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Enhancement of Power Quality in Wind Connected Grid System using SSFC with Fuzzy Logic Controller

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Abstract: Wind energy is an affluent renewable energy source that can be able to nourish isolated electric loads and also grid connected ones. Wind energy schemes have the capacity to considerably lessen the utilization of fossil fuels used in the generation of electric energy. The power quality issues occur when the grid is interfaced with the wind energy and nonlinear loads. Flexible AC Transmission (FACTS) has been broadly used to improve power transfer capability and power quality improvement. This study presents FACTS based Static Switched Filter Compensation (SSFC) scheme and a Fuzzy Logic Controller (FLC) for handling power quality issues. The proposed controller helps in power quality improvement, voltage stabilization, power losses reduction and power factor enhancement. The validation is done using MATLAB/Simulink environment.

Key words: FACTS, Static Switched Filter Compensator (SSFC), Fuzzy Logic Controller (FLC), wind energy, dynamic controllers, power quality

INTRODUCTION

Electrical energy is the simple form of energy and is well regulated. It can be simply changed to other forms. Besides its quality, continuity has to be maintained for good economy. Wind energy is a good source in supplying electricity obtained by the conversion of kinetic energy of moving air into electricity. It extensively reduces the environmental pollution and is almost the greatest economic sources of renewable energy sources. Power quality has turn out to be a major concern intended for today’s power industries and consumers. The power quality issues are occurred by increasing demand of electronic equipments and non-linear loads. A power quality problem can be defined as any variation in voltage, current or frequency that may result in an equipment failure or malfunction. The nonlinear loads for example power supplies, rectifier equipment used in telecommunication networks, domestic appliances, adjustable speed drives, etc., present highly non-linear characteristics (Ackermann, 2005). Because of their non-linearity, the loads have become the major causes and the major victims of power quality issues. Also, the continuous variations in wind speed resulting in the wind power variations lead to power quality issues (Baroudi *et al*., 2007; Carrasco *et al*., 2006).

FACTS devices help in eliminating line current harmonics, improving power factor and increasing power quality (Hingorani and Gyugyi, 2000). This study presents a FACTS based Static Switched Filter Compensator (SSFC) scheme and a Fuzzy Logic Controller (FLC) for effective power quality enhancement, voltage stabilization, power factor improvement and losses reduction in distribution grid networks. The FACTS SSFC scheme is based on the controlled complementary switching process between two capacitor banks. Two error dynamic regulation schemes are utilized with a tri-loop dynamic error inter-coupled control strategy and a VSC controller. The switching process is achieved by novel dynamic control strategies and the Pulse Width Modulation complementary switching (PWM). Fuzzy logic controller is primarily based on making decisions with imprecise, vague and inaccurate information. The FACTS-SSFC scheme and FLC has been validated using MATLAB/Simulink environment.

MATERIALS AND METHODS

Controller design

Static switched filter compensator: The static switched filter compensator scheme is depicted in Fig. 1. It is noticed that the series capacitor CS1 is in series with the

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line conductors to facilitate compensation of part of the feeder inductance dynamically. This results in the enhancement of the power flow and mitigation of the feeder reactive power loss. There are two shunt Capacitor banks CF1 and CF2 which are of three phase and are connected in parallel to the series capacitor terminal CS1. The CF1 and CF2 supply reactive power compensation and also progress the regulation of distribution feeder.

The series Capacitor bank CS1 serves as a dynamic voltage booster and inflow current limiting device. The path for the energy discharge is composed by the six pulses diode rectifier and the resistance (RF) and inductance (LF) branch. The RF and LF branch forms a tuned arm filter at the DC side of the rectifier. The two complementary switching pulses P1 and P2 controls the two IGBT switches S1 and S2 and pulses are generated by the modified VSC controller (Sharaf, 2006).

