

Power Quality Improvement in Wind Smart Grid Using Facts SSFC

K. S. Mani, D Padmavathi, R.Srinivasa Rao

Abstract: *In general, the FACTS concept is dependent on the significant inclusion of power electronic devices and methods into the side of the network at which the voltage is high, so that it is electronically controllable. However, FACTS is a novel concept that was brought to achievement during 1980s at the Electric Power Research Institute (EPRI). In this paper FACTS based Static Switched Filter Compensation (SSFC) scheme is presented. This FACTS SSFC scheme is an efficient tool for power quality improvement, voltage stabilization, power losses reduction and power factor enhancement and is interfaced with Smart Grid-Distribution Networks. The two regulators that control the FACTS SSFC-device are based on a tri-loop dynamic error driven inter-coupled input to VSC controller. The FACTS Static Switched Filter Compensator Scheme has been validated using Matlab/Simulink environment.*

Keywords: *FACTS, Static Switched Filter Compensator, Wind Energy, Dynamic Controllers, Power Quality, SSFC.*

I. Introduction

The utilization of the renewable energy resources such as wind, hydro, co-generation, biomass etc results in having sustainable growth and social progress. The usage of renewable source and energy conservation are the key paradigm in sustainable energy system. The environmental force on conventional plant is minimized by the integration of the renewable energy resource like wind energy into power system. This integration presents technical challenges for which voltage regulation and power quality problems are to be considered. The power quality is an essential customer-centralized measure which is greatly affected by the distribution and transmission network's operation. The power quality issue is of great significance to the wind turbine. There has been an extended growth and fast development in using wind energy these years.

Wind energy conversion systems (WECS) are a form of feasible and effective renewable energy source that converts the wind kinetic energy to the mechanical energy. This energy can be used to drive dissimilar AC and DC type generators. Generally, the WECS consists of a wind turbine, generator, gear box, interconnection converter, and the necessary control systems. The WECS can be connected as either standalone or connected to the electric grid system, in the standalone connection the power is supplied to local isolated loads in remote areas. It is required to provide economical and effective technical solutions for both power quality and security issues concerned to the electric grid with schemes such as distributed and dispersed wind energy schemes. Satisfyingly, the new arising FACTS technologies can perform stabilization and power control functions by rapidly switching solid-state devices.

Generally, FACTS devices are employed in transmission control while custom power devices are for distribution control. The custom power devices like Unified Power Flow Controller (UPFC), Synchronous Static Compensator (STATCOM), Dynamic Voltage Restorer (DVR), solid state transfer switch and solid-state fault current limiter have been developed for elaborating reliability and power quality of a system. Progressive control and enhanced semiconductor switching of these devices have arrived at a new era for mitigation of power quality. The development of these devices such as FACTS and custom power is for reducing specific power quality problems. For example, UPFC works best for control of power flow, DVR as a series compensator is used for voltage sag compensation and STATCOM as a shunt compensator is employed for compensation of both reactive power and voltage sag. As STATCOM, DVR, UPS etc are useful for compensating a specific kind of power quality problems, it has become significant to develop a new type of Unified Series-Shunt Compensator (USSC) which can reduce a wider range of power quality problems.

This paper presents a FACTS based Static Switched Filter Compensator (SSFC) scheme for effective power quality enhancement, voltage stabilization, power factor improvement and losses reduction in distribution grid networks with the distributed wind energy interface. The FACTS SSFC scheme is dependent on the controlled complementary switching process between two capacitor banks. The switching process is achieved by novel dynamic control strategies and the pulse width modulation-complementary switching (PWM). Two error dynamic regulation schemes are utilized with a tri-loop dynamic error intercoupled control strategy and a VSC controller. The FACTS-SSFC scheme has been validated for effective improvement of power quality, power losses reduction, voltage stabilization, and power factor enhancement using Matlab/Simulink environment.

II. The Static Switched Filter Compensator

Fig. 1 depicts the FACTS SSFC scheme in which the series capacitor C_{s1} is in series with the line conductors in order to compensate part of the feeder inductance dynamically. Such reduction enhances the power flow and mitigates the feeder reactive power loss. The two three phase shunt capacitor banks C_{f1} and C_{f2} are connected with the two series capacitor terminals in parallel. The shunt capacitor banks supply reactive power compensation and also improve the regulation of distribution feeder.

