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Turkish Journal of Electromechanics & Energy

ISSN: 2547-975X

A Flexible Alternating Current Transmission System-Green Plug Scheme for Smart Grid Applications

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Received: 13 July 2015; Accepted: 03 March 2016; Published: 30 March 2016
Turk J Electrom Energ Vol.: 1 No: 1 Page: 13-20 (2016)
SLOI: http://www.sloi.org/

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ABSTRACT: *The paper presents a new dynamic voltage stabilization Flexible AC Transmission System (FACTS) scheme for smart- grid applications with nonlinear loads and distributed generation. The use of wind, photovoltaic and battery storage systems with nonlinear loads and DC-AC solid state interface creates voltage stability and power quality problems and reduce energy efficient utilization. In this paper, a Green Plug Shunt Filter Compensator (GP-SFC) is validated as an effective FACTS-switched shunt LC compensation device for dynamically modulating the Thevenin's impedance at the point of common coupling for efficient energy transfer utilization as well as voltage stabilization. The GP-SFC FACTS device is validated using MATLAB-Simulink simulation environment at varying load and system conditions including open circuit, short circuit fault conditions, and load reductions. The coordinated, multi-regulation, inter coupled dynamic controller scheme ensures the GP-SFC device effectiveness in improving power quality at key AC buses, while reducing inrush currents and transient over-voltage/switching recovery voltage excursions.*

Keywords: Smart grid, Shunt filter compensator, Energy efficiency, Power quality enhancement.

Cite this article: *A. M. Sharaf, F. H. Gandoman, A. Rahimi, A Flexible Alternating Current Transmission System-Green Plug Scheme for Smart Grid Applications, Turkish Journal of Electromechanics & Energy 1(1) 13-20 (2016)*

1. INTRODUCTION

Power quality issues and reliability, security and voltage stability problems are new issues in electric utilities and emerging smart-grid systems. The increasing use of photovoltaic cell (PV) and wind farm and other distributed generation (DG) renewable energy resources have changed the reliability, security and power quality of the electrical systems remarkably [1, 2]. Fast controllable FACTS devices are considered as effective solutions for long and short duration voltage changes, voltage imbalances, waveform distortion, voltage fluctuation and power frequency of modern electrical networks that lead to improving power quality [3, 4].

In order to reduce feeder active and reactive power losses as well as to enhance recovery dynamic response on the electrical system after open, short circuit operations and load changing and modulated capacitor banks have been widely used in modern electrical system [5, 6]. Fixed power filters which are low-cost, simple, and robust structures are usually installed in industrial utilization networks to improve the power quality. Nonetheless, the fixed parameter power filters and capacitor banks are limited in effectiveness for dynamic type of loads and may result in resonance in some cases [7, 8].

In this paper a new Green Plug-Shunt Filter Compensator (GP-SFC) device is validated using Matlab-Simulink software environment with a new tri-regulation multi loop error driven controller for voltage stabilization, energy efficiency and secure delivery to the load. The new GP-SFC utilized an IGBT/GTO switch controlled by the dynamic error driven control strategies using a multi-loop dynamic error driven. Also, it is coordinated a regulation, control scheme and a Weighted–Modified fast to act PID (WMPID) controller.

The current manuscript is organized as follows: The FACTS scheme is described in Section 2. In Section 3, working principle of the system is explained. Finally, Sections 4 and 5 present the Matlab/Simulink digital simulation results under fault open circuit, short circuit and load varying conditions, and conclusions, respectively.

2. THE FACTS GREEN PLUG-SWITCHED FILTER COMPENSATOR

2.1. GP-SFC Scheme

The proposed GP-SFC dynamic voltage stabilization device is a member of modulated switched/modulated power filters and switched capacitor compensators family [9-15].

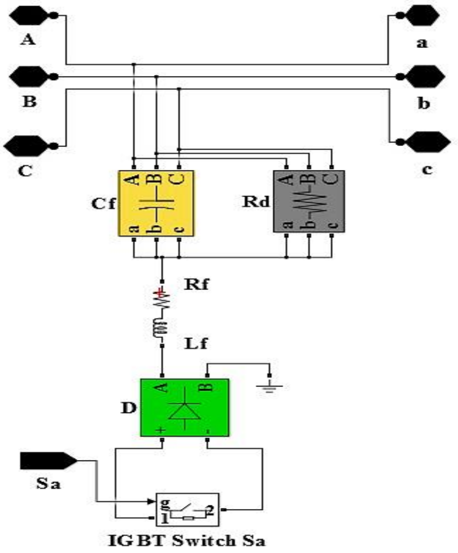


Fig. 1. GP-SFC device configuration

proposed GP-SFC a switching modes of operation using a tuned arm filter has been controlled solid state switch *(Sa)*. The configuration of the proposed GP-SFC is shown in Figure 1.