The VSC control of the FACTS SSFC scheme: Figure 2 and 3 show the VSC controller of FACTS SSFC scheme and fuzzy logic controller, respectively. The input for this is the global error signal which is sum of the output of the two inter-coupled regulators. The modulating control signal of the PWM switching block is regulated by the global error signal. The proposed inter-coupled dynamic control depends on two regulators A and B and it reduces the harmonics, soo the the buses voltage and progress the power factor using the FACTS SSFC scheme. The tri-loop error driven dynamic controller is a dual action control used to adjust the switched filter (Sharaf *et al*., 2011; IEEE Std., 1993).

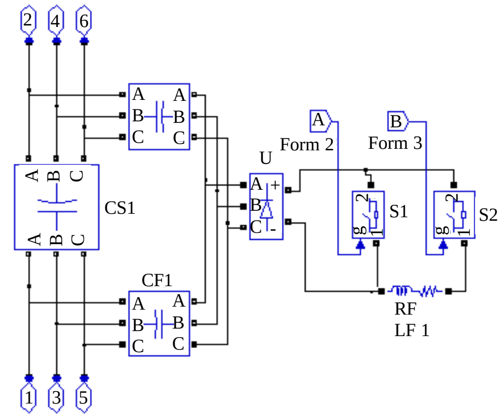

Fig. 1: The FACTS static switched filter compensator scheme

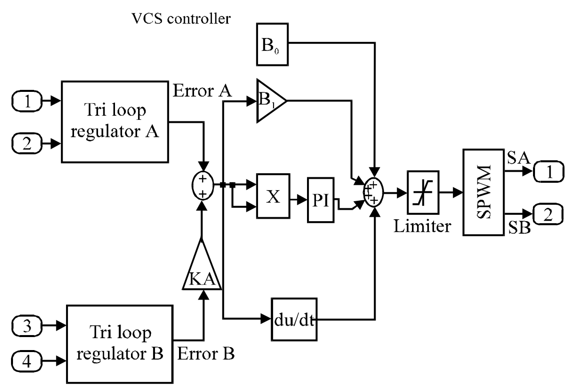

Fig. 2: The VSC control of the FACTS SSFC scheme

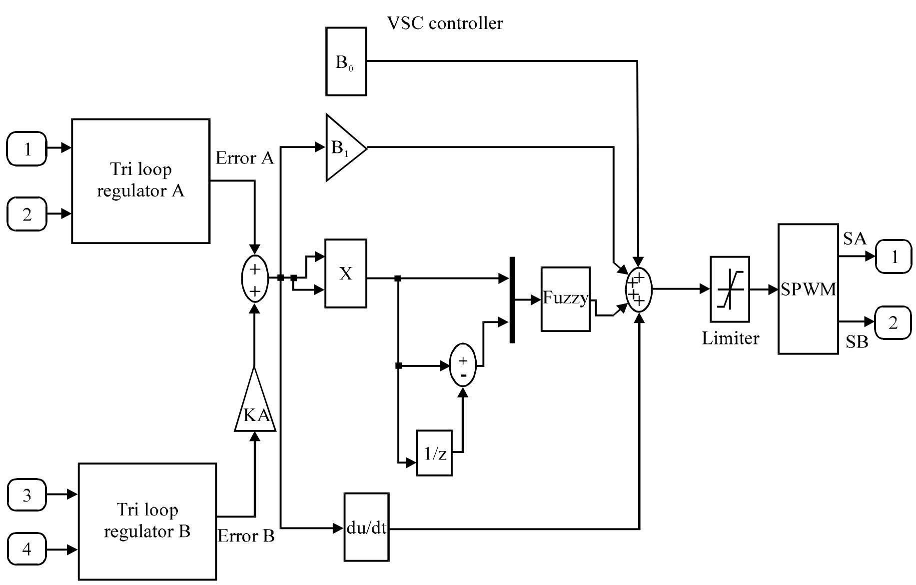

Fig. 3: The VSC control of the FACTS fuzzy logic controller

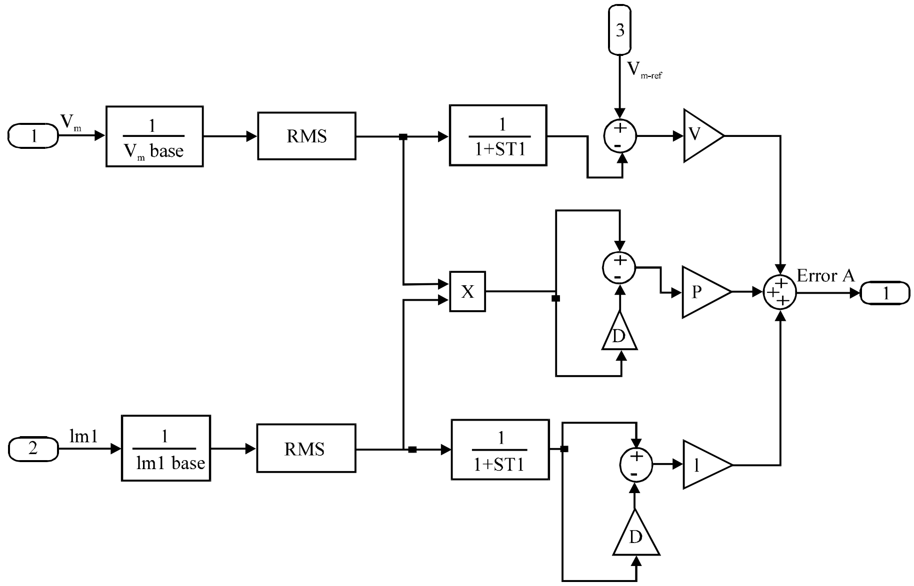

Fig. 4: The tri-loop error driven regulator A

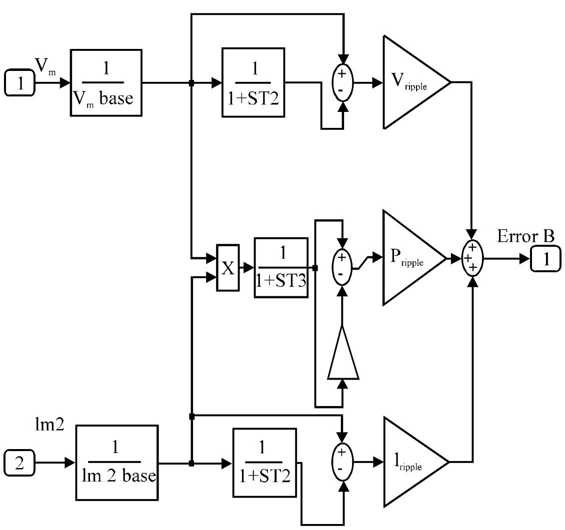

Fig. 5: The tri-loop error driven regulator B