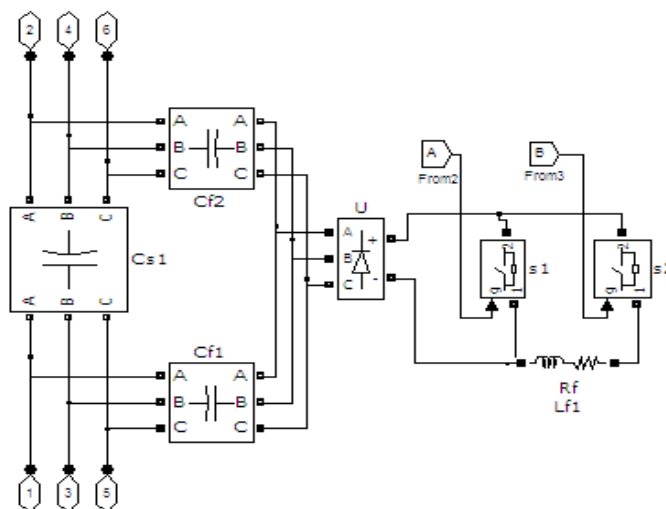


Fig. 1 The FACTS Static Switched Filter Compensator scheme

The series capacitor bank operates as a dynamic voltage booster and inflow current limiting device. For the capacitor, the energy discharge path is formed by the six pulses diode rectifier including the resistance (R_f) and inductance (L_f) branch which forms a tuned arm filter at the DC side of the rectifier. The two complementary switching pulses P_1 and P_2 controls the two IGBT switches S_1 and S_2 . The pulses are generated by the modified VSC controller, as depicted in Fig. 2. The fluctuating topology of the FACTS-SSFC can be varied by the complementary PWM pulses as follow:

Case 1: If P_1 is high and P_2 is low, the resistor and inductor will be fully shorted and the combined shunt and series capacitors will provide the required shunt and series capacitive compensation to the AC distribution system.

Case 2: If P_1 is low and then P_2 is high, the resistor and inductor will be connected into the circuit as a tuned arm filter.

III. Controller Design

Inter-coupled dynamic control depending on two regulators A and B are proposed to mitigate the harmonics, stabilize the buses voltage and improve the power factor using the FACTS SSFC. To adjust the switched filter compensator the tri-loop error driven dynamic controller is used which is a dual action control. The global error is the sum of the output of the two inter-coupled regulators. The input of the VSC controller is the global error signal which regulates the modulating control signal to the PWM switching block as depicted in Fig. 2.

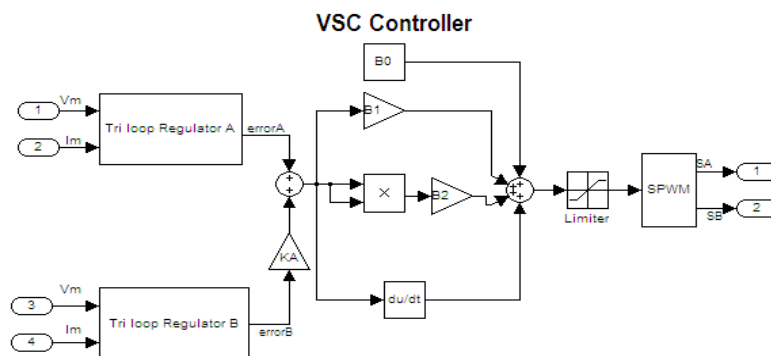


Fig. 2 The VSC control of the FACTS SSFC scheme

A. Regulator A:

Regulator A is shown in Fig. 3, in which the current and voltage waveforms are used in a tri loop error to give a stable voltage at all AC buses and also to improve the power factor. This is acquired by modulating the SSFC admittance.

B. Regulator B:

The regulator B which is shown in Fig. 4, is used to suppress any current and voltage harmonic ripples and thus mitigate the harmonics.

