FACTS BASED SFC SCHEME FOR PV- WIND SMART GRID

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Abstract: A FACTS based switched filter compensator (SFC) is a type of robust hybrid filter will be used to provide filtering in addition to reactive power compensation. It will ensure the power quality, improve the power factor, limit the inrush currents and reduce the tranmission losses in smart grid application. The PV-SFC scheme consists of PV generation feeding a local hybrid load (linear, nonlinear and induction motor) with (SFC) scheme. The system is analyzed under the normal operating condition, short circuit and open circuit fault conditions. SFC filter comprises two series capacitors and one shunt capacitor with complementary SPWM switched IGBT/GTO. It is controlled by fast-acting modified error driven dual regulation dynamic control scheme using a weighted modified (WMPID) controller. Additionally, it has error squared plus rate adjusting extra supplementary control loops. The system is simulated in MATLAB/SIMULINK environment. The digital simulation results validated voltage stabilization, power factor improvement and power quality enhancement. PV power and wind power are complementary since sunny days are usually calm and strong winds are often occurred at cloudy days or at night time. In order to extract more power from renewable energy sources and to improve reliability of the system, wind power is integrated with PV to deliver continuous power than either individual source. Hence PV-WIND-SFC scheme is designed and simulation results are presented.

Keywords**:** PV-smart grid interface; FACTS-SFC stabilization, switched SPWM controller.

1. INTRODUCTION: During the last two decades, renewable energy generation and utilization gained momentum and acceptance for sustainable and environmentally friendly green energy drive and interface to smart grid electrical networks. Hybrid AC-DC interface schemes of distributed generation and integration within the smart power grid can enhance Ac system security, reliability and provide effective energy management and stabilization of the AC system with improved stability and stabilization under different fault conditions.

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.

Towards the development of the smart grid networks; the quality of power has become a major issue with the increasing demand for the Distributed Generation (DG) systems either connected to the network through some power electronics grid-tie inverters or isolated [1]. Besides, using the flexible AC transmission system (FACTS) has been an essential solution for enhancing the power quality and for stabilization of voltage of the electrical grid [2], [3]. Accordingly, power filters are used to improve the quality of current, voltage, and power in the modern power systems.

Modern smart grid dynamic will comprises green renewable energy and distributed generation as well as FACTS stabilization and filtering devices to alleviate severe voltage instability, boost voltage regulation, and improve power factor and energy efficient utilization using switched/modulated FACTS based devices and flexible dynamic control systems are fully utilized [4], [5]. Therefore, the switched/modulated filter compensation FACTS schemes simplify the concept of FACTS fast stabilization using low cost devices and dynamic/flexible control strategies to improve security and system stabilization of smart grid networks supplied by renewable wind and small hydro energy sources [6]-[7].

In this paper a new switched filter compensator (SFC) scheme is validated using dynamic controller for stabilization and enhancement of AC networks under fault and load variations as well as changes in PV Insolation and Junction temperatures.[8]-[9] The low cost filter scheme utilized a dual IGBT/GTO switch that controlled by dynamic error driven control strategies using a multi-loop dynamic error driven coordinated dual regulation control scheme and a weighted– modified fast acting PID controller with additional error squared and rate adjusting supplementary loops to improve fast response. The FACTS SFC is based on controlled complementary switching process through a parallel capacitor and two series 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 inter coupled control strategy and a VSC controller. The SFC-FACTS device scheme has been fully validated for effective power quality mitigation, voltage stabilization, losses reduction and power factor correction.[10]-[11]

The new FACTS-SFC- scheme is presented in Section 2. The dynamic control strategy is described in Section 3 for both FACTS SFC and PV-VSI-6 pulse inverter DC-AC interface. In Section 4, a dynamic simulation result for the sample study system is presented using MATLAB/Simulink Software environment is presented in Section 5. In Section 6, conclusions and extended work is discussed.

II. AC FACTS SCHEME

The FACTS filter and compensation device is a member of a family of modulated switched/modulated power filters and switched capacitor compensators [7]-[13]. It is a low cost hybrid switched/ modulated power filter which comprises a shunt and series filters to mitigate harmonic and reduce total harmonic distortion as well as improve power quality and power factor using a switched shunt capacitor bank and two series connected fixed- capacitor banks connected to the AC side of a one-arm uncontrolled rectifier. In addition, a tuned arm filter is connected to the ground of system.

The two switches (S1 and S2) are controlled by two complementary switching pulses (P1 and P2) that are generated by the dynamic tri loop error driven weighted modified PID controller, as shown in Fig. 2. The upper pulse P1 switches S1, while the lower pulse P2 controls S2. The variable SFC filter topology can be changed by then complementary switching PWM pulses as follow:

Case 1: If pulses P1 is high and P2 is low, the resistor and inductor will be disconnected and the combined shunt and series capacitors will provide the required shunt and series capacitive compensation to the AC 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.

SFC is controlled by fast acting modified error driven dual regulation dynamic control scheme using a weighted-modified PID (WMPID) controller with additional error squared plus-rate adjusting extra supplementary control loops. In the other word, this paper presents a FACTS-based SFC scheme for effective voltage stabilization, power quality enhancement, losses reduction and power factor improvement in distribution grid networks with the dispersed solar PV energy interface. The FACTS SFC is based on controlled complementary switching process through a parallel capacitor and two series 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 inter coupled control strategy and a VSC controller.[10]