Figure 4 and 5 show regulator A and B, respectively. In Fig. 4 the voltage and current waveforms are used in a tri loop error, thus, providing constant voltage at all AC buses and improving power factor. The regulator B is used to suppress current and voltage harmonic ripples if any thus, mitigating the harmonics (Sharaf and Abdelsalam, 2011a-c).

Fuzzy logic controller: The structure of fuzzy logic controller is shown in Fig. 6, consists of four stages, namely fuzzification, knowledge base, fuzzy inference mechanisms and defuzzification.

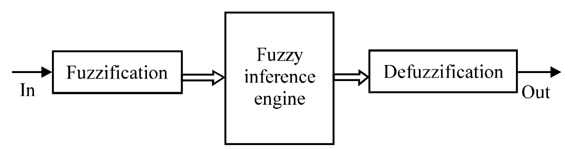

Fig. 6: Structure of fuzzy logic controller

Table 1: Fuzzy rules

Change in error	Errors NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	Z	NS	NM	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

The knowledge base comprising a data base and a rule base is designed to attain good dynamic responses under uncertain conditions. The data base contains of input and output membership functions and gives information for suitable fuzzification, the inference mechanism and defuzzification operations. The inference mechanism converts the input conditions into a fuzzified output by using a collection of linguistic rules. Lastly, defuzzification converts the fuzzy outputs.