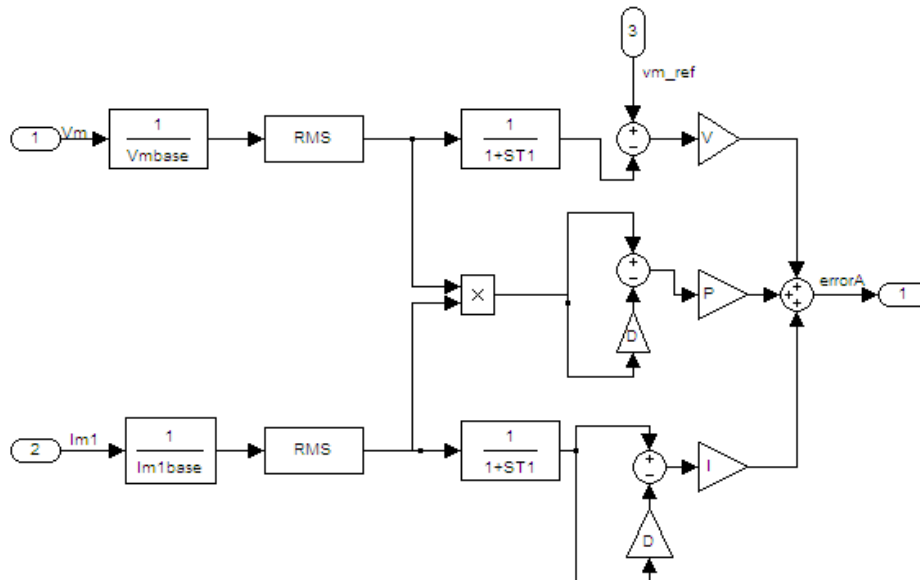


Fig. 3 The tri-loop error driven regulator A

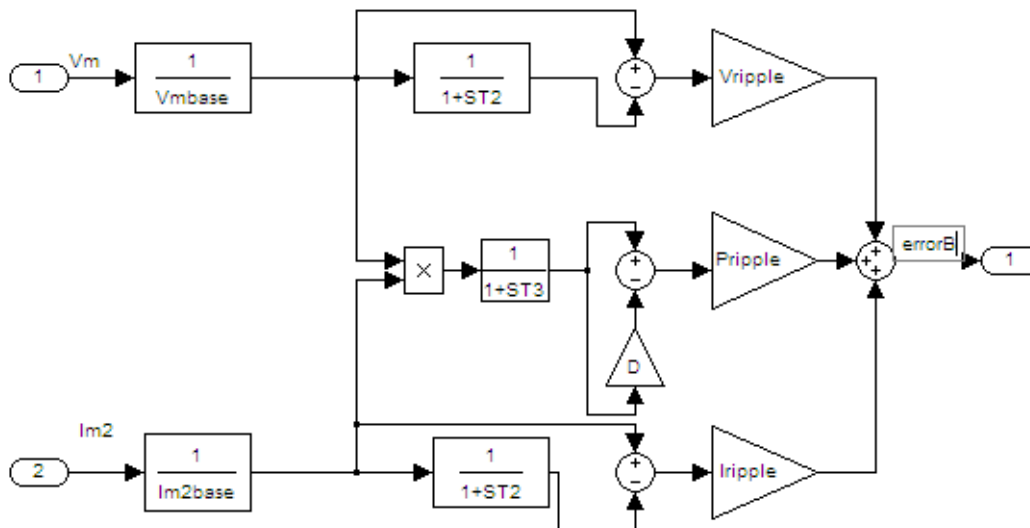


Fig. 4 The tri-loop error driven regulator B

3.1 PID Controller

PID controllers are the most commonly-used type of controller for applications in industries. Structurally they are simple in nature and show robust performance over a huge range of operating conditions. These kinds of controllers are the most effective of choices in the absence of the full knowledge of the process. The three main parameters involved in this controller are Proportional (P), Integral (I) and Derivative (D). The proportional part is responsible for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate of change of error in the process respectively. Figure 5 depicts the basic block diagram of a PID controller.