2.2. The Multi Regulation Controller

One of most important parts of FACTS devices is controller as it plays a crucial role to auxiliary the other devices in order to improve the power quality. The dynamic error driven tri-regulation controller of the proposed GP-SFC is given in Figure 2. It is based on measurement of the current I_{rms} at the source point. The current error signal is obtained by comparing the measured I_{rms} current against a reference current, I_{rms_ref}. The angle delta is used in the PWM generator as the phase angle of the sinusoidal control signal. The switching frequency used in the sinusoidal Pulse Width Modulation (PWM) generator is $f_{s/w}$ - 1250 Hz. Moreover, the global output signal from the dynamic error driven controller is followed by a WMPID controller is displayed in Figure 3. WMPID includes an error sequential activation supplementary loop, ensuring fast dynamic response and effective damping of large excursions, in addition to the conventional PID structure.

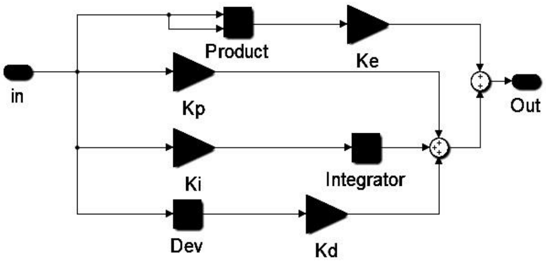


Fig. 3. Weighted-modified PID controller with error-squared loop.

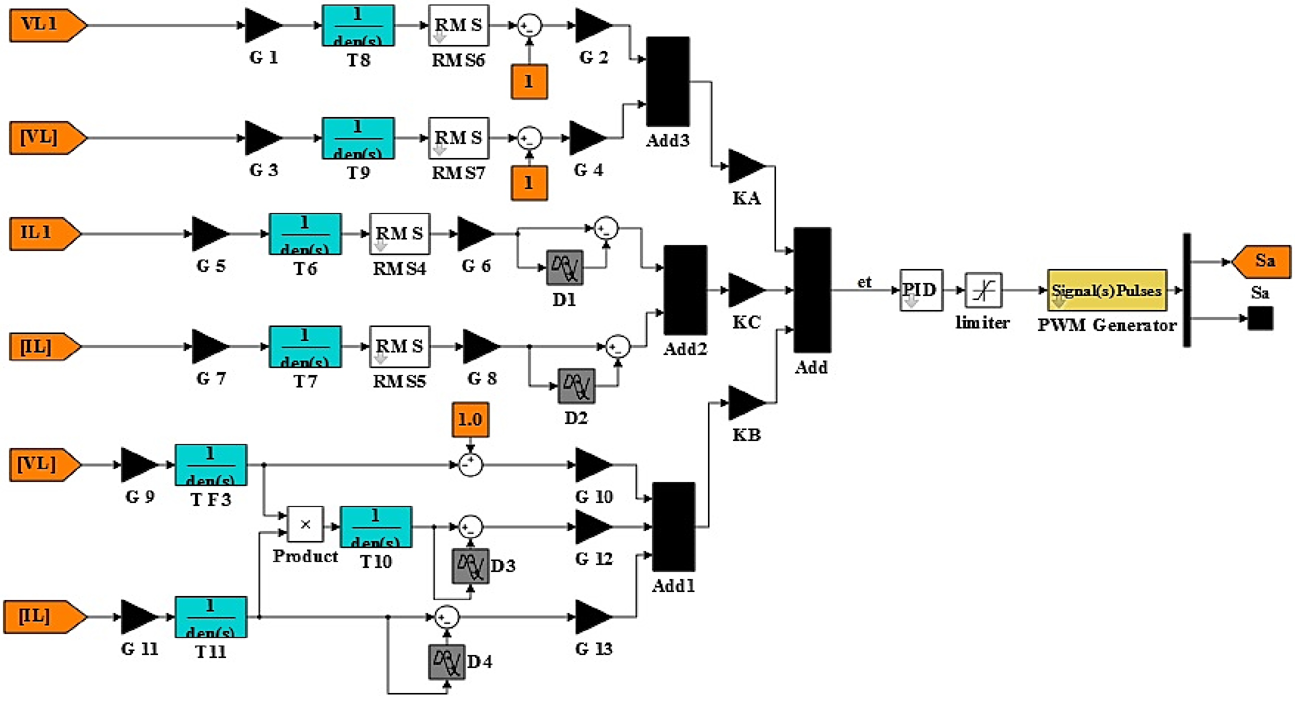


Figure. 2. Dynamic error driven Tri-regulation controller.