In fuzzy controller algorithm the optimum value of fuzzy gain (K) is measured by fuzzy inference system which receives as inputs the slope of DC average bus voltage and DC voltage error. Both quantities (error and slope of DC voltage) are normalized by suitable values. Thus, each range is from -1 to 1 and normalized to unity. The K's value is considered to be near unity. The fuzzy rules shown in Table 1 are used to maintain K gain's value to be near unity. To characterize this fuzzy controller, five sets each respective to the error and slope inputs are chosen. The output is defined by five sets. The error 'e' and the change of error 'ce' are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following five fuzzy sets are used: NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big).

RESULTS AND DISCUSSION

Figure 7 shows a block diagram of FACTS-SSFC scheme. The source for the AC system which is of 11 kV distribution network is renewable wind energy. The 11/138 kV step up transformer connects the AC system to the AC grid and 11/4.16 kV step down transformer connects the hybrid load comprising linear, nonlinear and an induction motor load to the distribution network. All the parameters of AC system are according to Sharaf *et al*. (2011a-c).

Case 1; Normal loading operation: In this case, the dynamic response of the voltage at the Generator Bus (B_G), Load Bus (B_L) and grid Bus (B_I) without and with using the FACTS filters such as SSFC and FLC are depicted in Fig. 8-10, respectively. 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 (Sharaf and Abdelsalam, 2011a-c). Table 2 shows the power factor values at generator bus, load bus and grid bus.

The graph shows the three buses, Generator Bus BG, Load Bus B_L, grid bus B_I without SSFC and also with SSFC, respectively. From the graph a considerable improvement is observed at load bus that is from 0.59-0.95. At infinite bus it is improved from 0.86-0.96. The performance of the system is observed with fuzzy controller and without fuzzy controller ensuring the improved performance compared with IEEE Std., 519-1992 with fuzzy controller and with SSFC. Table 2 and 3 show 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 fuzzy, respectively (Woo and Lee, 2010).

