. Recently, Wind power has experienced a rapid global growth rate and is expected to reach 15 GW/year in 2010 at a viable cost of (0.04-0.06) $/kWh with installation cost of 2000-3000 $/kW [1]. However, wind power production cannot be predicted with acceptable accuracy and the energy production is variable. Therefore, strong AC grid interface systems are needed if wind energy is fed into the grid without any stability control. This is justified for low wind energy penetration levels of the short circuit level of the grid, otherwise additional stabilization efforts are needed to guarantee the grid stability [2].

Security, stability and power supply quality challenges associated with the operation and control of grid integrated wind farms are immense [3, 4]. In order to ensure stable operation during grid disturbances and load excursions FACTS based devices should be installed in the distribution grid. This paper presents an efficient and low cost stabilization FACTS scheme to be connected to the distribution network. The novel scheme comprises the Modulated Power Filter Compensator (MPFC) developed by the Second Author for effective dynamic reactive power compensation using a coordinated multi-loop dynamic error-driven controller adjusts the pulse switching of the MPFC. In this paper, the effectiveness of MPFC scheme for voltage stabilization and power factor improvement is fully validated using MATLAB/Sumulink software for different excursions and load disturbances.

2. Wind Energy Conversion System

The power extraction of wind turbine is a function of three main factors: the wind power available, the power curve of the machine and the ability of the machine to respond to wind fluctuation. The expression for power produced by the wind is given by [4-6]

$$p_m(u) = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 u^3 \qquad (1)$$

Where ρ is air density, R is radius of rotor, u is wind speed, C_p denotes power coefficient of wind turbine, λ is the tip-speed ratio and β represents pitch angle.

The tip speed ratio is defined as

$$\lambda = \frac{R\omega}{u} \qquad (2)$$

Where ω is the rotor speed. It is seen that if the rotor speed is kept constant, then any change in the wind speed will change the tip-speed ratio, leading to the change of power coefficient C_p and the generated power out of the wind turbine. If, however, the rotor speed is adjusted according to the wind speed variation, then the tip-speed ratio can be maintained at an optimal point, which could yield maximum power output.

The wind speed gusting conditions has a great impact on the dynamic performance of the wind scheme, a dynamic wind speed model is required to represent the stochastic nature of wind variations for the power dynamic simulations. A simplified dynamic wind speed model is developed using the MATLAB/Simulink software. This stochastic model consists of four basic key components, namely the mean wind speed, a wind speed ramp, a wind gust, and the turbulence component. The eventual wind speed to be applied to the wind turbine is the summation of all four key components.

3. Sample Wind-Grid Study System

The study system model for wind energy utilization scheme shown in Fig.(1) comprises three key subsystems. The wind energy farm, Novel Modulated power filter and hybrid system load. The novel dynamic error driven coordinated control scheme are used to regulate the MPFC compensator. Six feeder sections each of 3 km length constitute the 11-kV (L-L) distribution grid network to interface wind generated power to the system loads located at the different distribution network buses. The use of the modulated power filter compensator is essential to ensure voltage stabilization, power quality and power factor enhancement [7].