3. AN AC SYSTEM CASE STUDY

An AC system case study with additional FACTS GP-SFC is shown in Figure 4. The case study is comprises a local hybrid load (linear, nonlinear and induction motor type loads) and is connected to the infinite bus with 138kV, substation bus through 8 km feeder. In this paper, a nonlinear load has been designed in MATLAB-Simulink in order to study behavior of nonlinear load under different circumstances (Figure 4). The unified AC system, GP-SFC and the dynamic control parameters are given in the Appendices *A* and *B*.

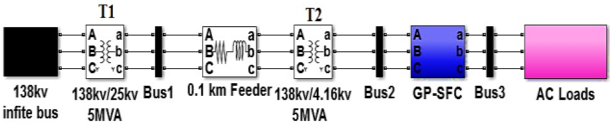
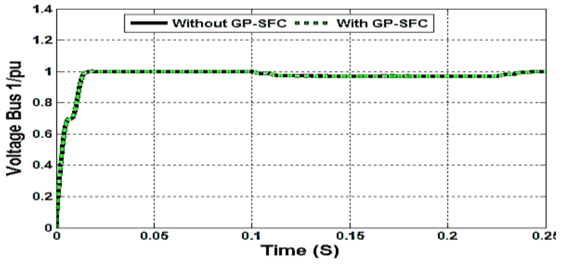


Fig. 4. The AC system case study.

4. DIGITAL SIMULATION RESULTS

4.1. Short Circuit Condition

The Matlab-Simulink Software environment was utilized to validate the effectiveness of the GP-SFC scheme of the host smart grid under short circuit (SC) condition. In addition, a three-phase short circuit in load bus is applied at time 0.02s of the AC grid, and it is cleared after 0.02s. The results of the simulation under short circuit condition in bus 1 and bus 2 are given in Figure 5. Based on the results obtained, the GP-SFC scheme was validated to be effective in stabilizing bus voltages, improving power factor and reducing inrush currents under short circuit faults.



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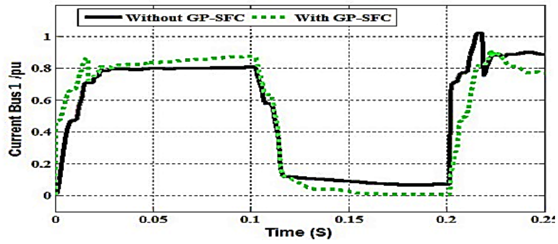

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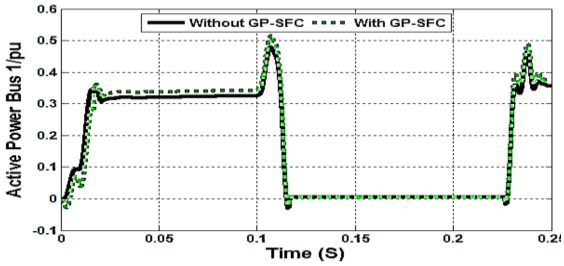

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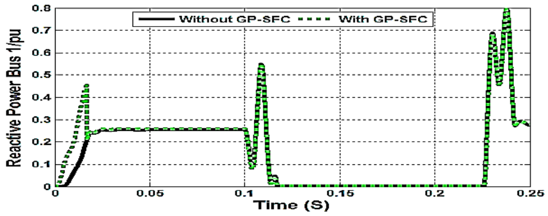

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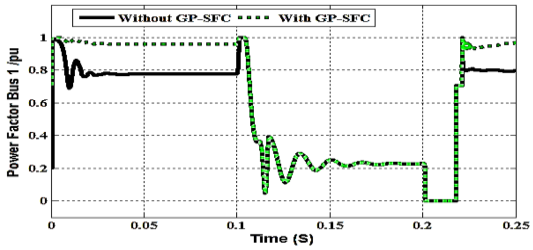

