Performance Analysis of SSFC for Power Quality Improvement in Wind Smart Grid

Bharathikannan S, Angalaeswari S

***Abstract*— In the research field of renewable energy sources Wind energy conversion systems have become a focal point. This is in no small part due to the rapid advances in the size of wind generators as well as the development of power electronics and their applicability in wind energy extraction. The variation of wind power with the continuous variations of wind speed can cause significant power quality issues. This paper presents a low cost static switched filter compensator for power quality enhancement, voltage stabilization and power factor improvement of wind schemes interfaced with Smart Grid- Distribution Networks. The proposed FACTS based scheme can also be extended to distributed/dispersed renewable energy interface and utilization systems and can be easily modified for other specific stabilization and compensation requirements.**

***Index Terms*— Dynamic Controllers, FACTS, Power Quality, Static Switched Filter Compensator, Wind Energy.**

I. INTRODUCTION

The wind power industry is one of the fastest expanding industries as a result of the rapid growth of installed capacity. The wind power over the last 20-30 years has become a competitive technology for clean energy production. The increasing demand for high quality, reliable and secure electrical power system with increasing the number of distorting nonlinear loads have led to rise in power quality problems. For power quality improvement, power electronic devices such as Flexible AC Transmission System (FACTS) and customizing power conditioning devices have introduced a new and emerging technology providing the power system with versatile new dynamic control capabilities [1], [2].

Wind energy has matured to a level of development where it is ready to become a generally accepted utility generation technology. Wind-turbine technology has undergone a dramatic transformation during the last 15 years, developing from a fringe science in the 1970s to the wind turbine of the 2000s using the latest in power electronics, aerodynamics, and mechanical drive train designs. In the last five years, the world wind-turbine market has been growing at over 30% a year, and wind power is playing an increasingly important role in electricity generation, especially in countries such as Germany and Spain. The legislation in both countries favors the continuing growth of installed capacity. Wind power is quite different from the conventional electricity generation with synchronous generators.

In general, FACTS devices are used in transmission control whereas customizing power devices are used for distribution control. Since the introduction of FACTS and custom power concept [3], devices such as unified power flow controller (UPFC), synchronous static compensator (STATCOM), dynamic voltage restorer (DVR), solid-state transfer switch, and solid-state fault current limiter are developed for improving power quality and reliability of a system [4], [5]. Advanced control and improved semiconductor switching of these devices have achieved a new era for power- quality mitigation. The major drawback of these devices, however, is that they are very expensive [7-9]. To assess the improvement resulting from the application of FACTS devices, a basic understanding of under lying characteristics of power quality events is essential. A power quality problem is defined as any variation in voltage, current or frequency that may lead to an equipment failure or malfunction [10-11].

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 [12].

This paper presents a FACTS based static switched filter compensator (SSFC) scheme for effective voltage stabilization, power quality enhancement, losses reduction and power factor improvement 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).Two error dynamic regulation schemes are utilized with a tri-loop dynamic error inter coupled control strategy and a VSC controller. The SSFC-FACTS device scheme has been fully validated for effective power quality mitigation, voltage stabilization, losses reduction and power factor correction using Matlab Simulink environment.

II. PROPOSED TOPOLOGY

The low cost FACTS Static switched filter compensator scheme, shown in Fig. 1, is a combination of two series capacitor banks (CS1and CS2) and two shunt capacitor

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banks (Cm1and Cm2) in parallel with the capacitor element (CF) of a tuned arm filter (RF, LF and CF). The series capacitor Cs is connected in series with the line conductors to offset dynamically part of the feeder inductance. Such reduction improves the power flow and reduces the feeder reactive power loss. In this SSFC scheme, two three phase shunt capacitor banks, Cf1 and Cf2 are connected in parallel with the two series capacitor terminals. The shunt capacitor banks provide reactive power compensation and improve the distribution feeder regulation. The series capacitor bank acts as a dynamic voltage booster and inrush current limiting device. Energy discharge path for the capacitor is formed by the six pulses diode rectifier with the resistance (Rf) and inductance (Lf) branch that forms a tuned arm filter at the rectifier's DC side. The two IGBT switches (S1and S2) are controlled by two complementary switching pulses (P1 and P2) that are generated by the dynamic tri loop error driven modified VSC controller, as shown in Fig. 2. An intermittent switching process between the two shunt capacitor banks is achieved by novel dynamic strategic control. The variable topology of the FACTS based SSFC can be changed by the complementary PWM pulses as follow:

Case 1: If P1 is high and P2 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 P1 is low and then P2 is high, the resistor and inductor will be connected into the circuit as a tuned arm filter.