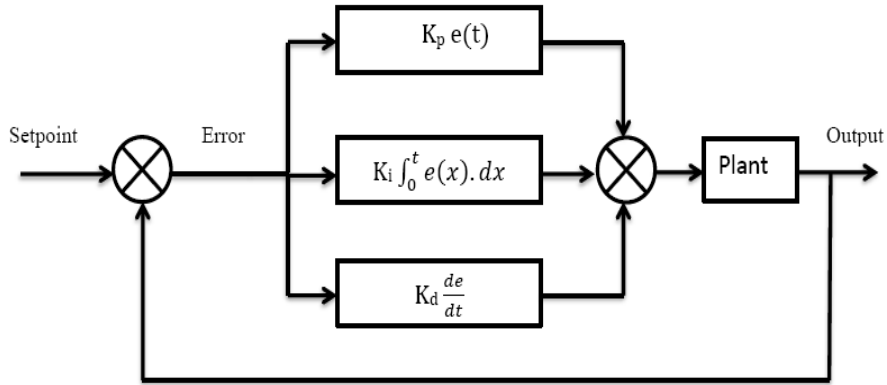


Fig. 5 Basic block diagram of a PID controller

For the PID controller presented in Fig. 5,
Output of the PID controller,

$$u(t) = K_p e(t) + K_i \int_0^t e(x) \cdot dx + K_d \frac{de(t)}{dt} \tag{1}$$

where,

Error $e(t)$ =Setpoint- Plant output

K_p = proportional gain, K_i = integral gain, K_d = derivative gain

IV. Simulation Results

A. The AC System Configuration

The studied AC system is 11 kV distribution network with a renewable wind energy source which is connected to AC grid of 138 kV via step up transformer which is of 11/138kV. A hybrid load consisting of a linear, nonlinear and an induction motor load is connected to the distribution network via 11/4.16kV step down transformer. Fig. 6 shows a block diagram of FACTS-SSFC scheme.

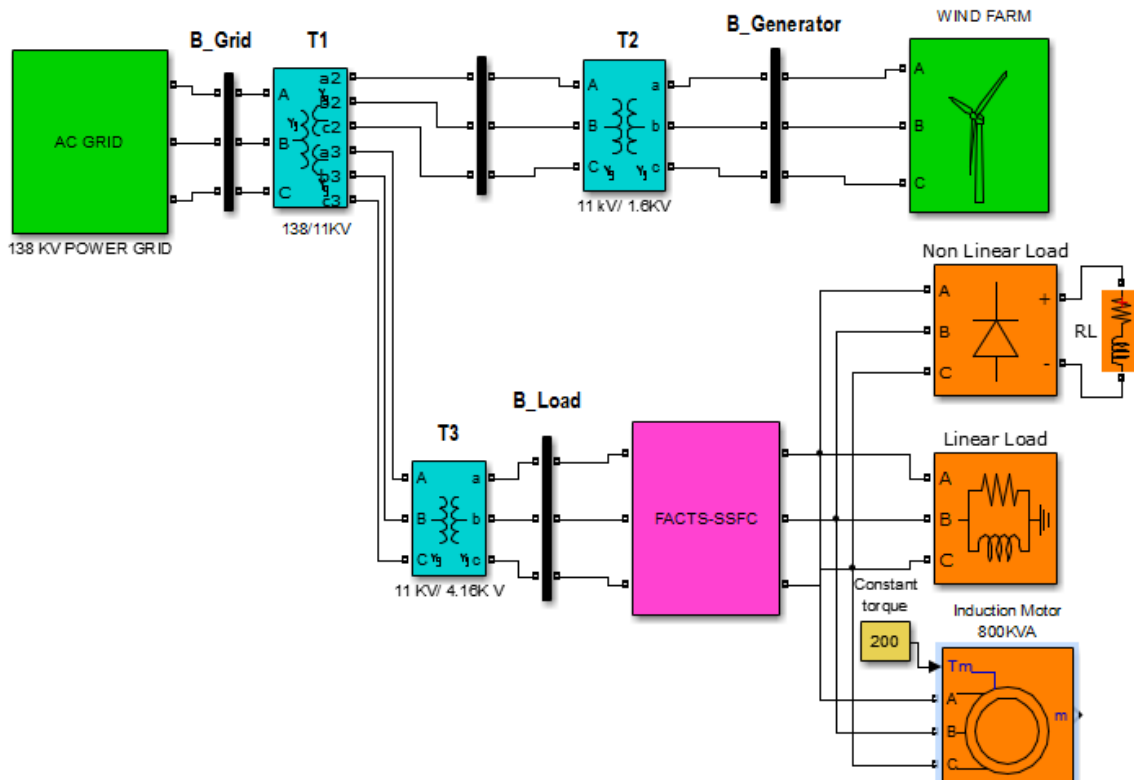


Fig. 6 Block Diagram of Grid connected wind smart system with FACTS-SSFC scheme

B. Simulation Results

The digital simulation results of the proposed SSFC scheme are carried out in Matlab/Simulink environment. Figures 7 and 8 shows the grid connected wind smart system without and with FACTS-SSFC scheme respectively. These are validated for one study case such as:

