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A Power Quality Enhancement in a Electric Grid Based Network Using MPFC with Fuzzy Controller

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Abstract: *In this paper a novel modulated power filter compensator (MPFC) is used for power quality improvement on transmission side for the smart grid stabilization and efficient utilization. The MPFC is controlled by a novel tri-loop dynamic error driven inter coupled fuzzy controller. The Fuzzy logic controller based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into automatic control strategy. This paper presents a Digital validation conducted for different cases of load, excursions and fault conditions using the Mat lab/Simulink/Sim-Power software environment without and with the modified power Filter Compensator scheme with fuzzy controller for effective voltage stabilization, power factor correction and transmission line loss reduction.*

Keywords: *FACTS, Dynamic Voltage stabilization, fuzzy controller, Smart Grid, Stabilization, Efficient, Utilization.*

I. INTRODUCTION

The proliferation of microelectronics processors in a wide range of equipments, from home VCRs and digital clocks to automated industrial assembly lines and hospital diagnostics systems has increased the vulnerability of such equipment to power quality problems [1]. These problems include a variety of electrical disturbances, which may originate in several ways and have different effects on various kinds of sensitive loads. As a result of this vulnerability, increasing numbers of industrial and commercial facilities are trying to protect themselves by investing in more sophisticate equipment to improve power quality [2]. 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 [3].Between the different technical options available to improve power quality, active power filters have proved to be an important alternative to compensate for current and voltage disturbances in power distribution systems [4], [5], [6] Different active power filters topologies have been presented in the technical literature, [7] [8] and many of them are already available in the market [1], [2]. Modern active filters are superior in filtering performance smaller inPhysical size, and more flexible in application, compared to traditional passive filters [9], [10]. 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 [11], [12]. Hybrid filters effectively mitigate the problems of both passive filters and pure active filter 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 characteristics of passive filters and hence reduce the rating of the active filters, compared to pure shunt or series active filter solutions [13]-[15]. Many power filter compensation configurations are proposed in literature to enhance power quality and to improve power factor [16]-[18].This paper explores design and analysis of a novel modulated power filter compensator along with fuzzy controller (mamdani rule base) for efficient stabilization and utilization. Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision [19], [20]. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, and fuzzy logic controllers [21]. The Mamdani rule base is a crisp model of a system, i.e. it takes crisp inputs and produces crisp outputs. It does this with the use of user-defined fuzzy rules on user-defined fuzzy variables. The idea behind using a Mamdani rule base to model crisp system behavior is that the rules for many Systems can be easily described by humans in terms of fuzzy variables. Thus we can effectively model a complex non-linear system, with common-sense rules on fuzzy variables [22], [23]. 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. The paper is organized in seven sections. Section II deals with the Modified power filter compensator. Section III Tri loop error driven fuzzy controller with mat lab models. Ac study system is presented in Section IV. Section V presents the Digital simulation results when different loads are applied, Section VI concludes the work.

II. MODIFIED POWER FILTER COMPENSATOR

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 fuzzy controller. The fuzzy controller is equipped with a error and derror-sequenced compensation loop for fast effective dynamic response inaddition to modified PID activation. This scheme of MPFC structure comprises a aeries 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 mat lab model of this scheme structure is shown in Fig. 1