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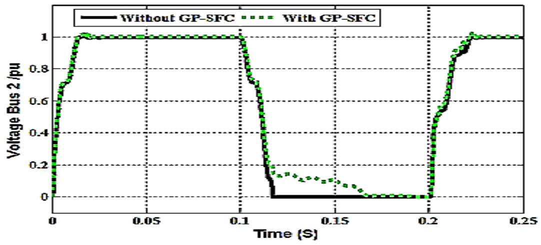

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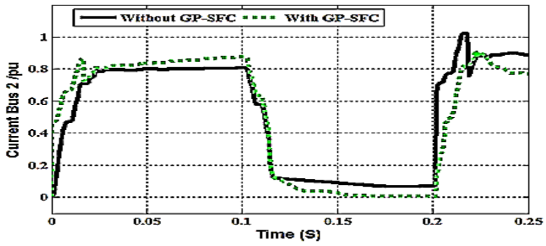

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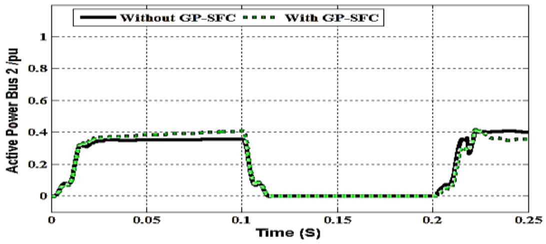

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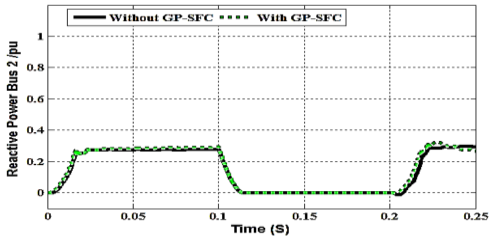

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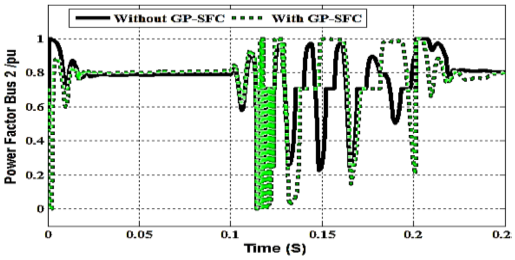
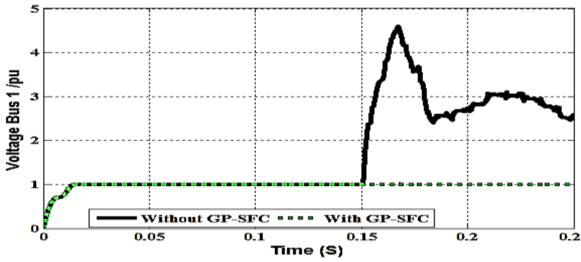


(j)

Fig. 5. (a) RMS voltage waveform in bus 1, (b) RMS current waveform in bus 1, (c) Active power waveform in bus 1, (d) Reactive power waveform in bus 1, (e) Power factor waveform in bus 1, (f) RMS voltage waveform in bus 2, (g) RMS current waveform in bus 1, (h) Active power waveform in bus 2, (i) Reactive power waveform in bus 2, (j) Power factor waveform in bus 2, all under short circuit operation.

4.2. Open circuit

In this section of the paper, an open circuit is occurred near to load and changing of key parameter shown in Figure 6. Additionally, as it can be seen, dynamic response and power quality in buses 1 and 2 have been improved. Also, the power factor during open circuit fault with GP-SFC in key buses has insignificant fluctuation, especially in bus 1.



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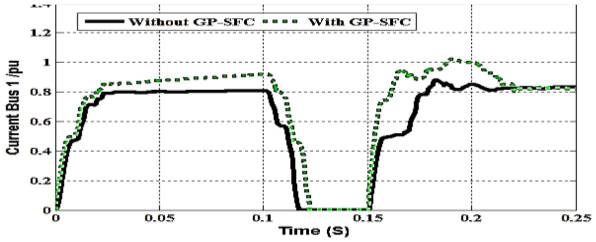

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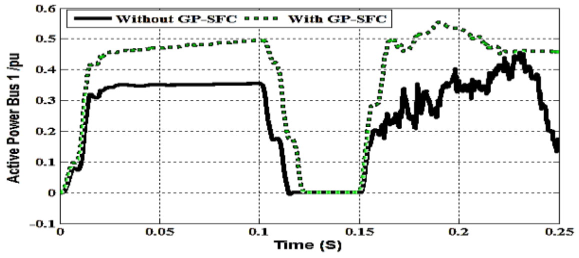