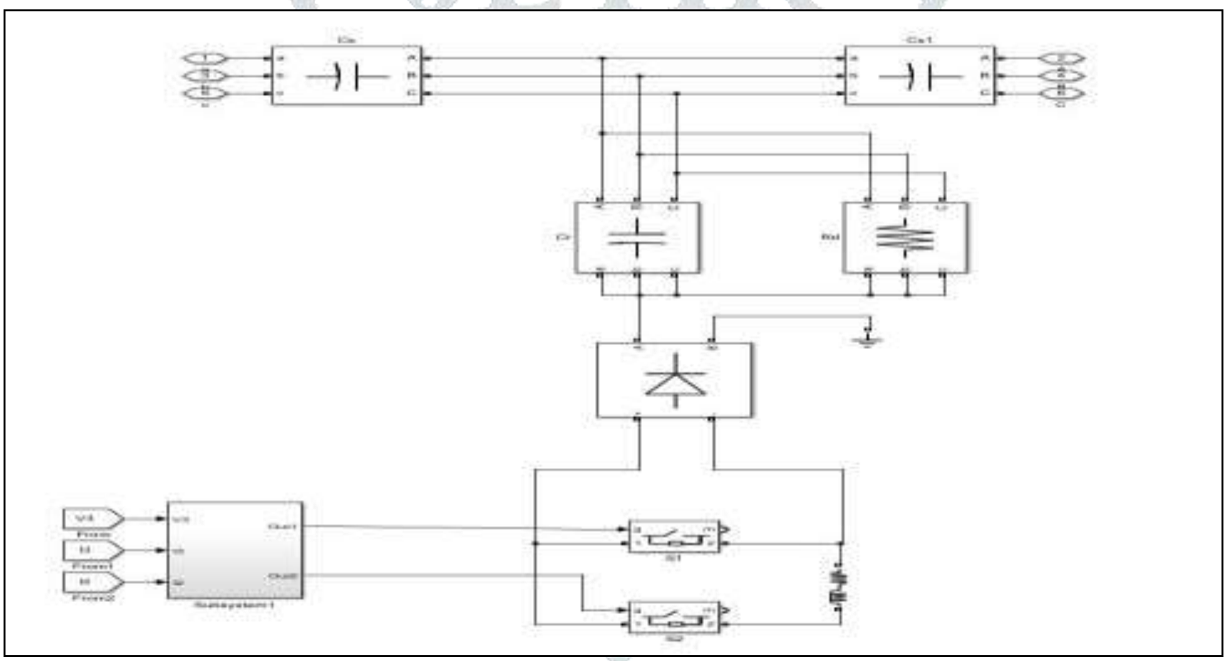

Figure 1 Novel FACTS based SFC series-shunt hybrid configuration

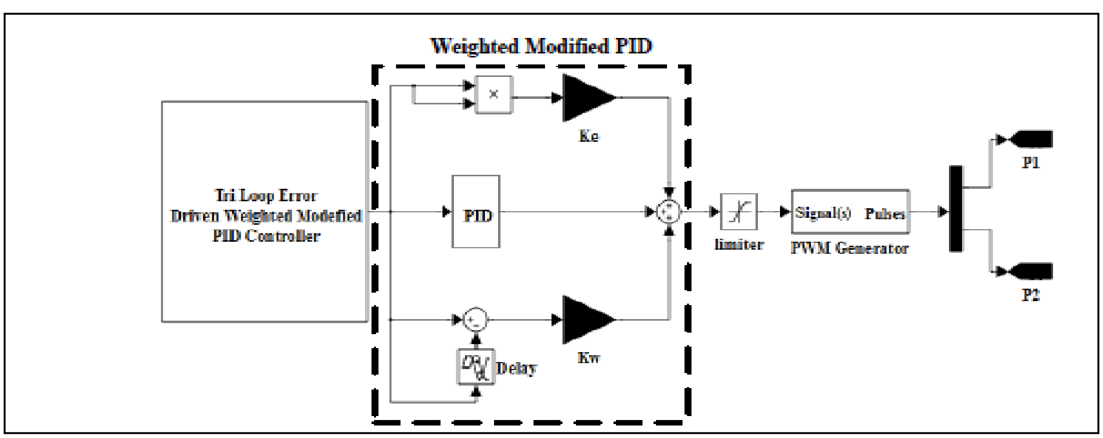

Figure 2 PID controller with weighted modified error- squared loop

III. CONTROL SYSTEM IN SMART GRID

The two main regulators are inter-coupled via a coordinated dynamic error driven time descaled-loop decoupled controller as shown in Figure 3 and Figure 4. Inter-coupled dynamic control based on two regulators (main and Box A) are proposed to improve the power factor and stabilize the buses voltage using the FACTS static SFC. The tri-loop error driven dynamic controller is a dual action control used to modulate the SFC. The output total error signal is an input to the WMPID controller to regulate the modulating control signal to the PWM switching block as shown in Figure 2. In addition, the SFC-power filter regulator utilises a dynamic tracking regulator with three decoupled, time-descaled dynamic loops. The first loop is a voltage regulator that tracks reference voltage (Vm-ref). The second and third loops are dynamic-derivative type error tracking loops to stabilize inrush currents and limit sudden power excursions and voltage transients. The second main regulator is used to control the dynamic DC-AC exchanged energy flow from the PV-solar-battery-DC capacitor bank via the VSI-6 pulse inverter as shown in Figure 3 using the DC side voltage, current and power input signals.[13]-[15]

Additionally, each signal dynamic error is obtained as the difference between the current value and the delayed value of the signal. Moreover, The three error dynamic voltage, current and power signals are time descaled by using selected weighting factors (Iγ, vγ and pγ) and the total error is the summations of three signals is multiplied by an effective weighting factor Kh and Kh1 for VSI-6 and the proposed SFC, respectively (Box A). This will ensure dominant loops and time descaling/decoupling of the three loops.

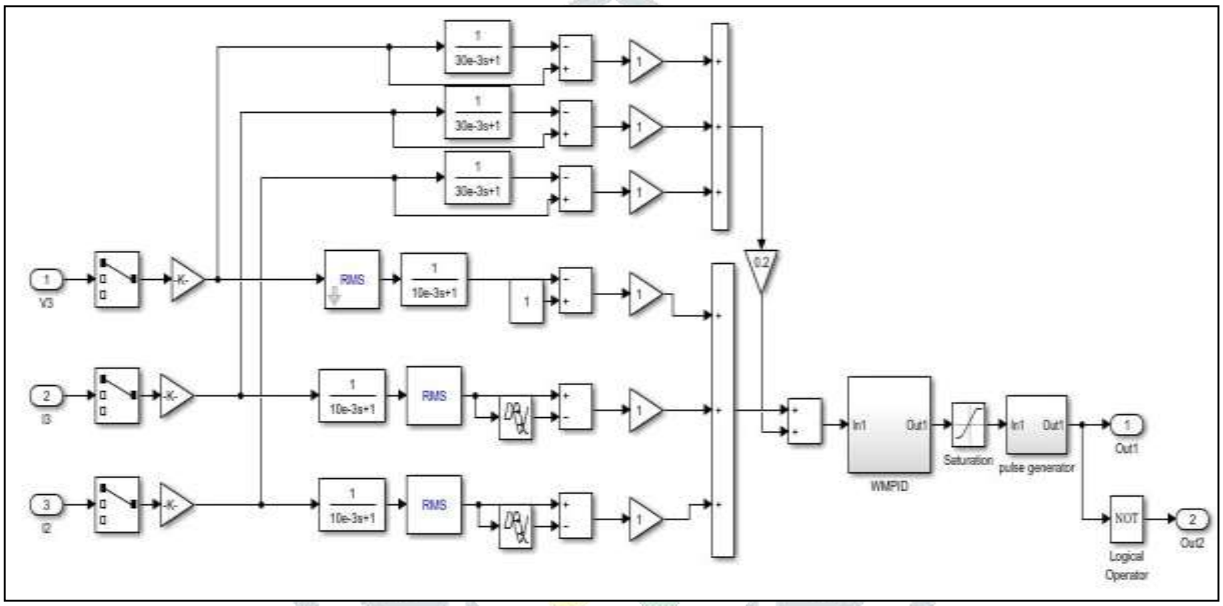

Figure 3 Dynamic control of Switched filter capacitor(SFC)