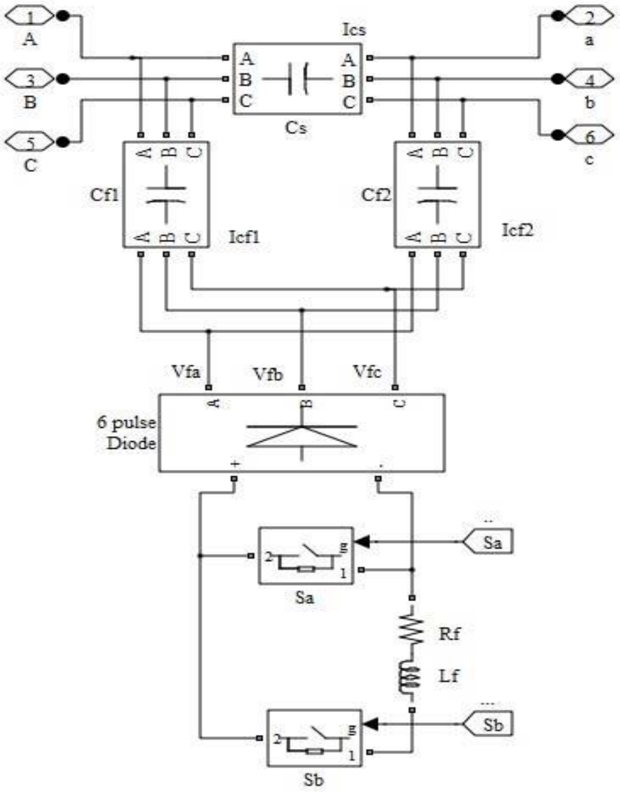


Fig. 1: Modified power filter compensator

III. TRI LOOP ERROR DRIVEN FUZZY CONTROLLER

The tri-loop error-driven fuzzy controller is a novel dual action control used to modulate the power filter compensator [24], [25]. The global error signal is an input to the fuzzy controller to regulate the modulating control signal to the PWM switching block as shown in Figs. 2a & 2b. The fuzzy controller includes an error sequential activation supplementary loop to ensure fast dynamic response and affective damping of large excursion, in addition to modified PID structure.