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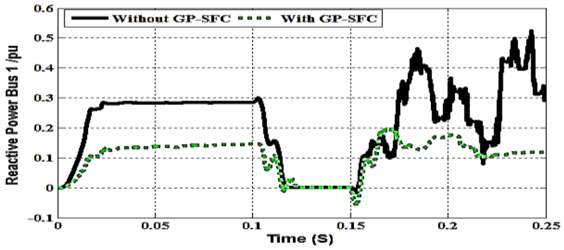

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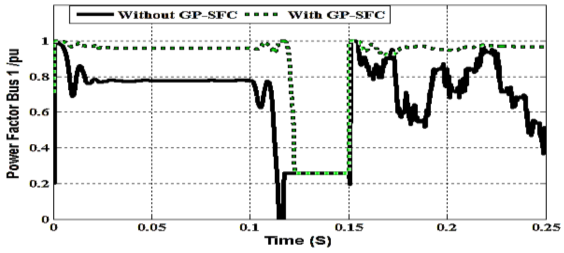

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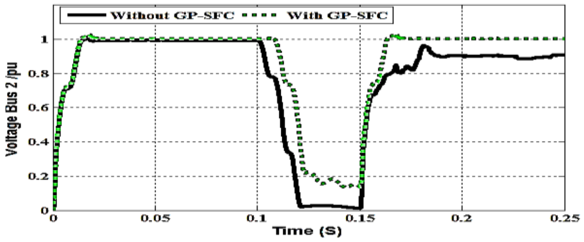

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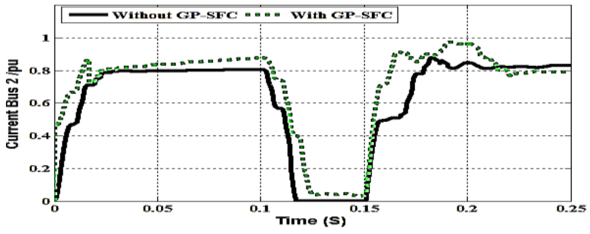

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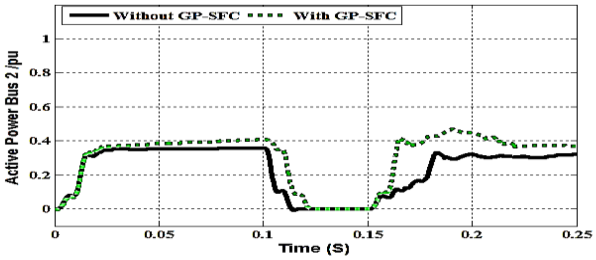

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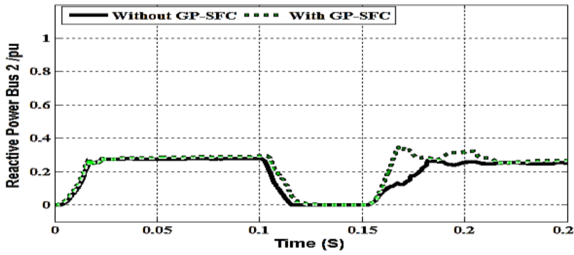

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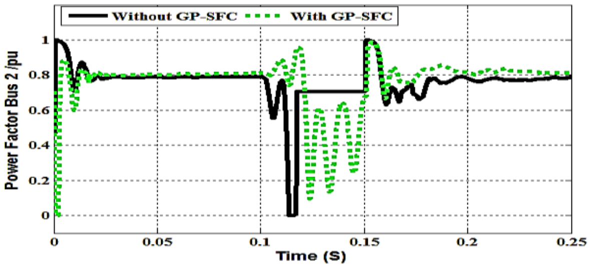

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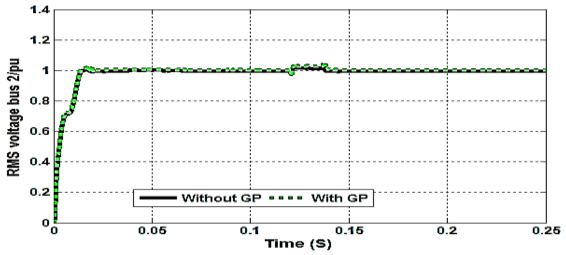
Fig. 6. (a) RMS voltage waveform in bus 1, (b) RMS current waveform in bus 1, (c) Active power waveform in bus 1, (d) Reactive power waveform in bus 1, (e) Power factor waveform in bus 1, (f) RMS voltage waveform in bus 2, (g) RMS current waveform in bus 1, (h) Active power waveform in bus 2, (i) Reactive power waveform in bus 2, (j) Power factor waveform in bus 2, all under open circuit operation.