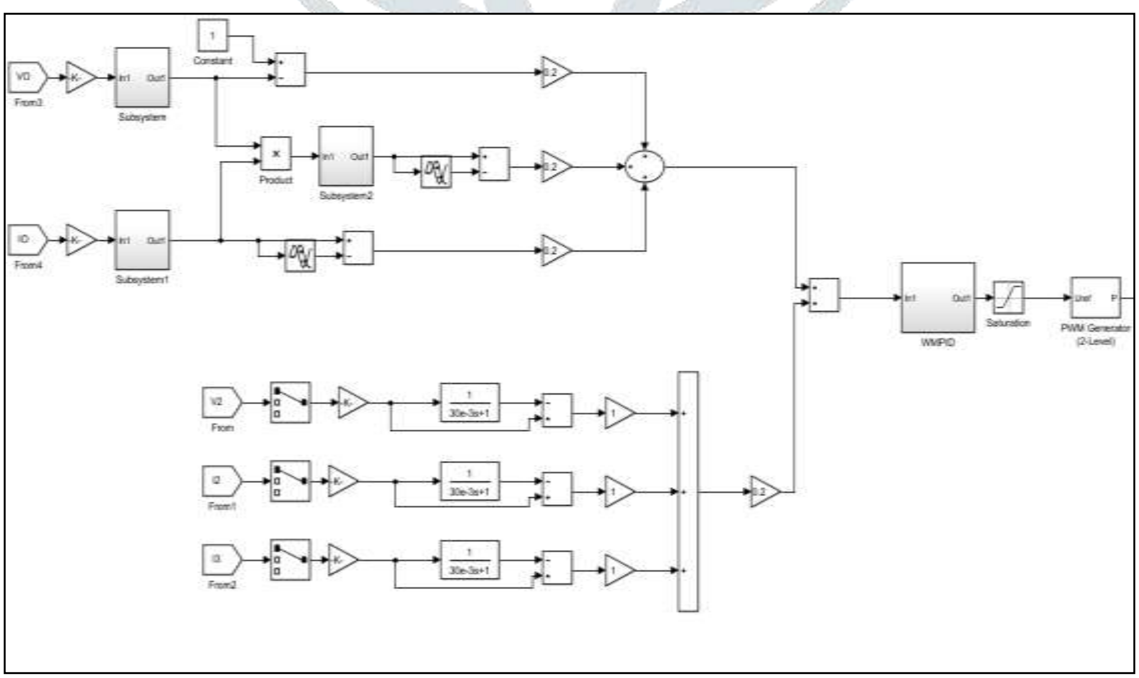

Figure 4 Six pulse dynamic controller VSI with PV inverter

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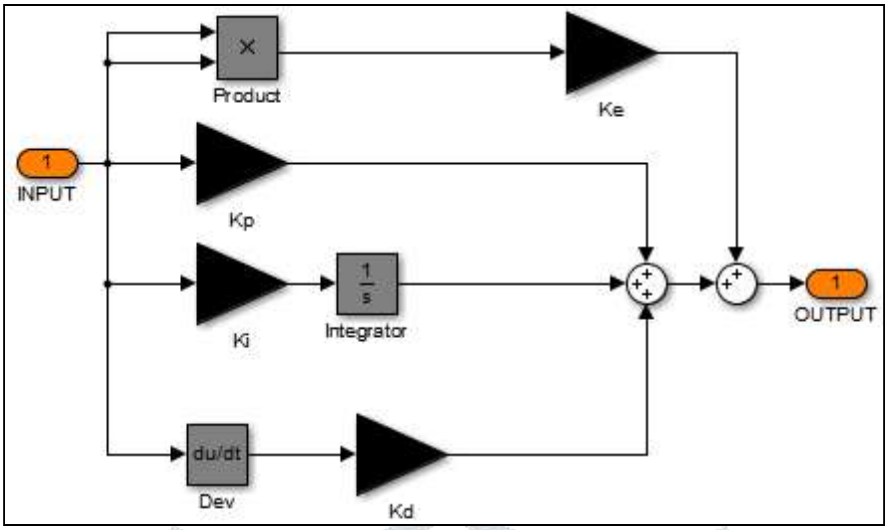

Figure 5 Switched filter SFC scheme

The global output signal of the dynamic error driven controller is followed by a modified WMPID controller displayed in Figure 5. WMPID includes an error sequential activation supplementary loop, ensuring fast dynamic response and effective damping of large excursions, in addition to conventional PID structure. Moreover, the output signal of the WMPID controller enters a PWM signal generator. On-off switching sequences produced by PWM define two operating modes of the FACTS device of SFC and PV-hybrid system.

IV. SYSTEM UNDER STUDY

The sample study AC grid network with the PV array interface is shown in Fig.6 It comprises a local hybrid load (linear, nonlinear and induction motor type loads) and is connected to an infinite bus through 6 km transmission line. The unified AC system SFC-filter/compensator and the TABLES respectively.

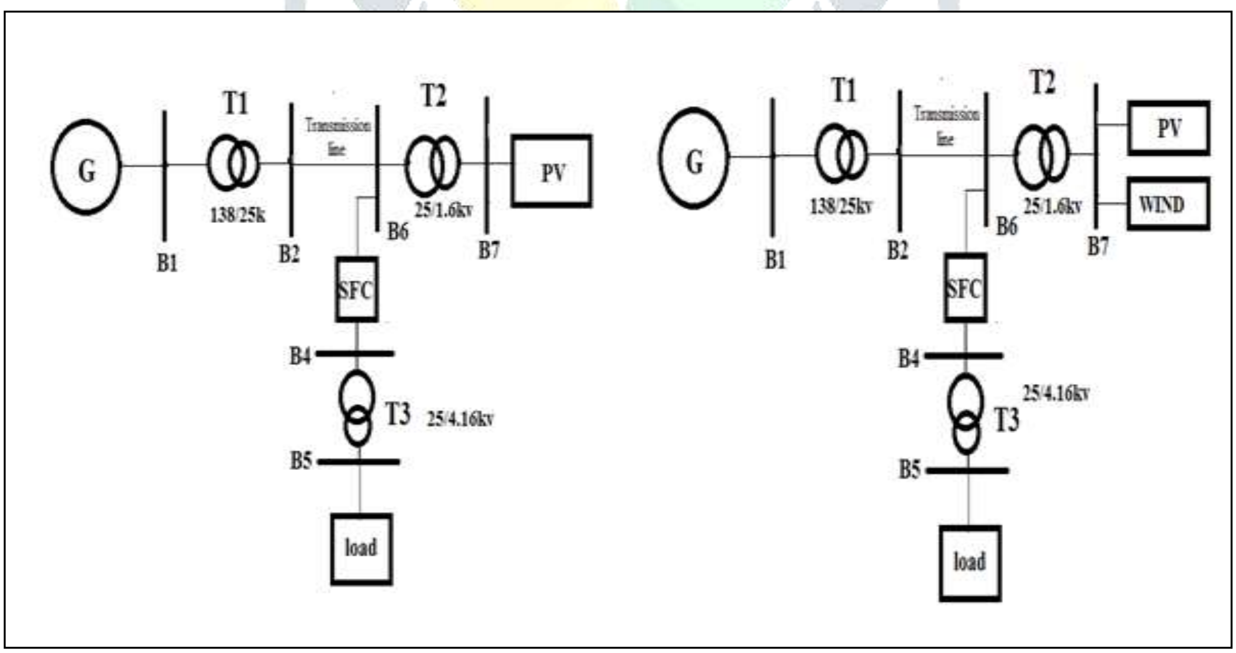

Figure 6 System under study

V. SIMULATION RESULTS

5.1 PV interfaced (with and without SFC) connected to AC grid network

The system is validated by PV-SFC based FACTS devices for stabilization of voltage, power quality improvement and for utilization of DC-AC energy with efficient schemes of control for stabilization and improvement of power quality under different fault conditions like short circuits and open circuits of a AC bus with and without SFC, The results are obtained in MATLAB simulink environment from AC grid network with PV interface with and without SFC are at all buses during normal operation, short circuit and open circuit conditions at load bus. The parameters for the simulation are indicated in the APPENDIXES.

The below shown wave forms are RMS voltage, RMS current, power factor , active and reactive powers during normal operation at bus1,bus2, bus5, bus6 and bus7 with and without application of SFC.