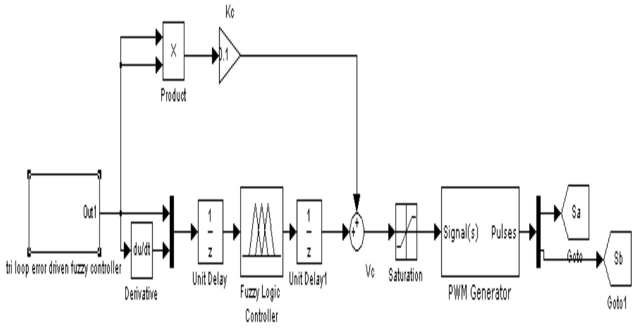


Fig. 2a Modified tri loop error driven fuzzy controller

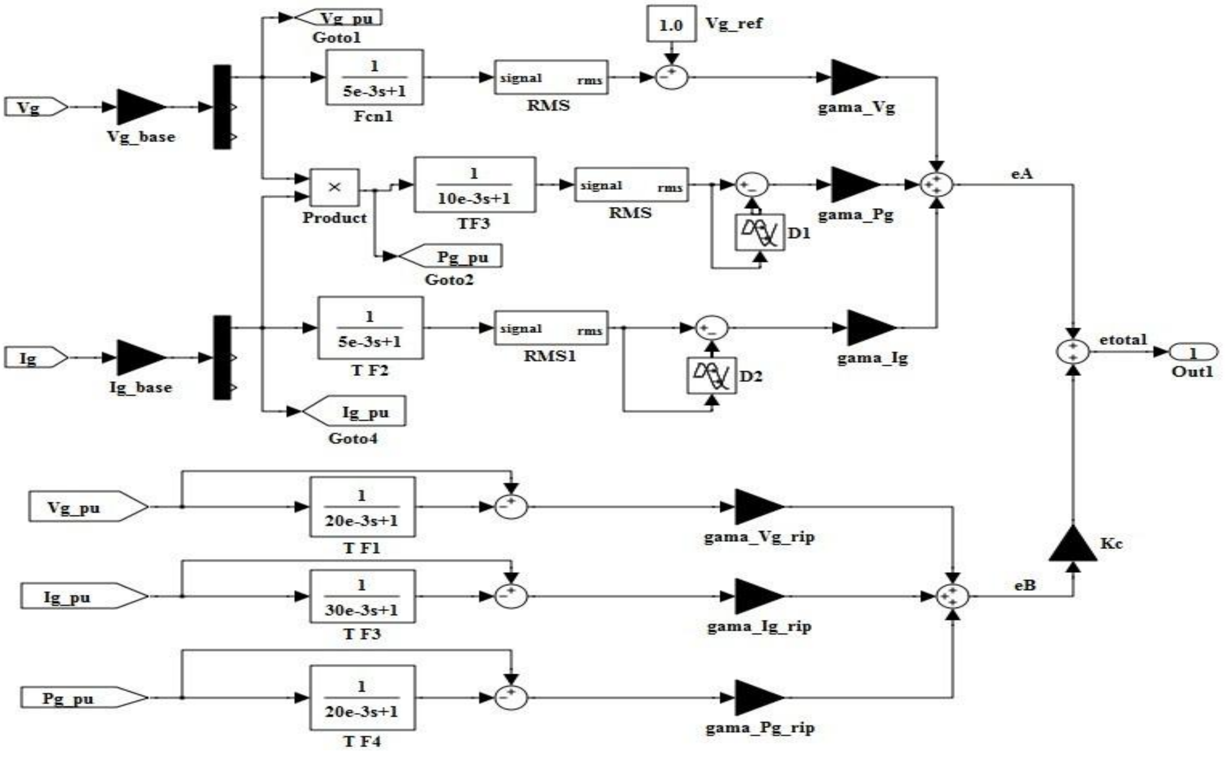


Fig. 2b Mat lab functional model of the Inter-coupled tri loop error driven fuzzy controller.

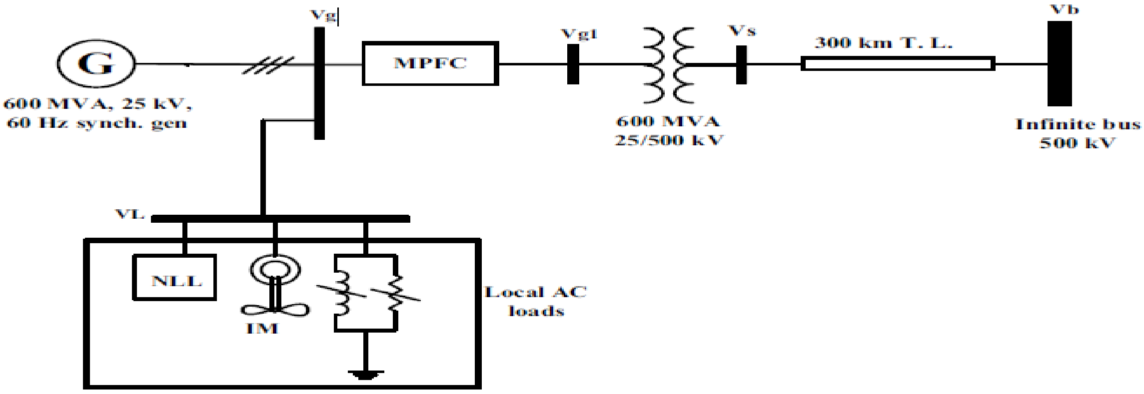


Fig. 3 The single line diagram of the unified EHV study AC system

IV. 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 parameters are given in the Appendix.

V. DIGITAL SIMULATION RESULTS

The Mat lab digital simulation results using MATLAB/SIMULINK/Sim-power Software Environment for proposed MPFC Scheme under three different study cases are:

A. Normal Loading Operating Case:

The dynamic responses of voltage, current, reactive power, power factor, $(THD)_V$, $(THD)_i$, $(FFT)_V$ and $(FFT)_i$at generator bus (V_g), load bus (V_L) and infinite bus (V_b) under normal operation are shown Figs. 4-13. The RMS of voltage and current waveforms of the MPFC are shown in Fig. 14 and Fig. 15. The modulated tuned power filter switching signals that are generated by the dynamic tri loop error driven fuzzy controller are shown in Fig16. The stable voltage signal of synchronous generator power system stabilization (PSS) is depicted in Fig. 17. The Transmission line losses are shown in Table I.