4.3. Hybrid Electric-Load Variations

In order to examine the AC grid response to load excursions in the presence of the GP-SFC and without FACTS-GP, following conditions are dictated to the grid. At 0.02s, linear load is disconnected and then reconnected after 0.04s. At 0.1s, nonlinear load is disconnected and reconnected after 0.04s. At 0.18s, motor load's torque decreases by 50% for the period of 0.04s. At 0.22s, motor's torque increased by 50% for the duration of 0.04s. Figure 7 show the results obtained for load variation condition with and without GP-SFC in the case study.



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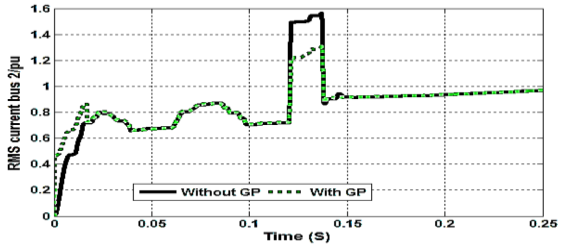

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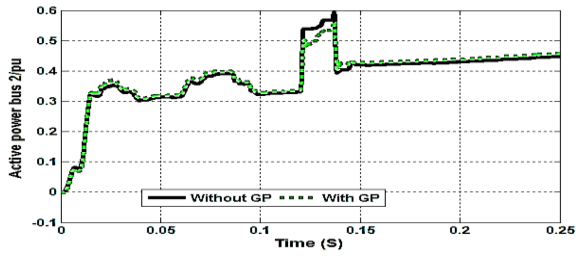

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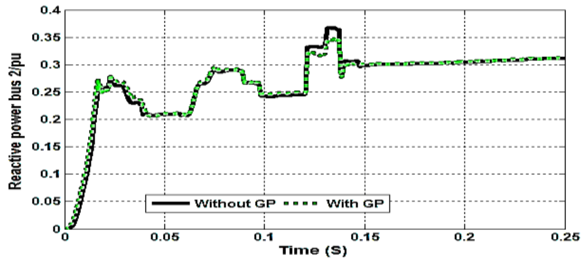

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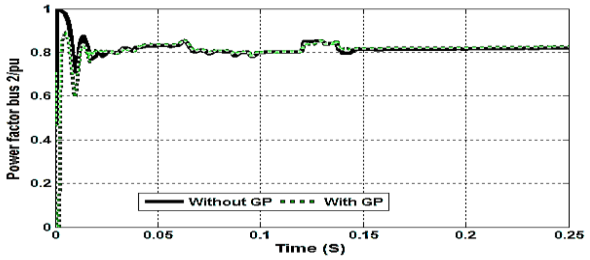
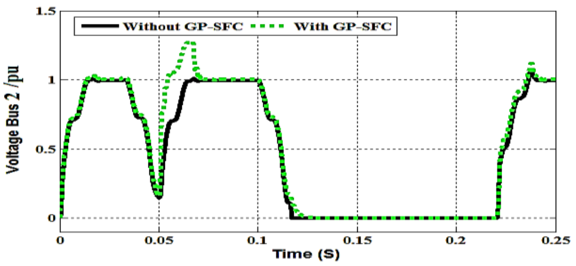


(e)

Fig. 7. (a) RMS voltage waveform in load bus, (b) RMS current waveform in load bus, (c) Active power waveform in load bus, (d) Reactive power waveform in load bus, (e) Power factor waveform in load bus, all under load variation operation.

4.4. Short and Open Circuit Condition

In order to show flexible performance of proposed GP-SFC, two different types of faults at same time has been analyzed in the case study. First, an open circuit is occurred near to load with 20ms duration time in 0.05s to 0.07s. After that, a short circuit is occurred near to load with 120ms duration time in 1s to 2.2s. The simulation results of case study with and without GP-SFC in load bus are shown in Figure 8.