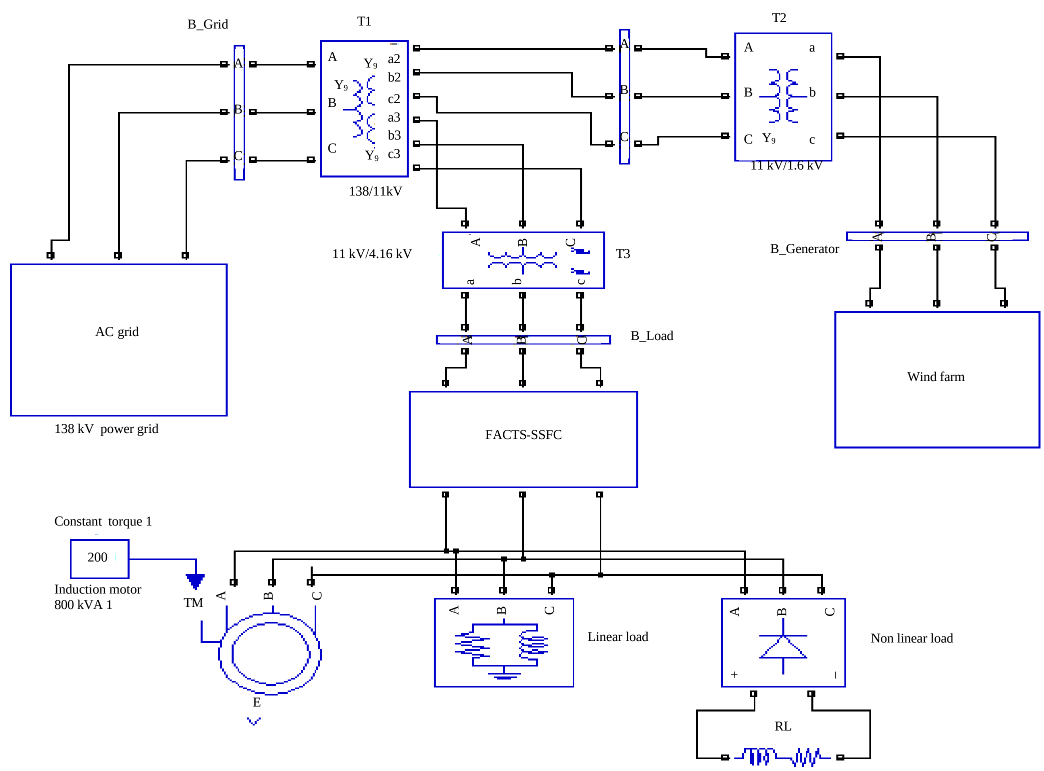

Fig. 7: Block diagram of grid connected wind smart system with FACTS-SSFC scheme

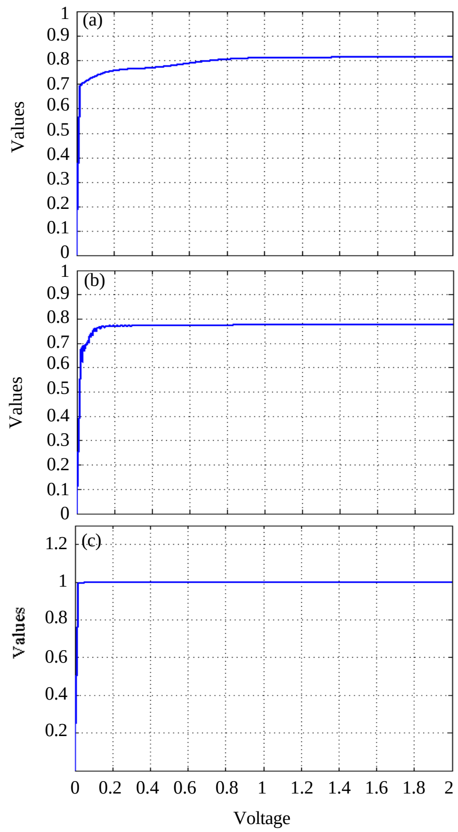

Fig. 8: The RMS voltage at; a) Generator bus; b) Load bus and c) Grid bus without SSFC