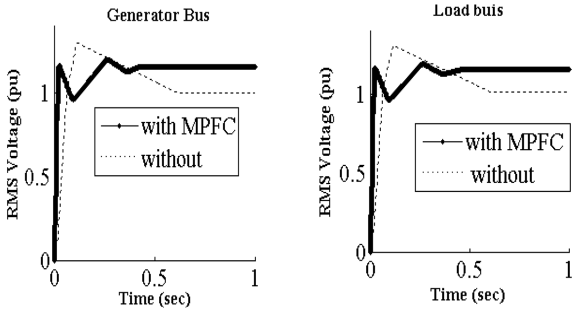


Fig. 4 The RMS voltage at AC buses under normal operation

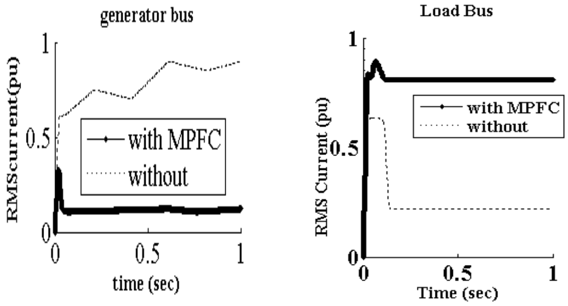


Fig. 5 The RMS current at AC buses under normal operation

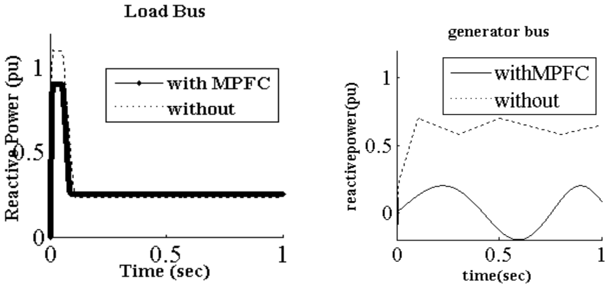


Fig. 6 The reactive power at AC buses under normal operation

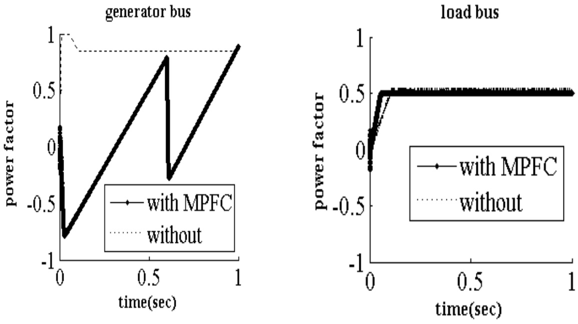


Fig. 7 The power factor at AC buses under normal operation

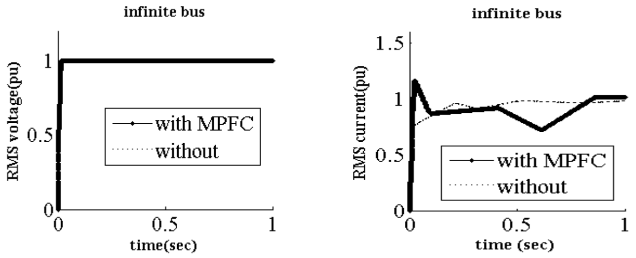


Fig. 8 The RMS voltage and current at the infinite bus under normal operation.

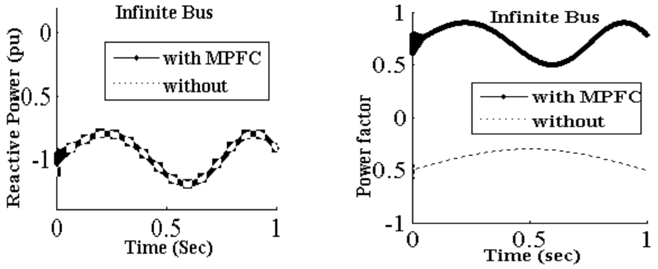


Fig. 9 The reactive power and power factor at the infinite bus under normal operation.