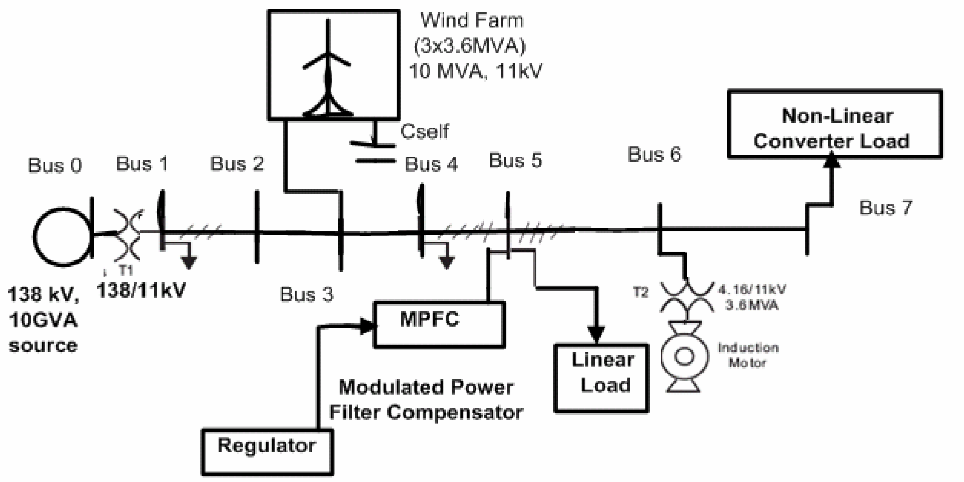


Fig.(1) Proposed Grid Connected Wind test System with MPFC compensator Scheme

The Matlab/Simulink model of the MPFC is shown in Fig.(2) with the novel dynamic regulator and regulated switches. In fact, the MPFC is a PWM converter with a capacitor on its DC side to provide the energizing voltage. The compensator capacitor size selection is essential for the combined reactive compensation and harmonic filtering. The filter compensator is controlled by error driven regulator to adjust the duty cycle ratio using the pulse width modulation technique.

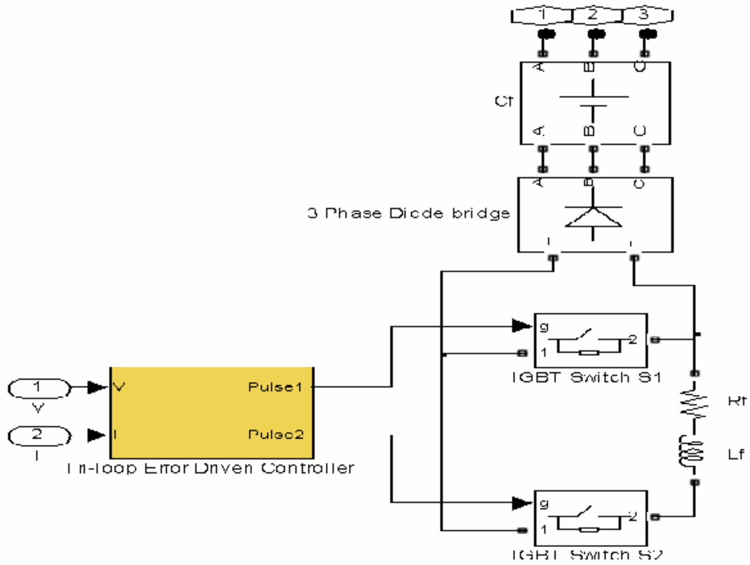


Fig. (2) Modulated Power Filter Compensator (MPFC) Scheme (Pulse2 = NOT Pulse1)

4. CONTROL STRATEGY

The tri loop error driven coordinated controller shown in Figure (3) is implemented to regulate the MPFC compensator. The Controller comprises three error driven loops: The load bus voltage stabilization loop, Current ripple loop and RMS current dynamic RMS loop [8, 9], using the Root-Mean-Square (RMS) voltage, phase RMS current, and current ripple content minimization loop.

1. The main voltage stabilization loop functions as the reference loop using the root mean squared value of load voltage at the radial distribution load bus 5 and maintaining the voltage at 1.0 per unit.
2. The second loop is the load bus current RMS error tracking loop, which is an auxiliary loop to compensate for any sudden electrical load excursions or wind speed variations.
3. The third supplementary loop is used to limit current ripples and harmonic content. The scaling and time delays of these loops were selected by an offline guided trial and error to insure fast response and effective damping [10, 11].

This is achieved by using a minimization functional of the total error squared. The time decoupled/descaled tri-loop supplementary regulation loops compensate for any dynamic inrush excursions of the load bus voltage and current. The total error signal is driven through a PID controller that is used to compensate the dynamic total error in order to provide a stabilized minimum total error.

Owing to the existence of the non-linear load and the complicated wind energy conversion system model, conventional optimization methods become ineffective to optimize the controller parameters. Consequently, the weights and time delays of these loops, as well as controller proportional, integral and derivative gains ((K_p K_d and K_i) were selected by a guided trial and error method to ensure fast and steady response. Thus the values of (K_p K_d and K_i) were selected off-line to minimize an objective function based on weighted control error squared [10,11].