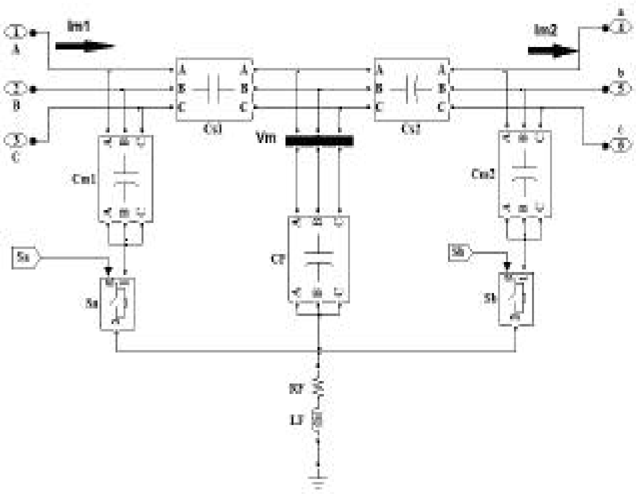

Fig. 1 The FACTS static switched filter compensator scheme

III. CONTROLLER DESIGN

Inter-coupled dynamic control based on two regulators A and B are proposed to reduce the harmonics, improve the power factor and stabilize the buses voltage using the FACTS static switched filter compensator. The tri-loop error driven dynamic controller is a dual action control used to modulate the switched filter compensator. The output total 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) & (b).

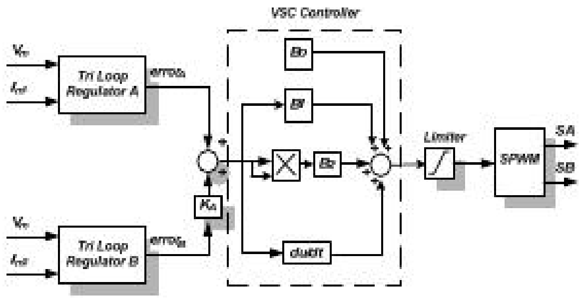

Fig. 2(a) The Modified VSC

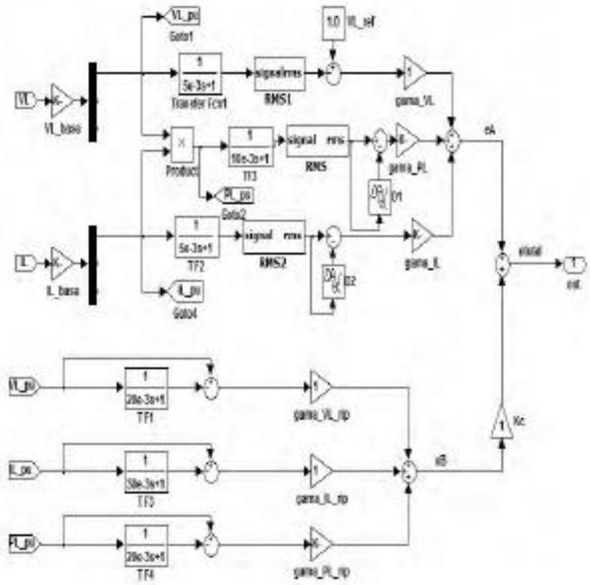

Fig. 2(b) Matlab functional model of tri loop error driven dynamic controller

Regulator A:

As the regulator scheme, shown in Fig. 3 the voltage and current signals are used in a tri loop error block to provide a stable voltage and current at all AC buses, also to improve the power factor. This specific control is achieved by modulating the admittance of the SSFC.

Regulator B:

This regulator, shown in Fig. 4 is used in a tri loop error block to suppress any harmonic contents in voltage and current signals, also consequently to mitigate the harmonics.