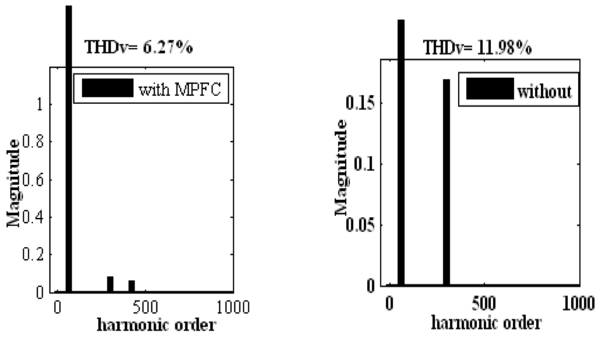


Fig. 10 THD and FFT of voltage waveforms at the load bus

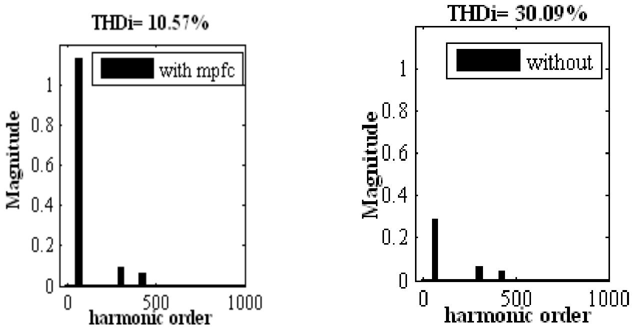


Fig. 11 THD and FFT of current waveforms at the load bus

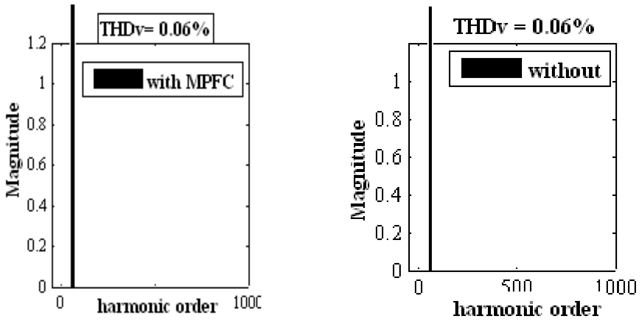


Fig. 12 THD and FFT of voltage waveforms at the infinite bus

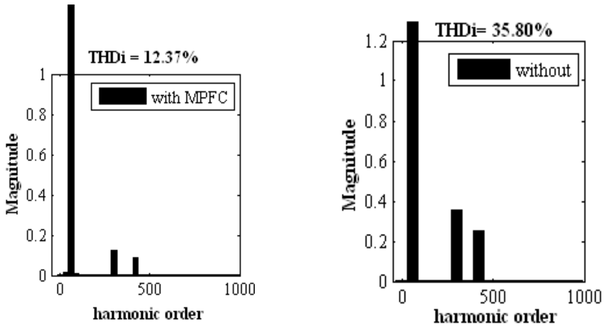


Fig. 13 THD and FFT of current waveforms at the infinite bus

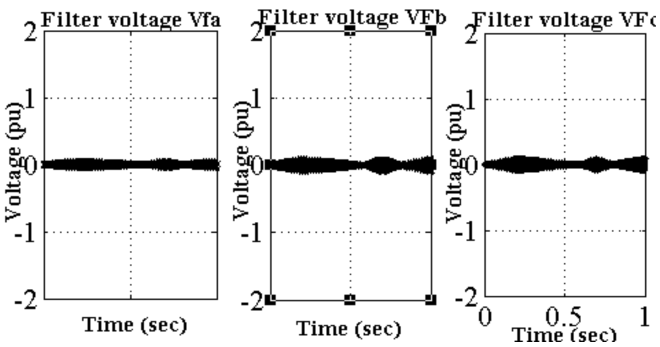


Fig. 14 The voltage waveforms of MPFC

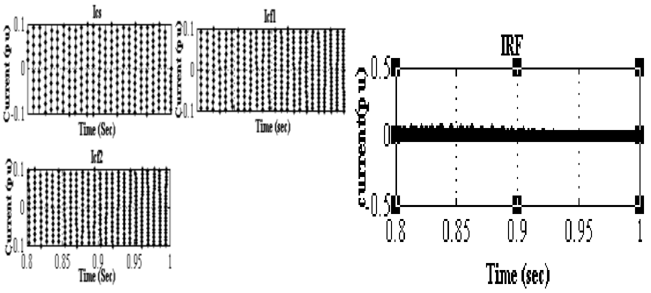


Fig. 15 The current waveforms of MPFC

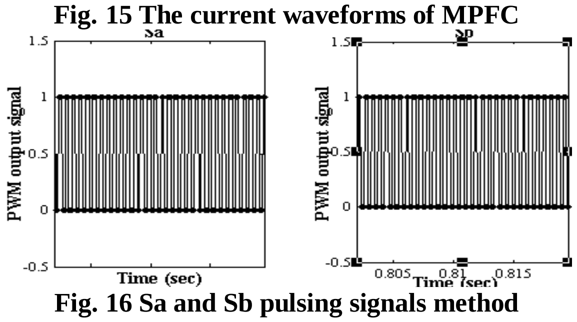


Fig. 16 Sa and Sb pulsing signals method

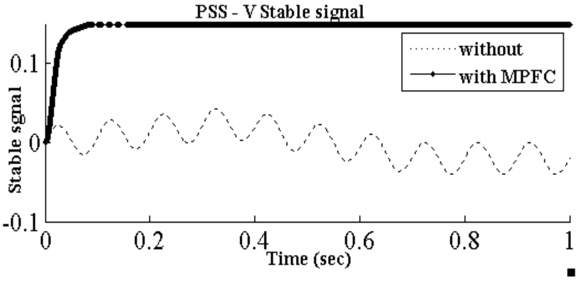


Fig. 17 PSS stable voltage signal