Case 1: Normal Loading Operation

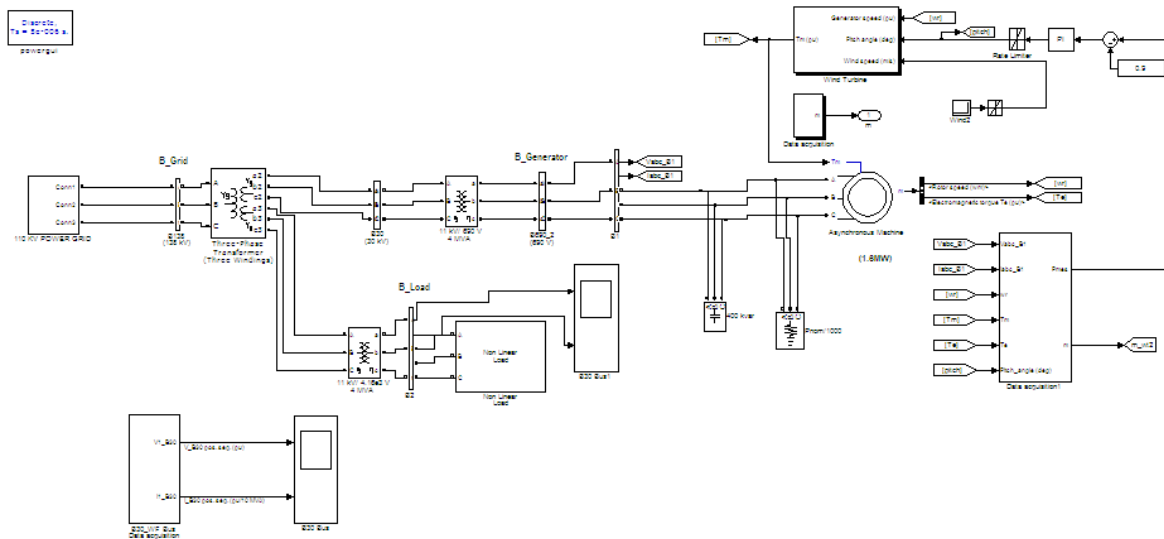


Fig 7. Grid connected wind smart system without FACTS-SSFC scheme

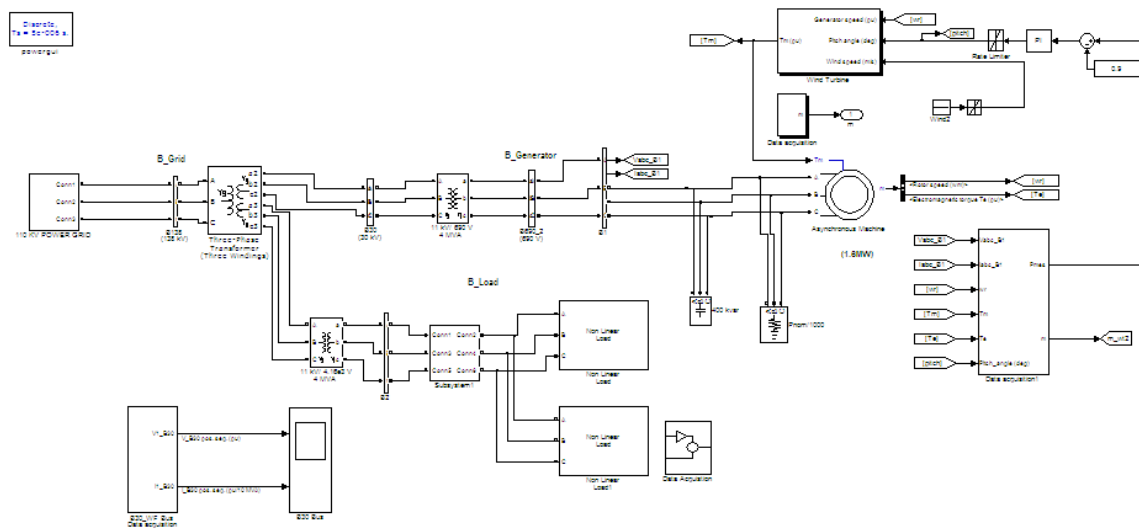


Fig 8. Grid connected wind smart system with FACTS-SSFC scheme

Case 1: Normal Loading Operation

Under normal loading operation condition, the dynamic response of the voltage at the generator bus (Bg), load bus (BL) and grid bus (Bi) without and with using the FACTS filter are depicted in Figs. 9 and 10. The rms value of the voltage at the generator bus and load bus is increased by using the FACTS-SSFC while at the grid bus it remained same.