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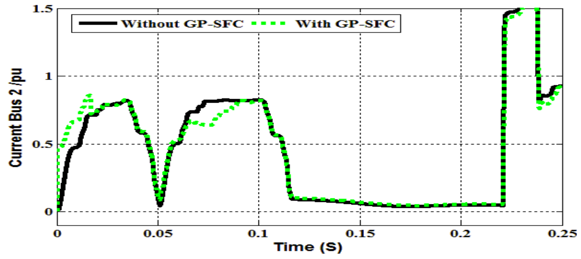

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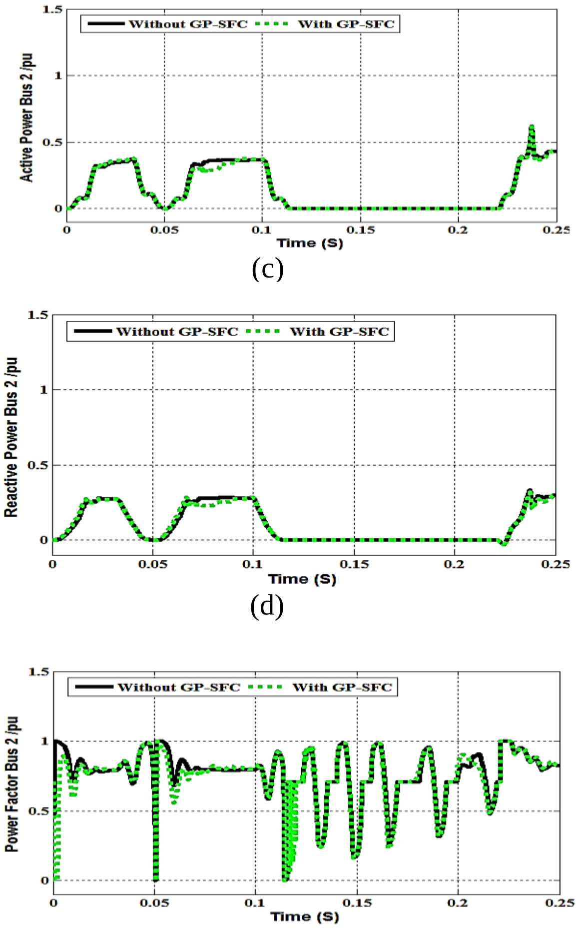

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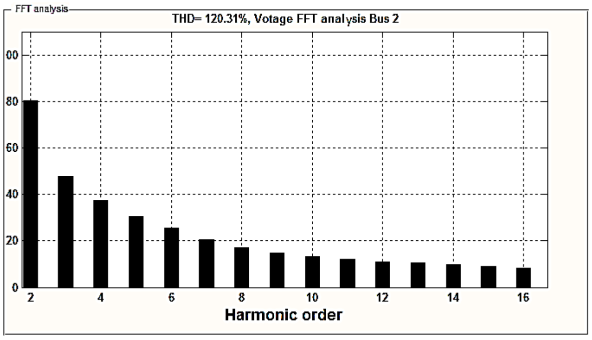
Fig. 8. (a) RMS voltage waveform in load bus, (b) RMS current waveform in load bus, (c) Active power waveform in load bus, (d) Reactive power waveform in load bus, (e) Power factor waveform in load bus, all under open and short circuit operation.

4.5. Power Quality Enhancement

The total harmonic distortion (THD) is an important feature of merit used to quantify the level of harmonics in voltage or current waveforms. In this section, the harmonics of the load bus of current and voltage are analyzed.

Figure 10 show voltage, and current of the THD of the load bus without FCTS-GP as a function of time, respectively. For constant series compensation, as seen in Figures 9(a) and 9(b), the rate of THD has been increased (by percentage) due to using nonlinear load on power system, however; as seen in Figure 9(c) and 9(d), utilizing the FACTS-GP, the THD of the line current terminal voltage in load bus is improved.