The previous figures confirm the compensation effectiveness as well as the harmonic filtering of the proposed MPFC.

B Short Circuit Fault Condition Case:

A three phase short circuit (SC) fault is occurred at bus Vs 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.

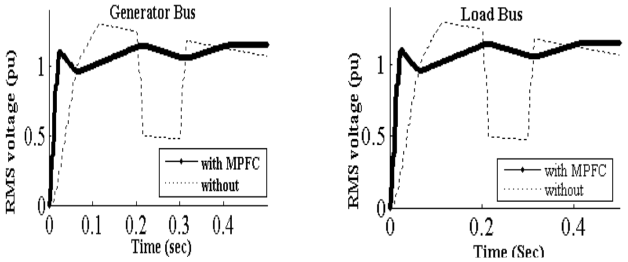


Fig. 18 The RMS Voltage at generator and load buses under short circuit (SC) fault condition at bus V_S

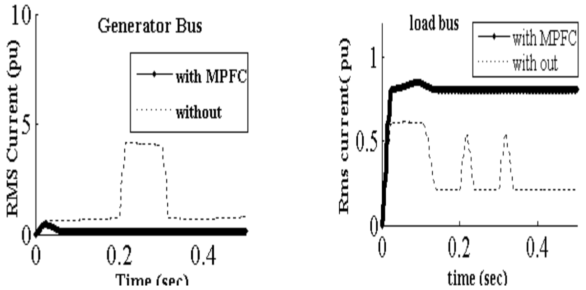


Fig. 19 The RMS current at generator and load buses under short circuit (SC) fault condition at bus V_S

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.

C Hybrid Local Load Excursions Case:

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 disconnected 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 duration 0.05 sec.