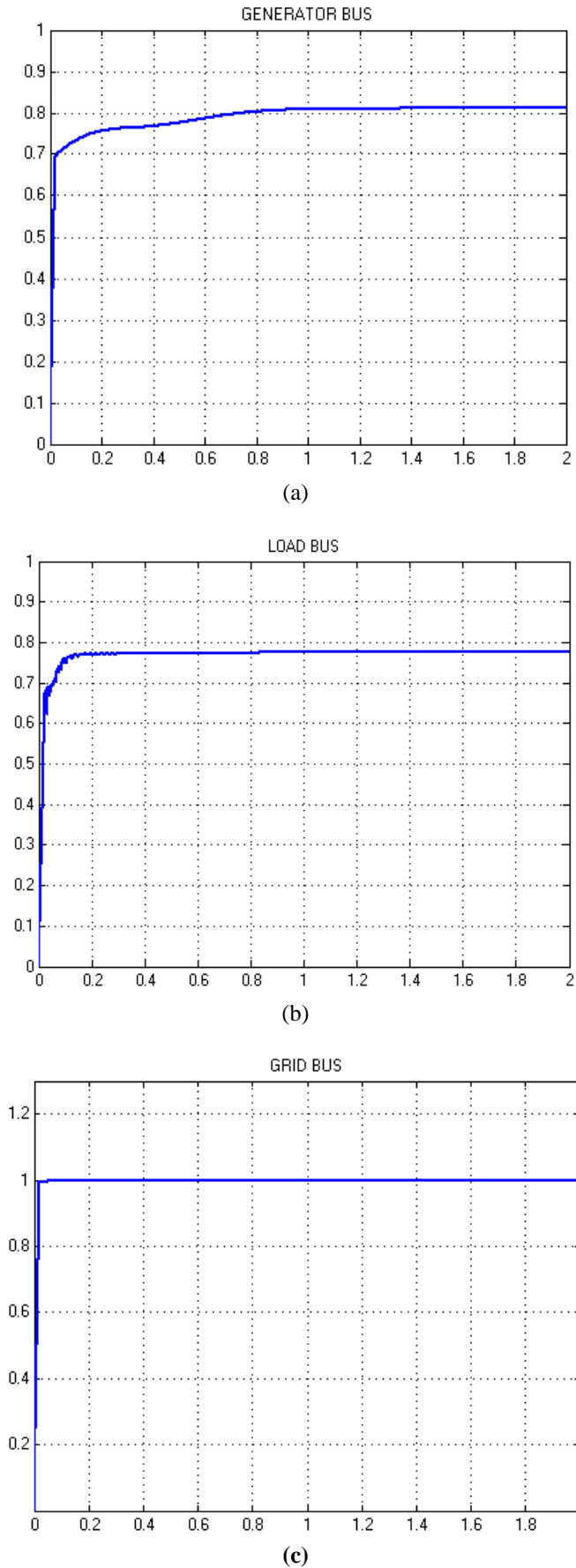


Fig.9 The rms voltage at (a) Generator bus, (b) Load bus, (c) Grid bus without SSFC