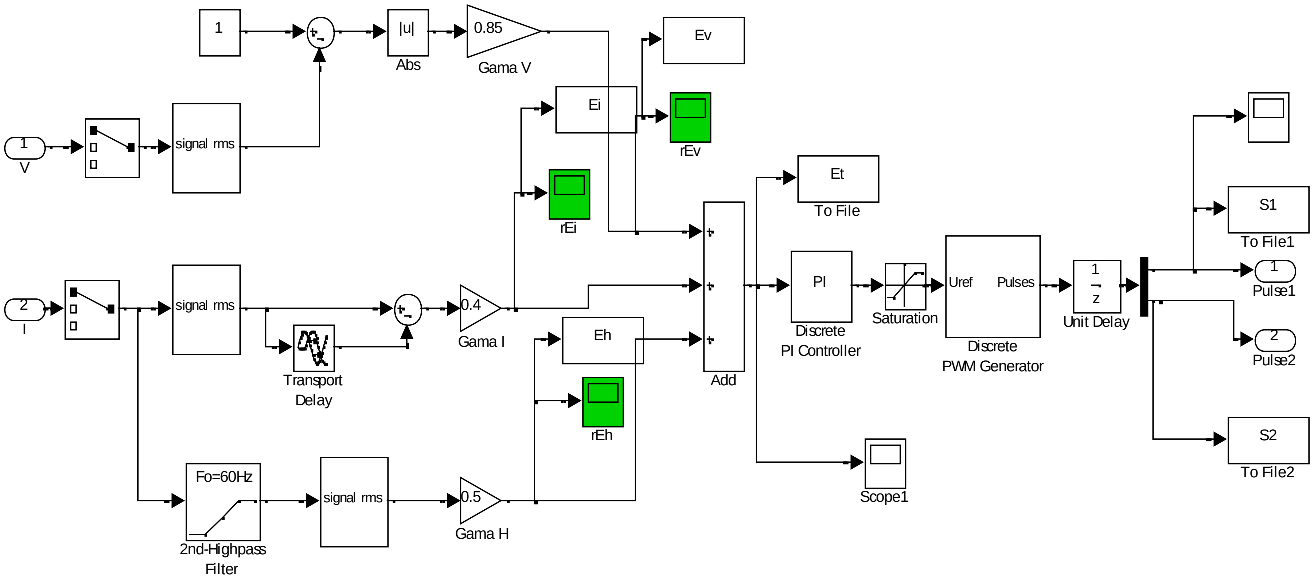


Fig. (3) Coordinated Time-Descaled Tri-loop dynamic (PID) Error Driven Controller for the Dynamic Modulated Power Filter Compensator MPFC

5. DIGITAL SIMULATION RESULTS

Digital simulations studies were carried out on the sample wind-grid seven bus study system shown in Fig. (1). The built-in functional blocks in SIMPOWER toolbox facilitate the simulation of large and complicated power system. The novel MPFC scheme is connected to the radial distribution grid network at bus 5 was validated using continuous mode of digital simulation. Full digital simulation and validation were carried out without and with MPFC located at bus 5. A test period of one second is selected in order to show the MPFC effect on dynamic voltage stabilization, harmonic content reduction and power factor improvement. The dynamic performance of the MPFC compensator was tested under the following load switching actions:

- At t=0.6 second, induction motor was removed at bus 6 for a duration of 0.1 second.
- At t=0.25 second, linear load was removed at bus 5 for 0.15 second.

The wind speed model described in fig.(1) was implemented to display the dynamic response of the system parameters for stochastic wind speed excursion.

The samples of dynamic responses of voltage and power factor at buses 3 and 5 of the distribution grid are shown in Figure 4 and 5, respectively. The voltage level along the distribution feeders are dramatically improved by using proposed MPFC. Besides voltage level improvement, the proposed MPFC is also powerful for power factor correction and regulating voltage profile along the feeder, since reasonable amount of reactive power can be injected by MPFC into the grid according to its demand. Numerical results have indicated that all power factors along the feeder are improved with introducing MPFC compensator above 0.8 and unit power factors are even achieved at bus 3, 4 and 5. In addition, the largest voltage drop is only 5% for the case with MPFC compensator, while the largest voltage drop comes to 20% in the case without MPFC.