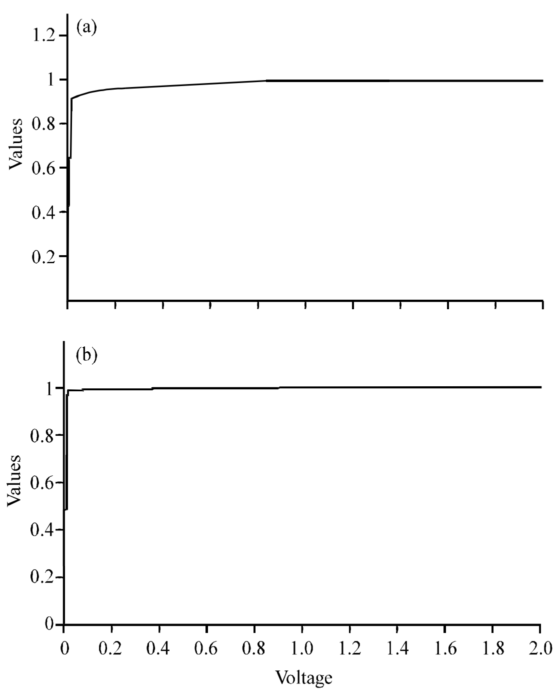

Fig. 9: Continue

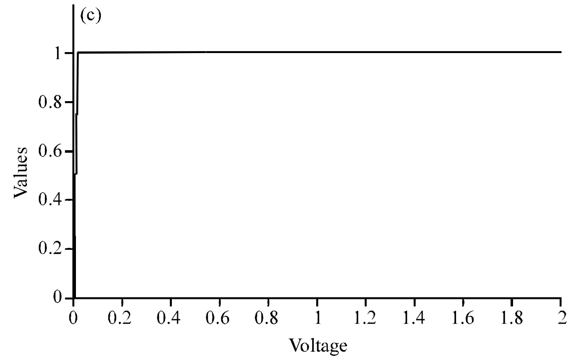

Fig. 9: The RMS voltage at; a) Generator bus; b) Load bus and c) Grid bus with SSFC

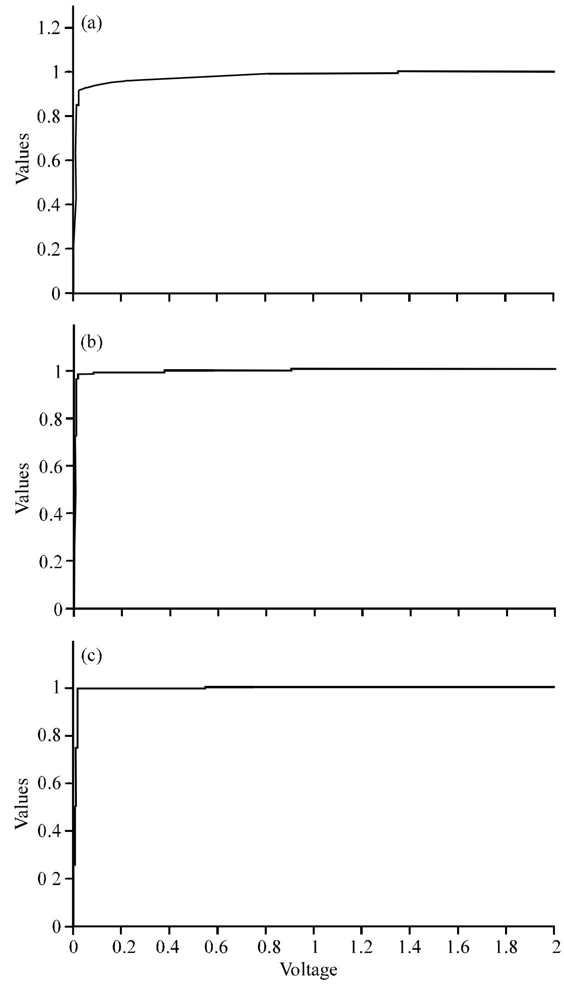

Fig. 10: The MS voltage at; a) Generator bus; b) Load bus; c) Grid bus with FLC

Table 2: Power factor comparison

Factors	Without SSFC	With SSFC	With fuzzy
Grid bus	0.85	0.95	0.9651
Generator bus	1.00	0.90	0.9760
Load bus	0.60	0.95	0.9700

Table 3: Total comparison table

	Without SSFC		With SSFC		With SSFC and with fuzzy	
Buses	THD voltage (%)	THD current (%)	THD voltage (%)	THD current (%)	THD voltage (%)	THD current (%)
Infinite bus (B_I)	0.09	12.49	0.01	0.98	0	0.74
Generator bus (B_G)	4.42	5.34	0.09	0.96	0.23	0.74
Load bus (B_L)	5.72	19.98	0.20	5.30	0.02	0.85

CONCLUSION

This study has proposed FACTS based Static Switched Filter Compensator (SSFC) scheme and Fuzzy Logic Controller (FLC) for effective power quality improvement, reduction of losses, voltage stabilization 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. And the fuzzy logic controller is primarily based on making decisions with indefinite indistinct and inaccurate information. The validation is done using MATLAB/Simulink environment.

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