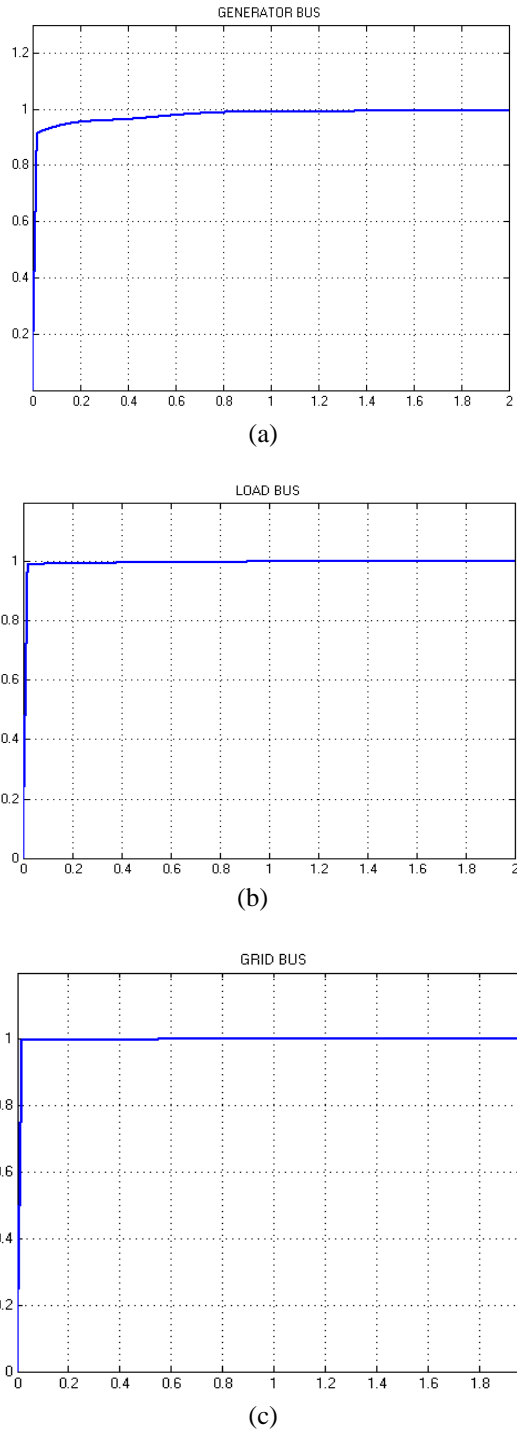


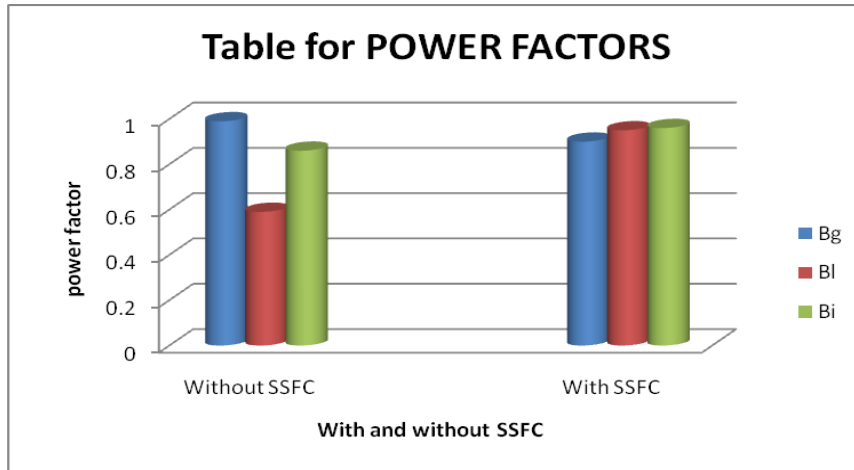
Fig.10 The rms voltage at (a) Generator bus, (b) Load bus, (c) Grid bus with SSFC

The analysis of current and voltage harmonics in terms of THD i.e., Total Harmonic Distortion is presented in Table I. The voltage harmonics are reduced to a level within the limit set specified by the IEEE Std.519-1992. The total harmonic distortion of the current waveform is decreased at each bus.

Table I THD of the Voltage and Current Waveforms

	%THD of Voltage Waveform		%THD of Current Waveform	
	Without	With SSFC	Without	With SSFC
Generator bus B_g	5.28	0.06	5.66	0.36
Load bus B_L	11.63	0.22	8.28	5.76
Infinite bus B_i	0.06	0.01	9.00	0.59

The following bar graph shows the power factor values at Generator bus, Load bus and Grid bus.



The graph shows the three buses, generator bus Bg, load bus Bl, grid bus Bi without SSFC and also with SSFC respectively. From the graph a considerable improvement is observed at load bus that is from 0.59 to 0.95. At infinite bus it is improved from 0.86 to 0.96. The performance of the system is observed with PID Controller and without PID controller ensuring the improved performance with PID controller and WITH SSFC. Table II shows the %THD voltage and %THD current of three buses such as infinite bus, generator bus and load bus without SSFC, with SSFC and with SSFC plus PID respectively.