The comparison of the total harmonic distortion and harmonic content at each AC bus is made for three specified cases first without, second with the hybrid MPFC compensator for deterministic and third with stochastic wind speed model. Voltage and current harmonic analysis in term of the total harmonic distortion (THD) and magnitude of certain low order harmonics are displayed in Table (1) and Table (2) for three different cases, respectively. It is obvious that the voltage harmonics are significantly reduced by installing MPFC compensator. Fig. (6) displays the dynamic response of the power exchange from the grid during load excursions. Fig. (7) shows the produced torque of the wind turbine for stochastic wind speed variations

6. CONCLUSION

The paper presents a novel MPFC Stabilization and error driven control strategy for wind-grid utilization scheme. The MPFC is digitally simulated and validated using the Matlab/ Simulink/ Sim-Power Software environment. The MPFC Compensator Scheme is controlled by a dynamic error driven action regulator using SPWM-pulsing control strategy. The voltage stabilization is fully validated as well as power quality (PQ) enhancement. Power Factor Correction at all buses is also improved.

The FACTS MPFC scheme can be extended to other distributed/dispersed hybrid renewable green energy interface systems including hybrid AC-DC common bus collection scheme using (Photo-voltaic, Wind, Fuel Cell, Micro-hydro, Wave and Tidal) renewable energy systems. The application of this novel FACTS device in loss reduction and dynamic energy management, demand side management DSM is currently investigated

7.References

[1] M. Marei, T. El-Fouly, E. El-Saodany, M. Salama, *A Flexible Wind Energy Scheme for*

Voltage Compensation and Flicker Mitigation, Power Engineering Society General Meeting, IEEE, vol. 4, 13-17 July, 2003.

[2]Red Electrica Espanola (REE), *Technical Conditions for Renewable Energy Production*, DDR-E/03/536, EDIC 4, 2006.

[3] Z. Saad-Saoud and N Jenkins, *Models for predicting flicker produced by large wind turbines*, IEE Trans., Energy Convesions, vol. 14, no.3, pp. 743-748, Sept. 1999.

[4]F. Kanellos, N. Hatziargyriou, *The effect of variable speed wind turbines on the operation of weak distribution networks*, IEEE Trans., Energy Conversion, vol 17 no. 4, pp 543-548, Dec. 2002.

[5] A. Sharaf, G. Wang, *Voltage Stabilization of stand-alone wind energy conversion system using active power compensator*, International Journal of Global Energy issues, vol. 26, No. 3-4, 2006, pp. 417-429.

[6] I. Abouzahr, R. Ramakumar, *An approach to assess the performance of utility-interactive wind electric conversion systems*, IEEE Transaction on Energy Conversion, vol. 6, No. 4, pp. 627-638, December, 1991.

[7] Adel M. Sharaf, Moataz Ammar, *A Switched Motorized Power Filter Compensator Scheme for AC Motorized Electric Loads*, IEEE Canada Electric Power & Energy Conference EPEC 2008, Vancouver, Canada, 6-7 Oct., 2008.

[8] Sung-Hun Ko, Seong R. Lee, Hooman Dehbonei and Chemmangot V. Nayar, *Application of Voltage- and Current-Controlled Voltage Source Inverters for Distributed Generation Systems*, IEEE Trans. on Energy Conversion, Vol.21, No.3, September 2006.

[9] A. Sharaf, M. El-Sayed, *Dynamic Control of Fuel Cell Powered Water Pumping Station*, International Conference on Renewable Energies and Power Quality (ICREPQ'09), Valencia (Spain), 15th to 17th April, 2009

[10] A. Sharaf, M. El-Sayed, *A Novel Hybrid Integrated Wind-PV Micro Co-Generation Energy Scheme for Village Electricity*, IEEE International Electric Machines and Drives Conference, Miami, Florida, May 3-6, 2009.

[11] Adel M. Sharaf, Mohamed A. H. El-Sayed, *Small Scale Wave Energy Utilization for Water Pumping*, submitted for publication in international journal of power engineering and Green Technology.