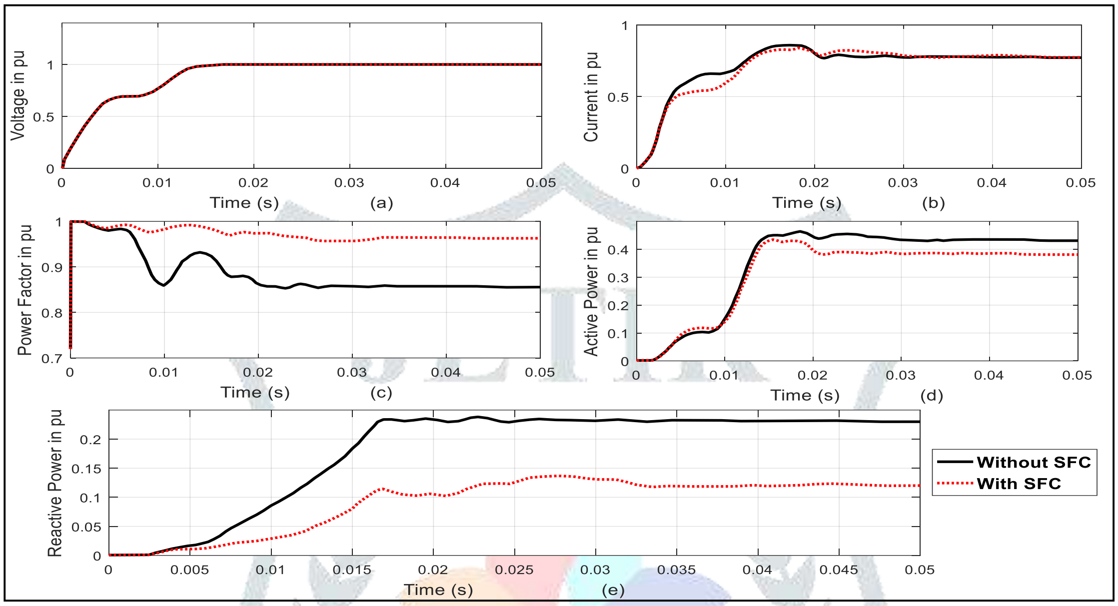

Figure 7 PV- SFC waveforms at bus 1 under normal operation

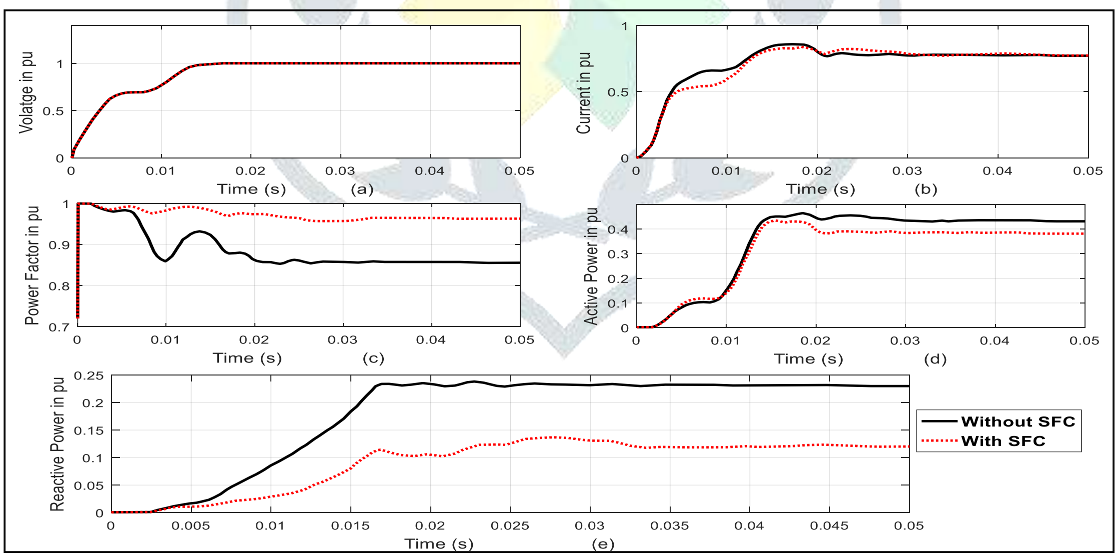

Figure 8 PV- SFC waveforms at bus 2 under normal operation

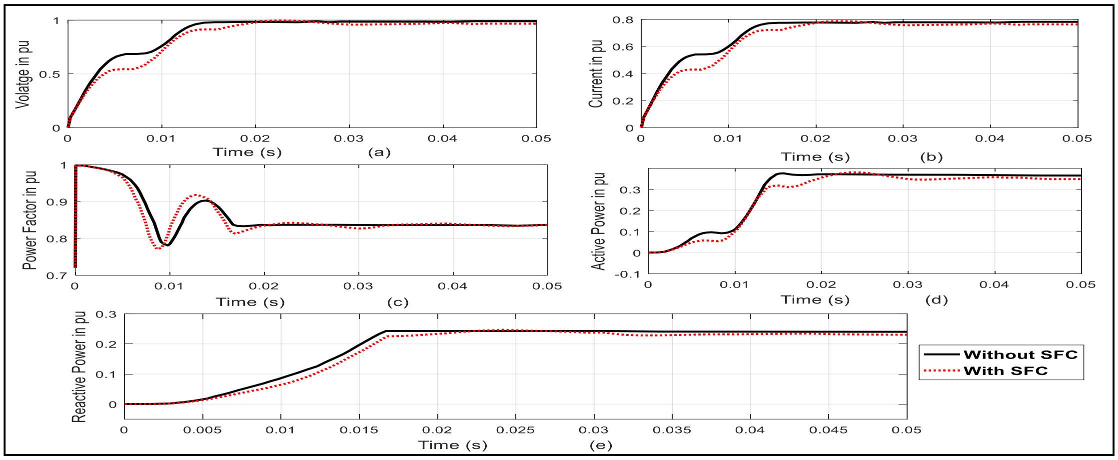

Figure 9 PV- SFC waveforms at bus 5 under normal operation

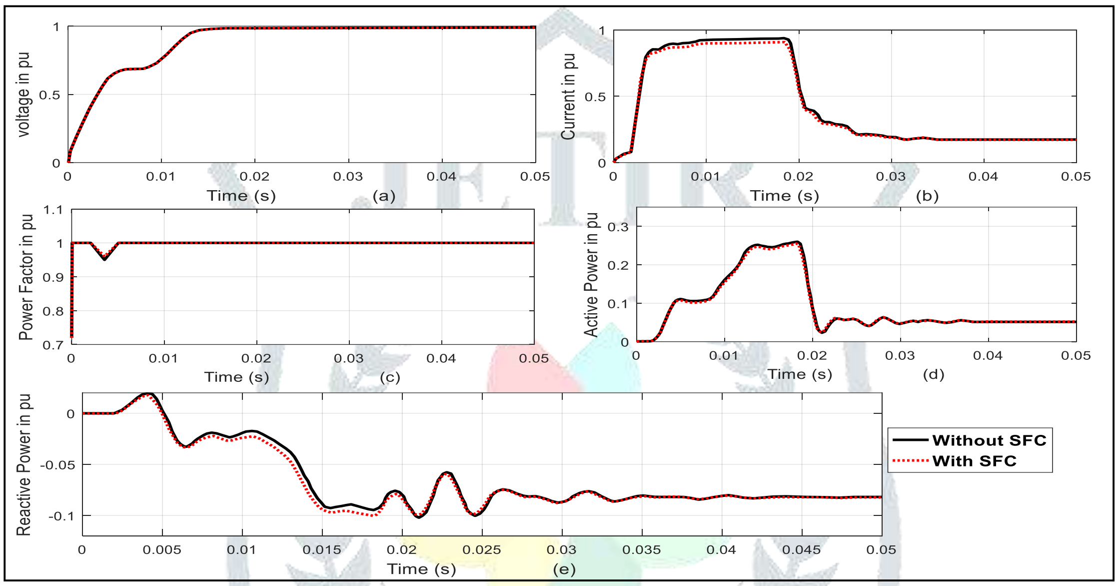

Figure 10 PV- SFC waveforms at bus 6 under normal operation

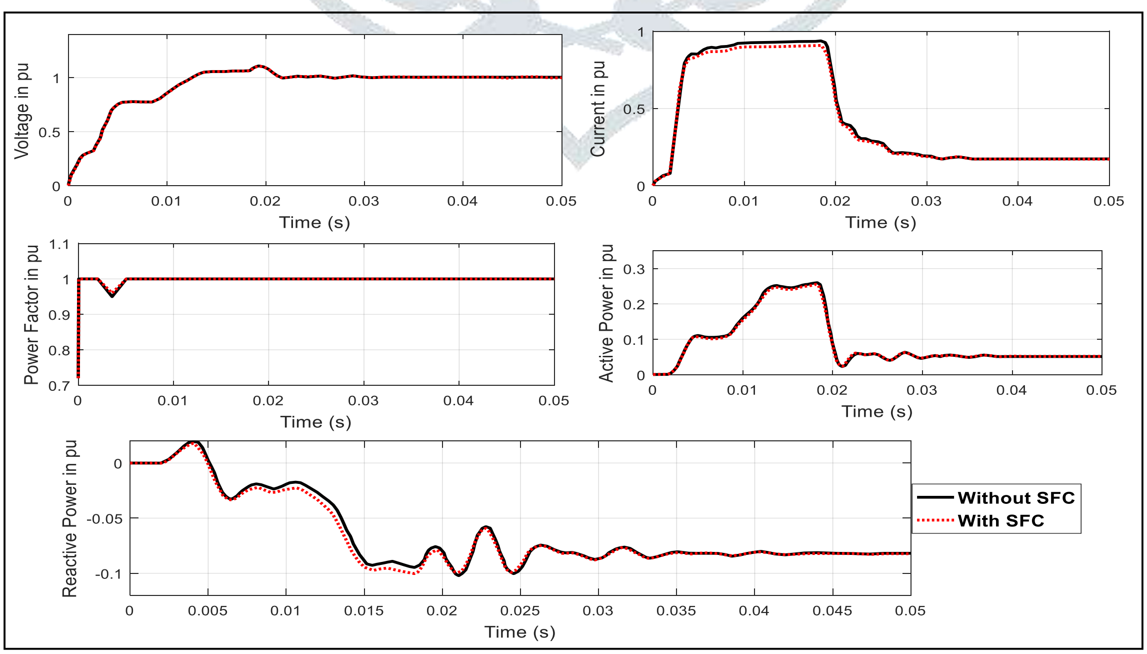

Figure 11 PV- SFC waveforms at bus7 during normal operation

5.1.2 Response at bus 5 during short circuit

The below shown wave forms are RMS voltage, RMS current, power factor , active and reactive powers at bus 5 during short circuit applied at middle of the transmission line with and without application of SFC.