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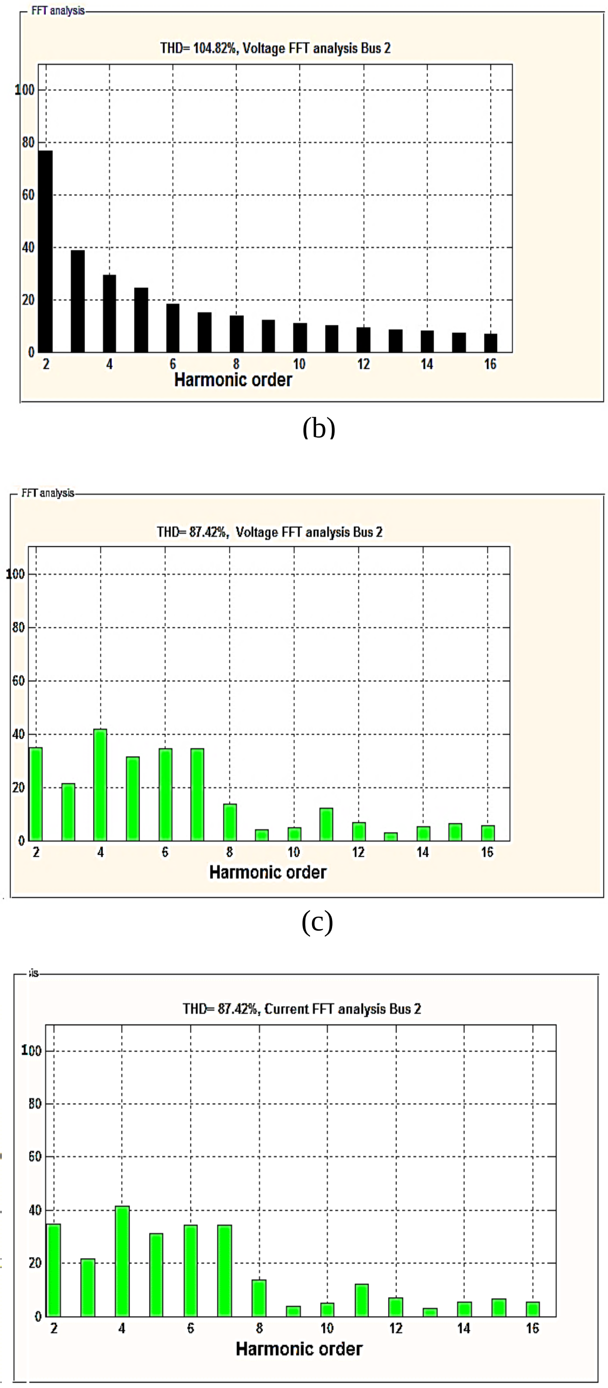

(b)

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Figure. 9. (a) FFT analysis of voltage at load Bus 2 without GP-SFC for load changing operation, (b) FFT analysis of current at load Bus 2 without GP-SFC for load changing operation, (c) FFT analysis of voltage at load Bus 2 with GP-SFC for load changing operation, (d) FFT analysis of current load Bus 2 with GP-SFC for load changing operation.

5. CONCLUSIONS

This paper presents a FACTS switched/modulated scheme (GP-SFC) to use in smart grid distribution systems. The GP-SFC is effective in dynamic voltage stabilization at load AC bus and in limiting dynamic transient recovery voltages and inrush current conditions. A tri-regulator coordinated error driven, is utilized to adjust the sinusoidal PWM switching patterns for the solid state switching to ensure fast dynamic bus voltage stabilization and power factor correction. The same GP-SFC topology can be utilized with different modified control strategies for hybrid DC-AC interface schemes using DG and renewable PV/Tidal/Wave/Wind/Micro-Hydro/Fuel Cell green energy and storage systems. The digital simulation results validated the dynamic fast response and stabilization effectiveness of the proposed FACTS GP-SFC scheme for improving voltage regulation, limiting inrush current conditions, and modifying power factor.

Appendix

A) Case study parameters

Transmission Line	25 kV (L-L), 8 km	
	R/Km=0. 35 Ω, L/Km=0.4 mh	
Infinite Bus	138 kV, X/R=10	
FACT-GP	Csh=275µf	
	Rf=0.15Ω, Lf=3mh	
Local Hybrid Ac Load	Induction Motor	0.2 MW, 4 Poles
		Rs=0.01965pu, Ls=0.0397 Pu
		Rr=0.01909pu, Lr=0.0397 Pu
		Lm=1.354 Pu
	Linear Load	P=1.8 Mw,Q=0.43Mvar
	Nonlinear Load	P=0.9 Mw,Q=0.43Mvar
Power Transformer	T1	138/25kV, 5 MW
	T2	25/4.16kV, 5 MW

B) Controller system parameters

Device	Value
GP-SFC Controller Gains	Ke=1, Kp=25, Ki=2, Kd=1, PWM Frequency Fs=1750 Hz

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Biographies

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Azad Rahimi was born in Iran, in 1975. He received the B.Sc. and MSc degrees from Shaid Rajaee University, and K.N. Toosi University of Technology in 2000 and 2005 in electrical power engineering, respectively. He is currently active researcher and lecturer at Technical and vocational University of Sanandaj in electrical power engineering, Iran. His research interests include load forecasting, smart and micro grid, renewable energy, power quality, electric vehicles.
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