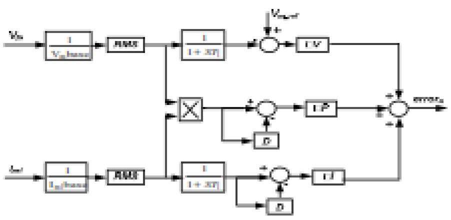

Fig. 3 The tri-loop error driven regulator A

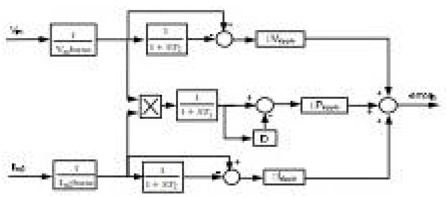

Fig. 4 The tri-loop error driven regulator B

IV. DIGITAL SIMULATION OF THE STUDIED AC SYSTEM

A. The AC System Configuration

The studied AC system is 11 KV distribution network with a renewable wind energy source and is connected to 138 kV AC grid through 11/138kV step up transformer. A hybrid load comprises a linear load, a converter type nonlinear load and an induction motor load is connected to the distribution network through 11/4.16kV step down transformer. Fig. 5 depicts a single line diagram of the studied AC system. The detailed parameters of the system are given in Appendix of [18].

B. Results of digital simulation

The Matlab/Simulink digital simulation results for proposed FACTS-Static Switched Filter Compensation scheme are validated as follow:

Case 1: Normal Loading Operation

The digital simulation is carried out with and without the controlled SFC located at load bus for 1.0 seconds in order to show its performance in voltage stabilization, harmonic reduction and reactive power compensation at normal operating condition. The dynamic responses of voltage, current, power factor at generator bus (Bg), load bus (BL) and infinite bus (Bi), without and with using the SSFC at normal operating conditions are shown in Figs. 6- 7.

The frequency spectra of the voltage waveforms are shown in Figs. 8- 10. It is obvious that the voltage harmonics are significantly reduced to a level within the limit set by the IEEE Std.519-1992 regarding the THD of bus voltage at low voltage system (less than 69 kV) [12]. Also the THD of current waveform at each bus is decreased as shown in [18].

Case 2: Sudden Change of the Wind Speed and the Load Excursion

In this case study, the digital simulation is carried out with and without the controlled SFC located at load bus for 1.0 second in order to show its performance under the following disturbance sequence:

1) At t = 0.1 second, the linear load is removed for a duration of 0.1 seconds;

2) At t = 0.3 second, the nonlinear load is removed for a duration of 0.1 seconds;

3) At t = 0.5 second, wind speed suddenly decreased to 9 m/s for a duration of 0.1 seconds;

4) At t = 0.7 second, wind speed suddenly increased to 21 m/s for a duration of 0.1 seconds;

5) At t = 0.8 the system is recovered to its initial state.

The rms values of voltage waveforms at generator (Bg), load (BL) and infinite buses (Bi) under load excursions are depicted in Fig.11, shows, without using the FACTS SSFC scheme, the disconnection of the linear and nonlinear loads have an effect on the value of voltage at the generator and load buses. It causes a voltage swell. While with using the controlled FACTS SSFC scheme, there is no effect on the voltage waveforms. This means that the controlled FACTS SSFC scheme mitigates the swell event of PQ disturbances.

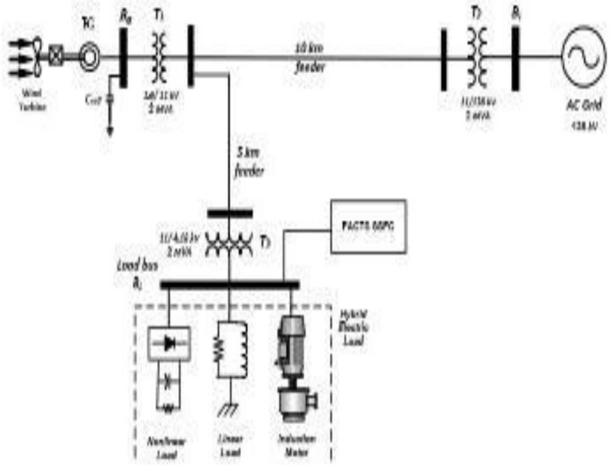

Fig. 5 Single Line Diagram of the sample study distribution system with the novel FACTS switched filter compensation schemes