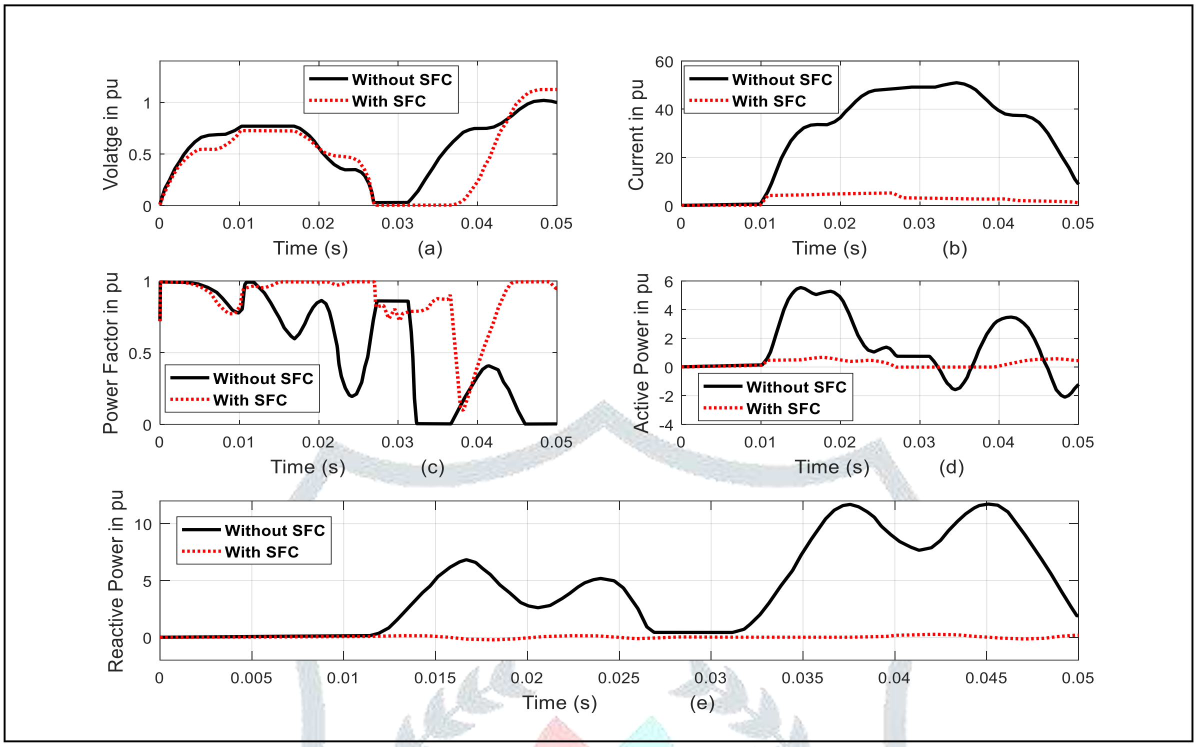

Figure 12 PV- SFC waveforms at bus 5 during SC operation

5.1.3 Response at bus 5 during open circuit operation

The below shown wave forms are RMS voltage, RMS current, power factor ,active and reactive powers during short circuit operation at bus7 with and without application of SFC.

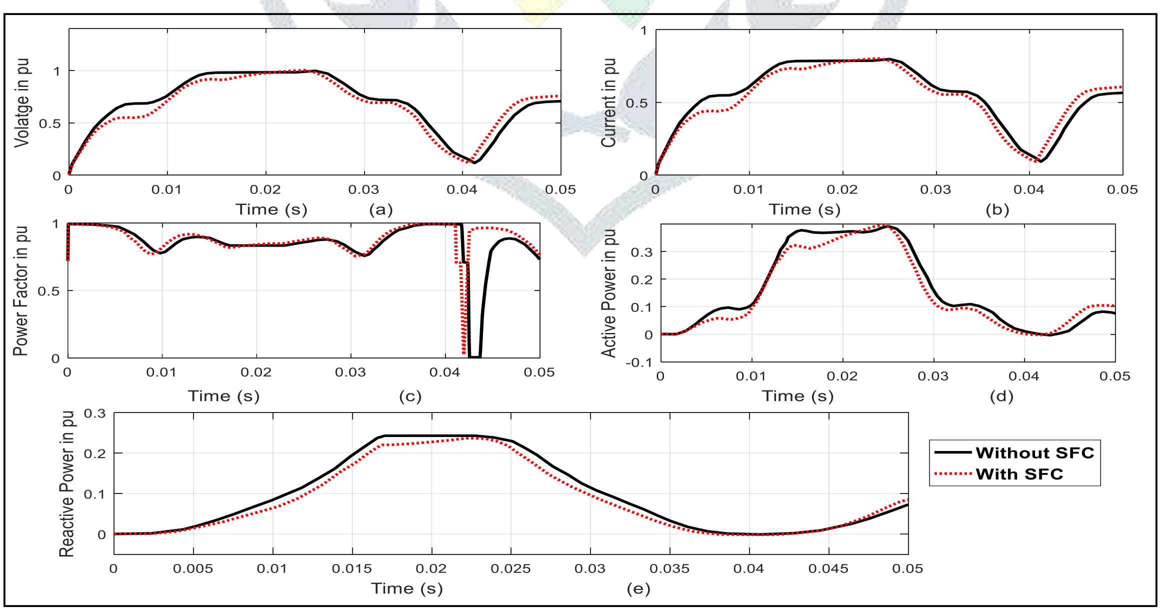

Figure 13 PV- SFC waveforms at bus 5 during OC operation

5.2. Comparative results between PV interfaced (with and without SFC) and PV-WIND interfaced with SFC

The results obtained from AC grid network with PV interface with and without SFC is compared with AC grid network having PV-Wind interface with SFC at all buses during normal operation, short circuit and open circuit conditions at load bus. As shown in wave forms blue line indicate PV interface system without SFC, dotted red lines indicates PV interface system with SFC and blue line indicates PV-WIND interface system with SFC.

5.2.1. Normal operation

The below shown wave forms are RMS voltage, RMS current, power factor , active and reactive powers during normal operation at bus1,bus2, bus5, bus6 and bus7 with and without application of SFC.