Appendix

Wind Energy

(3x3.6 MVA) wind Turbine driven -Induction Generator V_r = 11 kV (L-L) S_r = 10 MVA, C_{self}=170 uf

Modulated Power Filter (MPFC)

C_f = 180 µf R_f = 0.15 Ω L_f = 0.10 mH

PID controller gains:

Kp =10 K_I =5 K_d =5 E-3 weights: γ_v=0.85, γ_{id}= 0.4 and γ_i=0.5 Delay = 20 ms

PWM Switching Frequency:

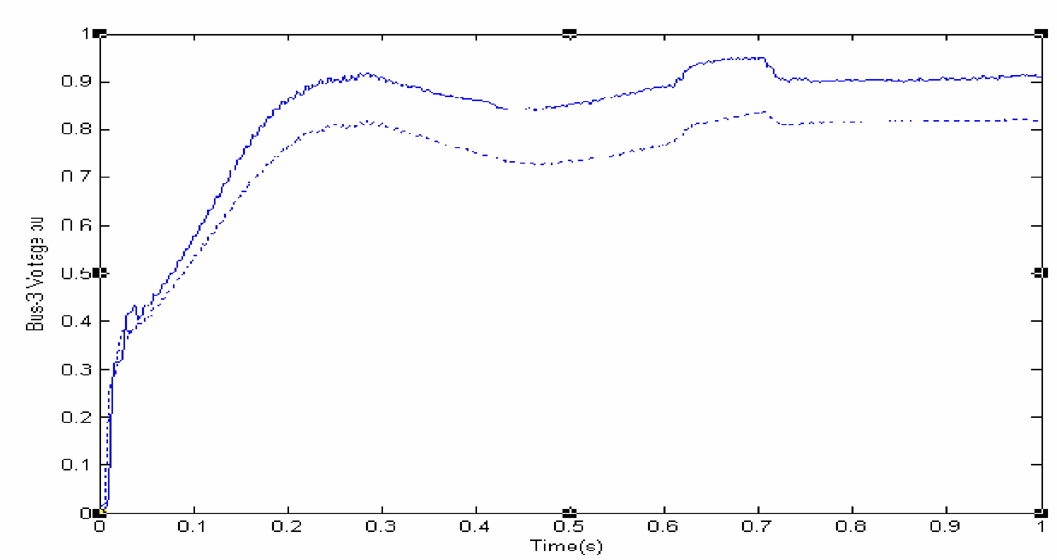
F s/w 1080 Hz

Table(1) Voltage harmonics and $(THD)_v$ at network buses for the three case studies

Bus	Case	THD	3rd	5th	7th	9th
1	1	0.01753	0.001927	0.01556	0.00595	0.0006059
	2	0.02924	0.010151	0.01676	0.00601	0.0011941
	3	0.03435	0.011736	0.02806	0.01209	0.0012131
3	1	0.02185	0.002312	0.02018	0.00766	0.0006141
	2	0.03061	0.012231	0.02021	0.00644	0.0012213
	3	0.05078	0.011941	0.03613	0.02847	0.0014537
5	1	0.03518	0.004983	0.03778	0.01371	0.0009225
	2	0.03537	0.017691	0.03781	0.01411	0.0012051
	3	0.09995	0.018301	0.06802	0.04236	0.0025493
6	1	0.03781	0.005226	0.04351	0.00759	0.0009634
	2	0.06462	0.010873	0.03998	0.01186	0.0030713
	3	0.12823	0.015391	0.08497	0.06508	0.0033431
7	1	0.05579	0.01566	0.04026	0.01182	0.007073
	2	0.09172	0.02744	0.04321	0.01260	0.007615
	3	0.1581	0.01809	0.10340	0.07890	0.004214