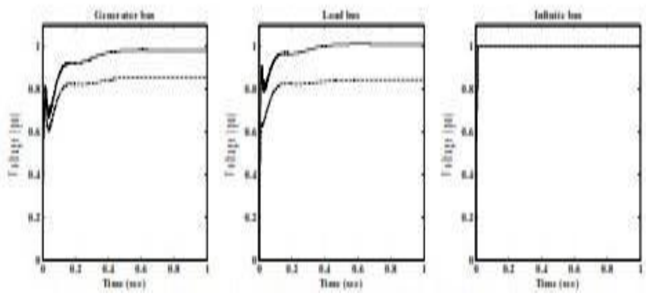

Fig. 6 The rms voltage at the generator, load and infinite buses without (dashed line) and with SSFC (solid line)

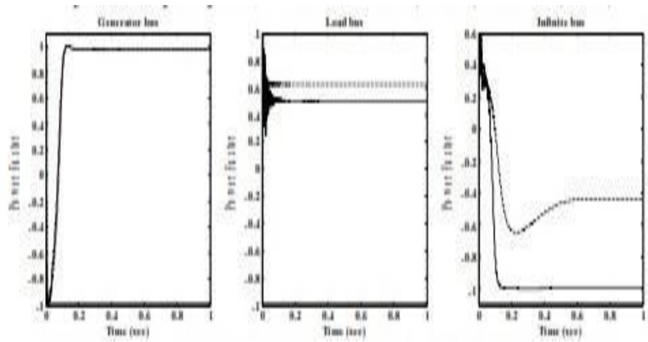

Fig. 7 The power factor at the generator, load and infinite buses without (dashed line) and with SSFC (solid line)

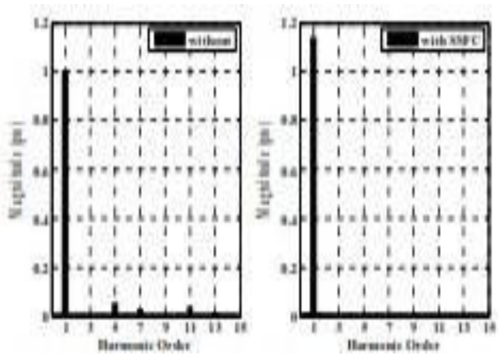

Fig. 8 The frequency spectrum of voltage waveform at the generator bus, Bs, without and with the FACTS filter compensator

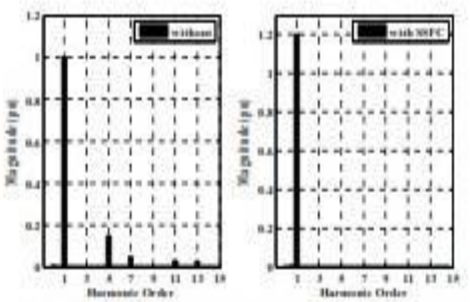

Fig. 9 The frequency spectrum of voltage waveform at the load bus, BL, without and with the FACTS filter compensator

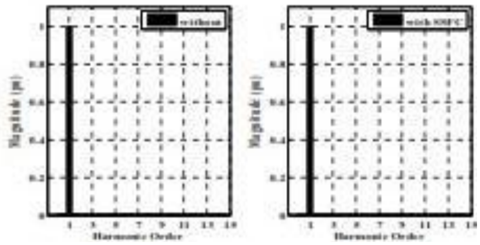

Fig. 10 The frequency spectrum of voltage waveform at the infinite bus, Bi, without and with the FACTS filter compensator.

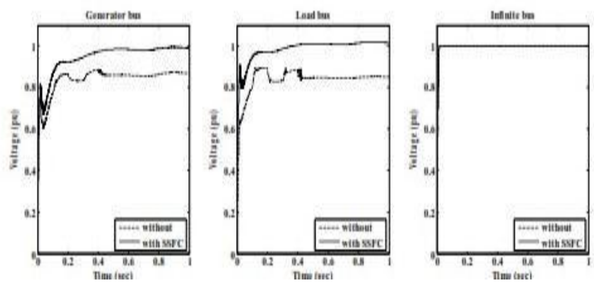

Fig. 11 The rms voltage at the generator, load and infinite buses without (dashed line) and with SSFC (solid line)

V. CONCLUSION

This paper presents a power quality mitigation scheme based on the Static Switched Filter Compensator (SSFC). The SSFC is controlled by a dynamic tri-loop error driven modified VSC controller. The digital simulation model of the proposed SSFC scheme has been validated for effective power quality improvement, voltage stabilization and power factor correction in distribution network with wind energy.

The proposed SSFC 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.

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