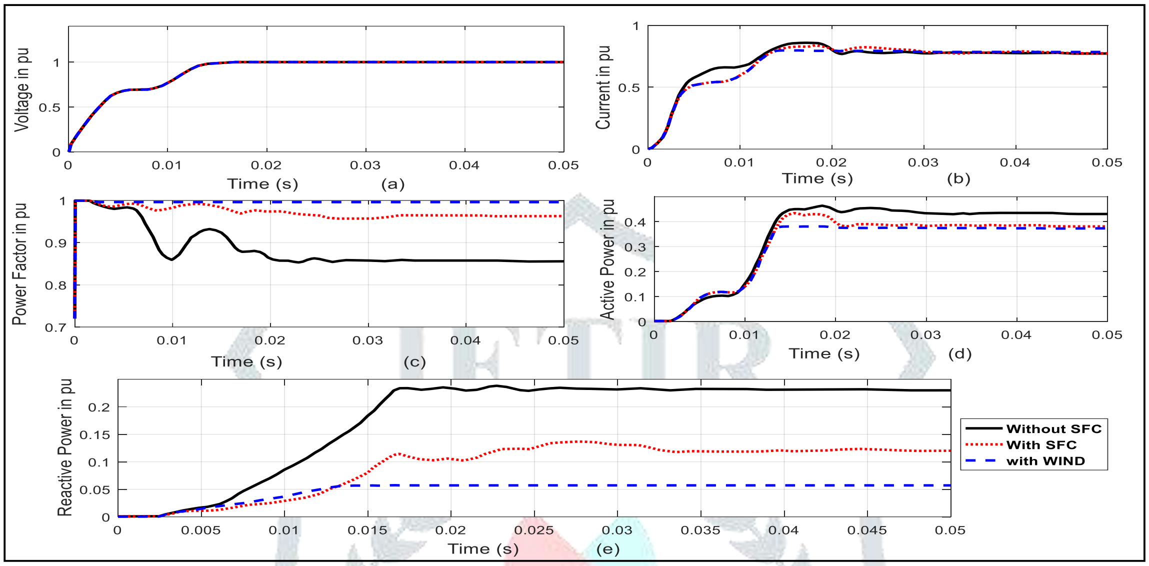

Figure 14 PV- WIND-SFC waveforms at bus 1during normal operation

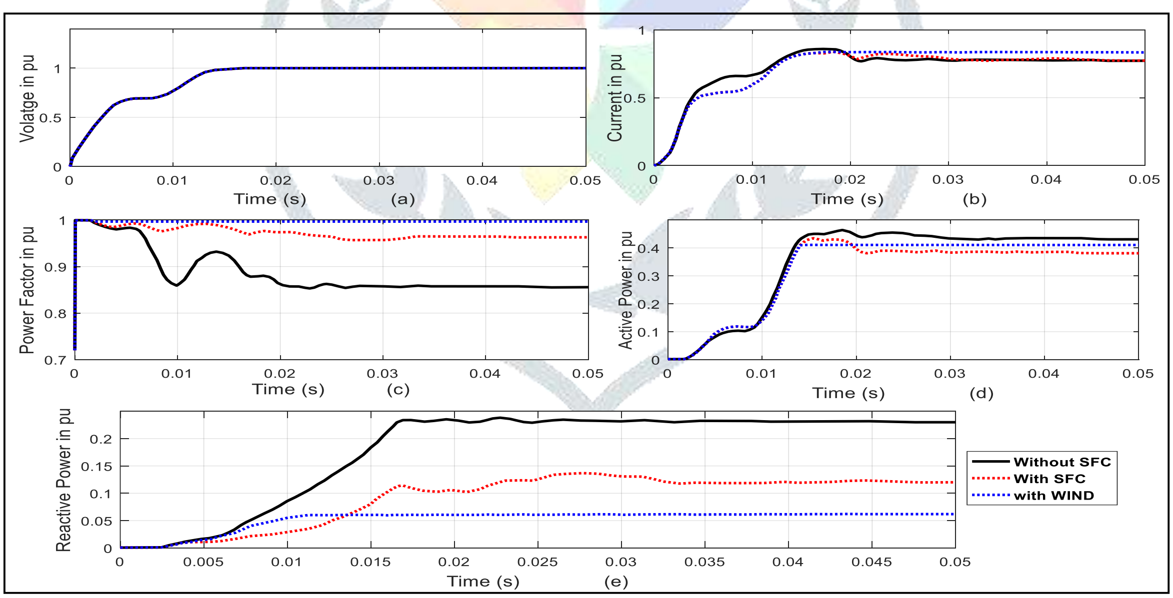

Figure 15 PV-WND- SFC waveforms at bus 2 during normal operation

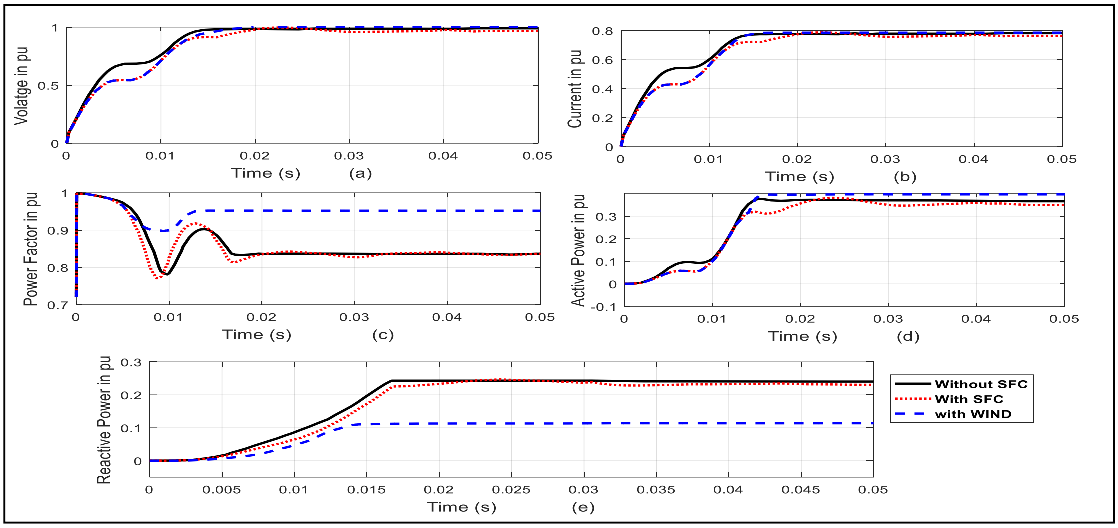

Figure 16 PV-WND- SFC waveforms at bus 5 during normal operation

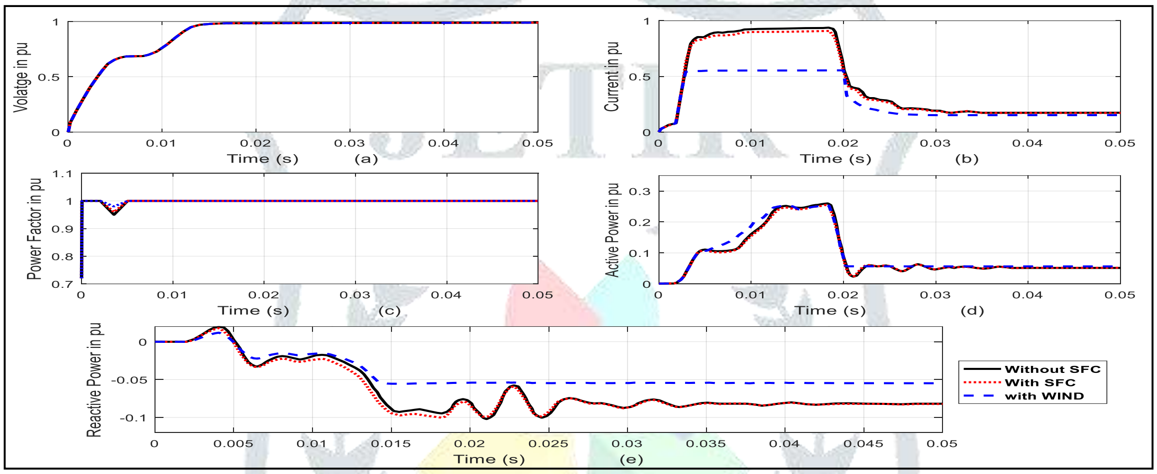

Figure 17 PV-WND- SFC waveforms at bus 6 during normal operation

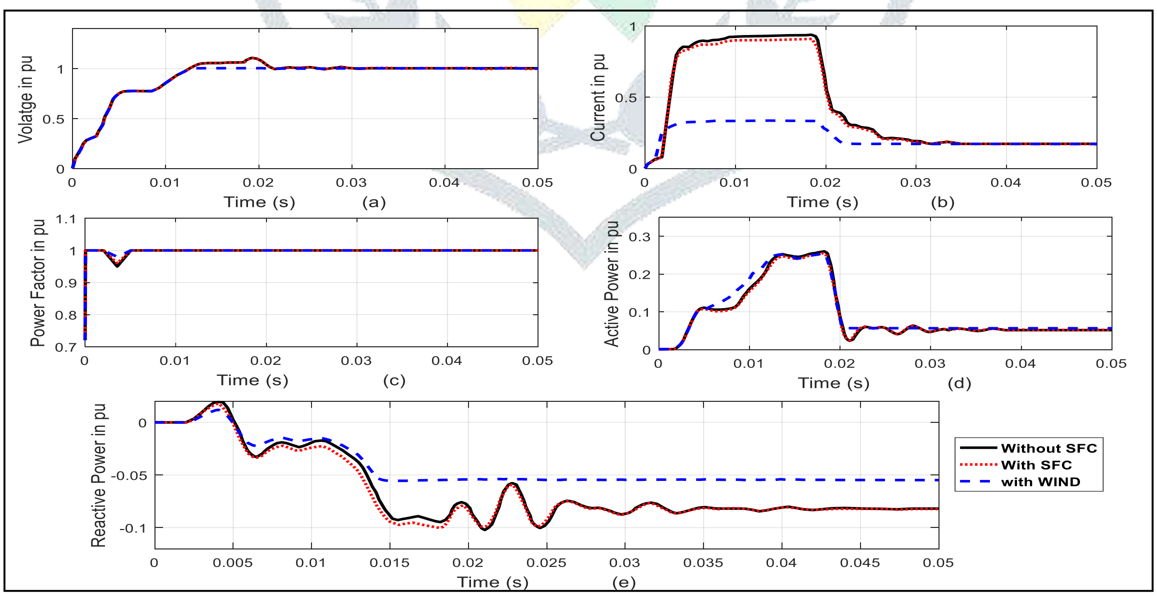

Figure 18 PV-WND- SFC waveforms at bus 7 during normal operation

5.2.2. Response at bus 5 during short circuit

The below shown wave forms are RMS voltage, RMS current, power factor , active and reactive powers at bus7 during short circuit applied at middle of the transmission line with and without application of SFC.

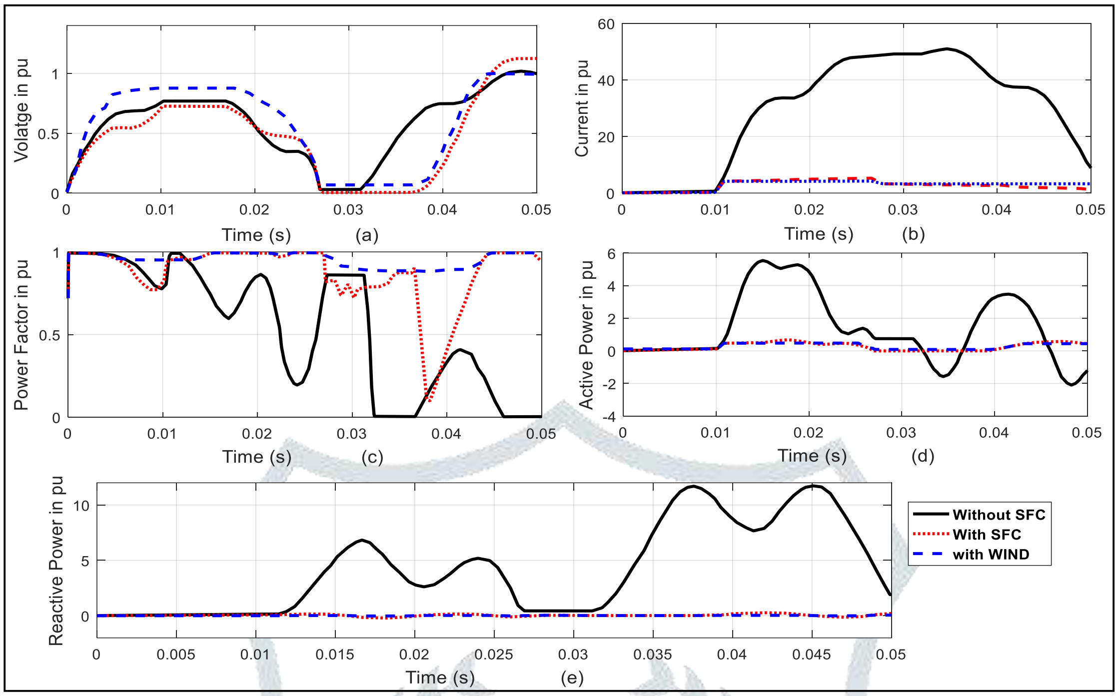

Figure 19 PV-WIND-SFC waveforms at bus 5 during SC operation

5.2. 3. Response at bus 5 during open circuit operation

The below shown wave forms are RMS voltage, RMS current, power factor , active and reactive powers during short circuit operation at bus7 with and without application of SFC.