Table II Total Comparison Table

S.NO	BUSES	WITHOUT SSFC		WITH SSFC		WITH SSFC AND WITH PID	
		%THD voltage	%THD current	%THD voltage	%THD current	%THD voltage	%THD current
1	Infinite Bus, Bi	0.09	12.49	0.01	0.98	0	0.97
2	Generator Bus Bg	4.42	5.34	0.09	0.96	0.13	0.96
3	Load Bus, Bl	5.72	19.98	0.20	5.3	0.01	0.39

V. Conclusion

This paper has presented a FACTS based Static Switched Filter Compensator (SSFC) scheme for effective power quality improvement, voltage stabilization, reduction of losses and power factor enhancement in distribution grid networks with the dispersed wind energy interface. The FACTS SSFC is based on controlled complementary switching process between two capacitor banks to be connected with the classical tuned. The switching process is achieved by novel dynamic control strategies and the pulse width modulation complementary switching (PWM). The power quality can be further improved by using fuzzy logic controller in future.

Appendix

Parameters of the AC system with wind energy

- 1) Wind turbine $P_{out} = 1.6$ MW.
- 2) Squirrel cage induction generator
 - 3 phase, 1 pair of poles, $V_g = 1.6$ kV, 60 Hz, $S_g = 1.6$ 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 (1.6 MVA, 4.16 kV)
 - Linear load: 300 kVA, 0.8 lag pf.
 - Non-linear load: 500 kVA.
 - Induction motor: 3phase, 800 kVA, 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) 10 km & 5 km feeders
 - $V_{L-L} = 11$ kV, $R/km=0.01273 \Omega$, $L/km=0.9337$ mH
- 5) AC Grid: $V = 138$ kV
- 6) SFC: $C_s = 3\mu F$, $C_{f1} = C_{f2} = 12.5\mu F$, $R_f = 0.25\Omega$ and $L_f = 3mH$
- 7) Controller gains: $\gamma_{vg}=1$, $\gamma_{ig}=0.5$, $\gamma_{pg}=0.25$, $\gamma_{vg-rip}=1$, $\gamma_{igrip}=1$, $\gamma_{pg-rip}=0.5$, $B_0=0.5$, $B_1=10$, $B_2=0.1$, and PWM frequency $f_s=1750$ Hz.

References

- [1]. Thomas Ackermann, Wind Power in Power Systems, 2005, John Wiley & Sons Ltd.
- [2]. Jamal A. Baroudi, Venkata Dinavahi, Andrew M. Knight," A review of power converter topologies for wind generators", Renewable Energy, vol. 32 , pp 2369-2385, 2007.
- [3]. J. M. Carrasco, and etc," Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey", IEEE Transactions on Industrial Electronics, vol. 53, no. 4, pp 1002-1016, August 2006.
- [4]. Narain G. Hingorani and Laszlo Gyugyi, Understanding FACTS: concepts and technology of flexible AC transmission system, Institute of Electrical and Electronics Engineers, Inc. 2000.
- [5]. A.M. Sharaf, and K. 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.
- [6]. E. Babaei, M. F. Kangarlu, M. Sabahi, "Mitigation of Voltage Disturbances Using Dynamic Voltage Restorer Based on Direct Converters", IEEE Transactions on Power Delivery, vol. 25, no. 4, pp 2676-2683, October 2010.
- [7]. W. C. Lee, D. M. Lee, T. K. Lee," New Control Scheme for a Unified Power- Quality Compensator-Q With Minimum Active Power Injection", IEEE Transactions on Power Delivery, vol. 25, no. 2, pp 1068-1076, April 2010.
- [8]. A. M. Sharaf, A. A. Abdelsalam, "A Novel FACTS Based Dynamic Voltage Compensation Scheme for Smart Electric Grid Stabilization and Efficient Utilization" IEEE Canadian Conference on Electrical and Computer Engineering, 2011, CCECE '11, pp 42-47.
- [9]. 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.
- [10]. 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, pp 404- 409.
- [11]. 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.
- [12]. IEEE Std 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems", 1992.

BIOGRAPHIES

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