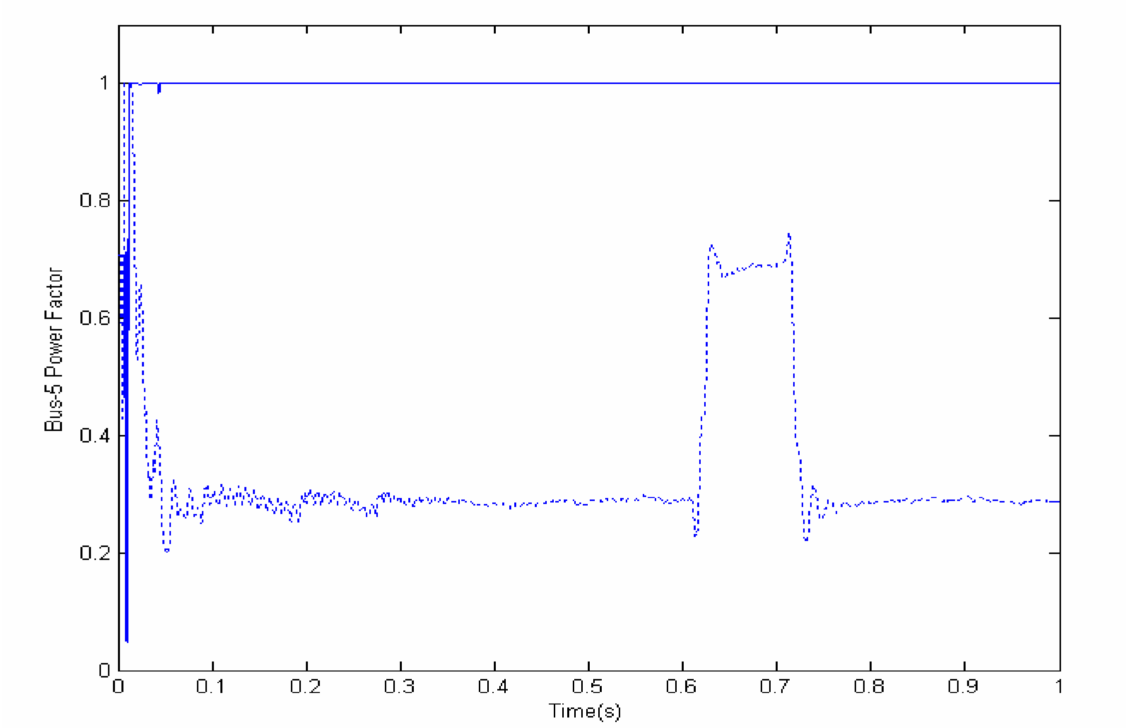
Table(2) Current harmonics and $(THD)_i$ at network buses for the three case studies

Bus	Case	THD	3rd	5th	7th	9th
1	1	0.01343	0.002016	0.004836	0.00276	0.000141
	2	0.01474	0.005795	0.006033	0.00395	0.000235
	3	0.01493	0.006108	0.007626	0.00435	0.000267
3	1	0.04862	0.004701	0.018770	0.00535	0.000681
	2	0.06953	0.017130	0.021250	0.00814	0.003654
	3	0.08175	0.018036	0030711	0.01643	0.003875
5	1	0.06188	0.004943	0.02029	0.00869	0.004068
	2	0.09051	0.001870	0.02308	0.00904	0.004172
	3	0.13010	0.019051	0.042601	0.0289	0.01165
6	1	0.15690	0.006101	0.04861	0.02962	0.004230
	2	0.17411	0.006578	0.04987	0.03021	0.004403
	3	0.18009	0.006691	0.05108	0.03160	0.004585
7	1	0.1569	0.00665	0.04862	0.02962	0.004037
	2	0.1574	0.02720	0.06271	0.01622	0.006210
	3	0.215	0.03058	0.06510	0.01866	0.008271