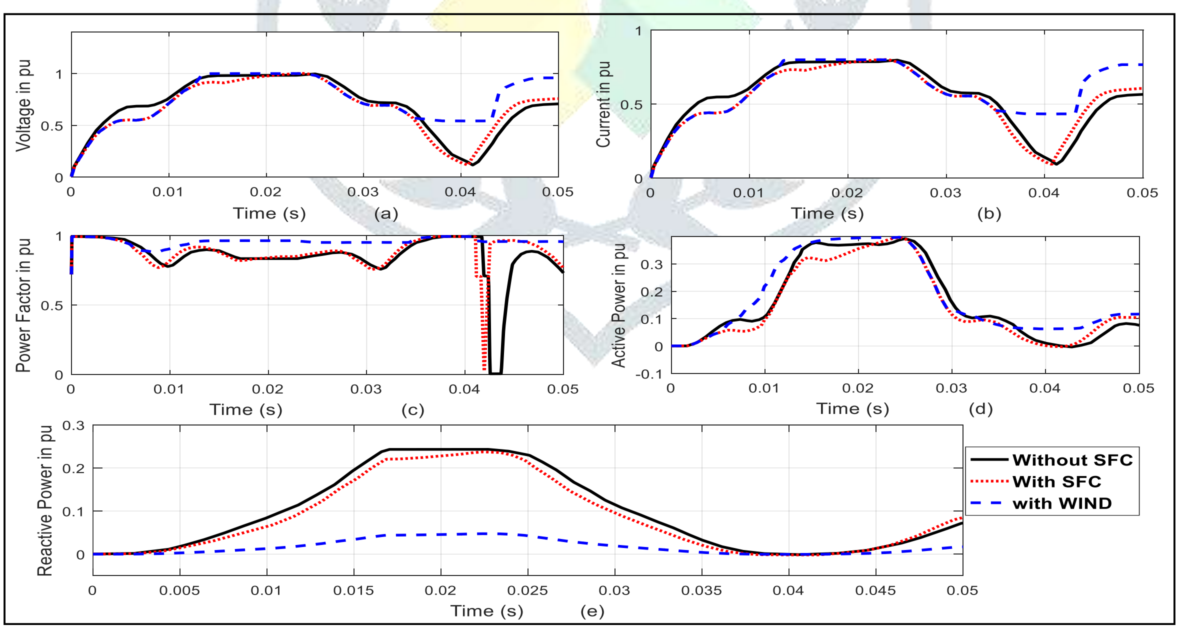

Figure 20 PV-WIND-SFC waveforms at bus 5 during OC operation

In the case of PV-WIND-SFC scheme, from simulation results it can be observed that the less transients, improved voltage profile, power factor correction.

V1. CONCLUSION

The paper represents a hybrid FACTS based modulated power filter compensator (SFC) scheme is developed for micro-grid smart grid and smart grid application. FACTS-based switched filter-capacitor compensator is equipped with modified-weighted PID controller scheme for dynamic controlling of the network. The proposed hybrid FACTS based switched/modulated power filter compensator (SFC) scheme is applied to PV-WIND system. Simulation results are valid for stabilization of voltage, improvement of power factor and enhancement of power quality.

The proposed switched filter compensator scheme with photo-voltaic(PV) -WIND filter scheme is extensive to other energy sources like micro gas turbines with fuel cell , rural generation of electricity and utilization of energy.