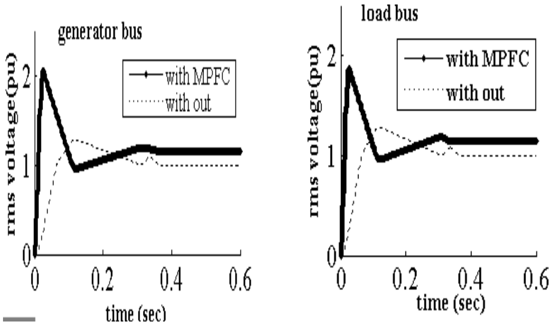


Fig. 20 The RMS voltage waveform at the generator and load buses under load excursions

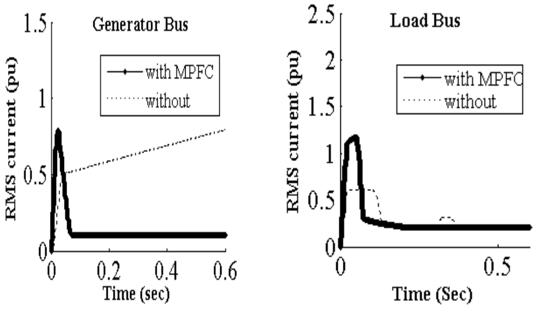


Fig. 21 The RMS current waveform at the generator and load buses Under load excursion

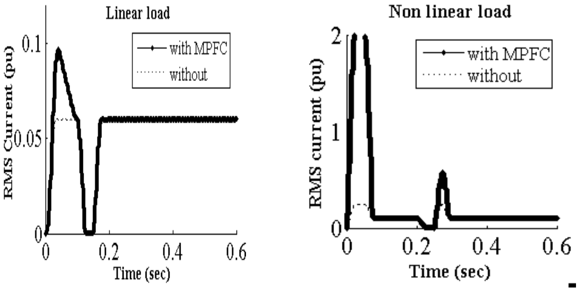
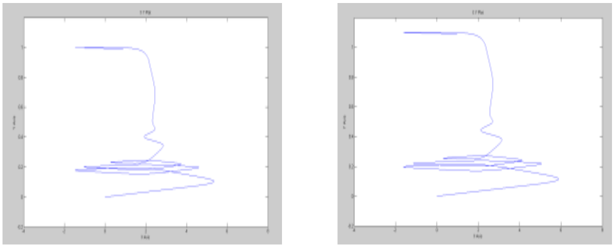


Fig. 22 The linear and nonlinear load RMS current waveforms

The RMS 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.



(a) (b)

Fig. 23 The speed-torque relationship of the induction motor with (a) and without mpfc (b)

TABLE I THE TRANSMISSION LINE LOSSES

		PLoss	Qloss	Sloss
Case 1	**without**	0.0832	0.1542	0.1752
	with	0.008	0.005	0.005064
Case 2	**without**	0.1954	0.3467	0.398
	with	0.0008	0.005	0.005064
Case 3	**without**	0.1018	0.1869	0.2128
	with	0.0009	0.0045	0.004589

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 excursion, it is quite apparent that the proposed MPFC enhanced the power quality, improved power factor voltage and reduced the transmission line losses.

VI. CONCLUSION

This paper presents a novel modulated switched power filter compensator (MPFC) scheme is controlled by a dynamic tri-loop dynamic error driven fuzzy controller. 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. The proposed MPFC scheme has been validated for effective power quality improvement, voltage stabilization, and power factor correction and transmission line loss reduction when the system is extensively simulated in MATLAB/SIMULINK.

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

Rotor resistance and leakage inductance (Pu)

R_r = 0.01909, L_r=0.0397

Mutual inductance Lm (Pu) =1.354

4) Transmission Line

$V_{L\text{-}L}$ = 500 kV, 300 km length, R/km=0.01273 Ω, L/km=0.9337 mH

5) Infinte Bus: $V_{L\text{-}L}$ = 500 kV

6) MPFC: C_s = 30µF, C_{f1} = C_{f2} = 125µF, R_f = 0.25Ω, L_f =3mH

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