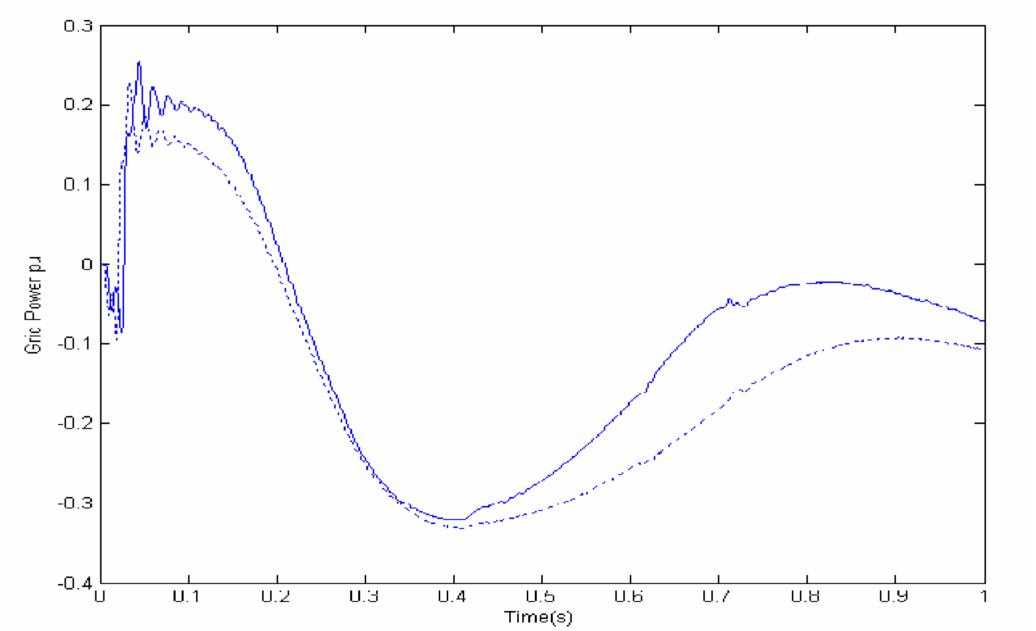
………. Without MPFC _____ With MPFC

Fig.(4) Dynamic Response of voltage at Bus-3 For Load excursion (Removing Linear load between 0.25-0.4s and Induction Motor between 0.6-0.7s)



………. Without MPFC _____ With MPFC

Fig.(5) Power Factor -vs-Time at MPFC Bus-5 For Load excursion (Removing Linear load between 0.25-0.4s and Induction Motor between 0.6-0.7s)



………. Without MPFC _____ With MPFC

Fig.(6) Dynamic Response of Power exchange from the Grid For Load excursion (Removing Linear load between 0.25-0.4s and Induction Motor between 0.6-0.7s)

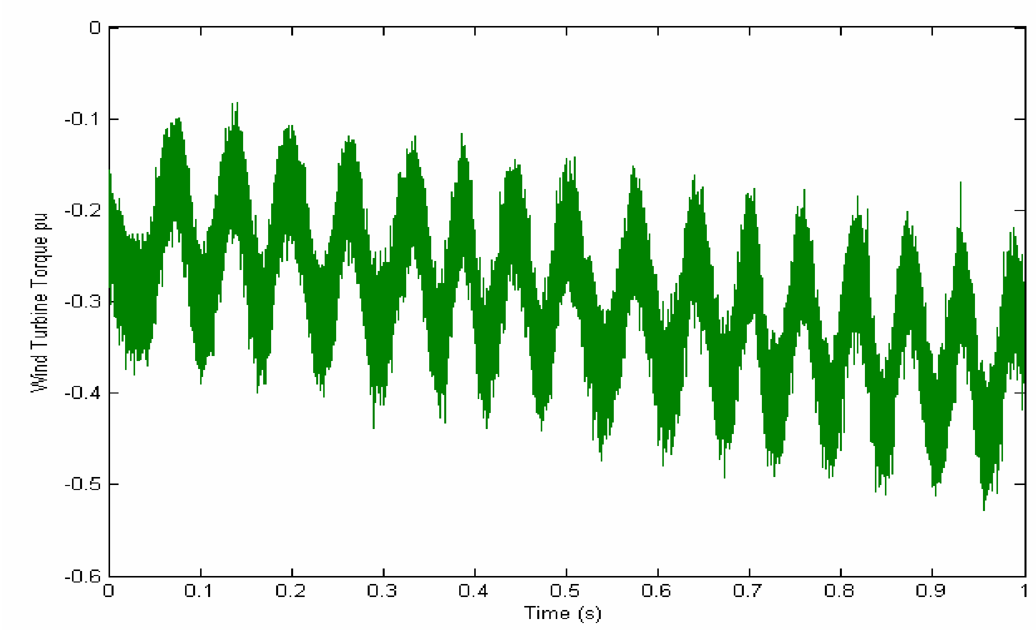


Fig.(7) Torque-vs-time of the Wind Turbine for Stochastic Speed Model with a start speed of 10 m/s, a wind speed ramp of 2 m/s , a wind gust of one m/s at frequency of 100 r/s, and a turbulence component of 0.1 m/s