NOMENCLATURE:

FACTS Flexible ac transmission system
SFC Switching filter compensator
SPWM Sinusoidal pulse width modulation
WMPID Weighted modified PID Controller
PID Proportional, integral, derivative

TABLE 1

Device	Value
PV-hybrid scheme	Resistance (R_o =R_b = 0.5 Ω), L_o = R_b = 0.05 mH, C_d = 700 mF
PV controller gains	K_e = 1, K_p = 25, K_i = 2, K_d = 1 F_s = 1,750 hz (Frequency of PWM)
SFC controller gains	K_e = 1, K_p = 25, K_i = 2, K_d = 1 F_s = 2,500 hz(Frequency of PWM)
LC filter	Inductance(L) = 0.1 mH, resistance(R) = 0.5 Ω , Capacitance(C) = 200 mF

TABLE 2

Parameters of a transmission line	25 KV (L-L), 6km R/km = 0. 35 Ω, L/km = 0.4 mH
BUS at infinity	138KV, X/R=10
Switched Filter Capacitor	C_s = 145 μ F, C_{s1} =145 μ F, C_{sh1}=225μF R_f = 0.15 Ω L_f= 3 m H
Local hybrid AC load	
IM(induction motor)	0.2 MVA, 4 poles R_s=0.01965pu, L_s=0.0397pu R_r=0.01909pu, L_r = 0.0397 pu
Linear load	L_m = 1.354 pu p = 0.1 MW, Q = 0.043 MVAR
Load(Non linear)	0.1 MVA, Power factor = 0.9
PV Cell	V_{out} = 1,600 V, P_{out} = 1 MW
Power transformer	
Transformer1	138 / 25 KV, 5 MVA
Transformer2	25 / 1.6 KV, 1MVA

Transformer3	25 / 4.16 KV, 5MVA
Model of wind turbine	
Nominal output mechanical power	3.6(MW)
Mean speed of a wind	10 (m/s)
Per phase localized capacitor bank	30(µF)
Induction generator stator resistance	0.016 (pu)
Induction generator mutual inductance (Lm)	3.65 (pu)
Resistance of a Rotor	0.015(pu)

REFERENCES

[1] A.M. Sharaf, F.H. Gandoman, A Robust FACTS PV-Smart Grid Interface Scheme for Efficient Energy Utilization, International Journal of Power and Energy Conversion, 6(4), 344-358, (2015).

[2] Paul Byrne, Nandy Putra, Thierry Mare, Nasruddin Abdallah, Pascal Lalanne, Idrus Alhamid, Patrice Estellé, Ardiyansyah Yatim, Anne-Lise Tiffonnet "Design of a Solar AC System Including a PCM Storage for Sustainable Resorts in Tropical Region" EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. XX, Issue XX, pp00-00, November 2018.

[3] Syed Bilal Qaiser Naqvi ,Bhim Singh "Grid Connected Two Stage PV-Battery System with PV Intermittency and Improved Power Quality" 2020 international conference on Electrical and Engineering(IC3)

[4] Mohammad Javad Sanjari , Hoay Beng Gooi, Nirmal-Kumar C. Nair "Power Generation Forecast of Hybrid PV–Wind System" 2020 IEEE Transactions on Sustainable Energy.

[5] RoopalPancholi,Sunita Chahar "Amelioration of decisive Neural Network Technique in PV-Wind Hybrid Technology along ingenious DVR system" International Journal of Advance Science and TechnologyVol. 29, No. 10S, (2020), pp. 7293-7311

[6] A.A. Abdelsalam, H.A. Gabbar, A.M. Sharaf, Performance Enhancement of Hybrid AC/DC Microgrid Based D-FACTS, International Journal of Electrical Power & Energy Systems, 63(3), 382- 393, (2014).

[7] P.A. Desale, V.J. Dhawale, R.M. Bandgar, Brief Review Paper on the Custom Power Devices for Power Quality Improvement, International Journal of Electronic and Electrical Engineering, 7(7), 723-733, (2014).

[8] A.M. Sharaf, F.H. Gandoman, FACTS Based Stabilization for Smart Grid Applications, International Journal of Electrical, Computer,

[9] M. Rastogi, N. Mohan, A. Edris, Hybrid Active Filtering of Harmonic Currents in Power Systems, IEEE Trans. On Power Delivery, 10(4), 1994- 2000, (2005).

[10] H. Fujita, H. Akagi, A Practical Approach to Harmonic Compensation in Power System-series Connection of Passive, Active Filters. IEEE Trans. on Ind. App, 27(6). 1020-1025, (1991).

[11] A.M. Sharaf, P. kreidi, Dynamic Compensation Using Switched/Modulated Power Filters, Canadian Conference on Electrical and Computer Engineering, Winnipeg, Canada, 24 February, (2002).

[12] Singh, S.P., Singh, B., and Jain, M.P., "Performance Characteristic and Optimum Utilization of a Cage Machine as a Capacitor excited Induction Genertor", *IEEE Trans. On E.C.,* Vol. 5, No.4, pp.679-685, Dec.1990.

[13] Hillowala, R.M., and Sharaf, A.M., "Modeling, simulation and analysis of variable speed constant frequency wind energy conversion scheme using self excited induction generator", *South eastern symposium on Circuits and Systems*, October 1990.

[14] A.M. Sharaf, P. kreidi, Power Quality Enhancement Using a Unified Switch Capacitor Compensator, Canadian Conference on Electrical and Computer Engineering, Canada, May 4-7 ,(1989).

[15] A.A. Abdelsalam, M.E. Desouki, A.M. Sharaf, Power Quality Improvement Using FACTS Power Filter Compensation Scheme, J. Electrical Systems, 9(1), 86-96, (2013).

[16] A textbook on "Power Electronics Handbook" by MUHAMMAD H. RASHID. H. Bellia, R. Youcef, M. Fatima, "A detailed modelling of photovoltaic module using MATLAB," NRIAG Journal of Astronomy and Geophysics, April 2014, pp. 1-9.

[17] Keskar Vinaya N, "Electricity Generation Using Solar Power", IJERT, ISSN: 2278-0181, Vol. 2 Issue 2, February- 2013.

[18] R. Krishan, Y. R. Sood and B. U. Kumar, "The Simulation and design for analysis of photovoltaic system based on MATLAB," in proc. ICEETS, April 2013, pp. 647-671.

[19] F. Mendes, and J.P.S. Catalão, Simulation of a Solar Cell considering Single-Diode Equivalent Circuit Model, International Conference on Renewable Energies And Power Quality, ICREPQ'11, Las Palmas, Spain, (2011).

[20] Trishan Esram and Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", Energy Conversion, IEEE Transactions on (Volume:22 , Issue: 2), june 2007.

[21] Poller.M.A, "Doubly-fed induction machine models for stability assessment of wind farms," Power Tech Conference Proceedings, IEEE Bologna, Volume 3, 23-26 June 2003 Page(s):6 pp.

[22] M. D. Mufti, R. Subramanian, S. C. Tripathy, "Dynamic performance assessment of an isolated wind-diesel power system with superconducting magnetic energy storage unit under turbulent wind and load disturbances", International Journal of Energy Research, Volume 26, Issue 3, March 2002, Page (s): 185-201.

[23] K. Nandigam, B. H. Chowdhury. "Power flow and stability models for induction generators used in wind turbines," IEEE Power Engineering Society General Meeting, Vol.2, 6-10 June 2004 Page(s):2012 – 2016

[24] M. D. Mufti, R. Subramanian, S. C. Tripathy, "Dynamic performance assessment of an isolated wind-diesel power system with superconducting magnetic energy storage unit under turbulent wind and load disturbances", International Journal of Energy Research, Volume 26, Issue 3, March **2002**, Page (s): 185-201.

[25] E. Ozkop, A.M. Sharaf, I.H. Altas, An Intelligent Self-Adjustable FACTS Device for Distribution System, International Journal of Power Engineering & Green Technology, 2(1), 11-26, (2011).