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Research Article

Simulation of 48 Pulse GTO Based STATCOM, SSSC & UPFC Controller

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Abstract

This paper examines effective operation of both static synchronous compensator (STATCOM), static synchronous series compensator (SSSC) and unity power factor controller (UPFC) based on a new full model consisting of 48 - pulse gate turn off thyristor voltage source converter for connected reactive power compensation and voltage stabilization of the electrical grid network. Three controllers of STATCOM, SSSC and UPFC are presented in this paper based on a decoupled with voltage and current control strategy. The performance of STATCOM, SSSC and UPFC is verified by simulation using MATLAB environment. The performance of STATCOM, SSSC and UPFC schemes connected to the 500 - KV grid are evaluated. The proposed to ensure the stable operation of the STATCOM under various load conditions. Unified Power Flow Controller (UPFC) has its unique capability to control simultaneously real and reactive power flows on a transmission line as well as to regulate voltage at the bus where it is connected, this device creates a tremendous quality impact on power system stability. In this paper a proposed control method, GTO based controller has been developed by using SSSC of MATLAB this will applied to STATCOM part of the detailed model of UPFC. The MATLAB simulation results shows that GTO controller has an effective power flow control, less settling time and less overshoot when compared to PI controller in different operating modes.

Keywords: Gate Turn-Off dynamic performance; Static synchronous series compensator; Static synchronous compensator; Unified Power flow controller; Voltage stabilization; 48 - pulse converter; Power System.

Introduction

The static series synchronous compensator (SSSC) is able to control active and reactive in a transmission line in a small range via stored energy in capacitor DC-link where static synchronous compensator (STATCOM) with injecting reactive power can control the bus voltage in a transmission line [1,2]. Unified Power Flow Controller (UPFC) is the most functional and Flexible AC Transmission Systems (FACTS) equipment that has emerged for the control and optimization of power flow in power transmission systems. It has the combining features of both series converter and shunt converter based FACTS devices and is capable of realizing voltage regulation, series compensation and phase angle regulation at the same time [3,4]. Therefore, the UPFC is capable of independently controlling the active power and reactive power on the compensated transmission line.

GTO thyristors are implement the design of the solid-state shunt reactive compensation and active filtering equipment based upon switching convertor technology. These power quality devices (PQ Devices) are power electronic converters connected in parallel or in series with transmission lines and the operation is controlled by digital controllers. The interaction between these compensating devices and the grid network is preferably studied by digital simulation [5]. Flexible alternating current transmission systems (FACTS) devices are usually used for fast dynamic control of voltage, impedance and phase angle of high-voltage AC lines. FACTS devices provided strategic benefits for improved transmission system power flow management through better utilization of existing transmission belongings, increased transmission system security and reliability as well as availability, increased dynamic and transient grid stability and increased power quality for sensitive industries (e.g., computer chip manufacture) [6].

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The approach of FACTS systems is giving rise to a new family of power electronic equipment for controlling and optimizing the dynamic performance of power system. e.g., STATCOM, SSSC and UPFC [7]. The use of voltage source inverter (VSI) has been widely accepted as the next generation of flexible reactive power compensation to replace other conventional VAR compensation, such as the Thyristor Switched Capacitor (TSC) and Thyristor Controlled Reactor (TCR). This paper proposes novel cascade multilevel converter model which is a 48 - pulse (three levels) source converter [8].

It consists of four three phase, three-level inverters and four phase shifting transformers [9]. In 48 - pulse voltage source converter, the DC bus V_{dc} is connected to the four three-phase inverters. The voltages are generated by the inverters are applied to secondary windings of four zigzag phase-shifting transformers connected in Y or Δ [10]. The four transformer primary windings are connected in series and the converter pulse patterns are phase shifted. So, that the four voltage fundamental components sum in Phase on the primary side.

Materials and methods

Power Flow Controlling Devices

Power flow regulated by adjusting the parameters of a system, such as voltage magnitude, line impedance and transmission angle. The device that attempts to vary system parameters to control the power flow can be described as a Power Flow Controlling Device (PFCD) as shown in Fig.1.

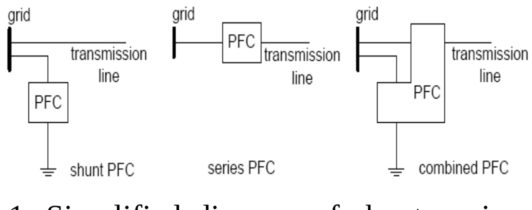

Fig. 1. Simplified diagram of shunt, series and combined devices

A shunt component is a device that connects between the grid and the ground. Shunt devices generator absorb reactive power at the point of connection thereby controlling the voltage magnitude. Because the bus voltage magnitude can only be varied within certain limits, controlling the power flow in this way is limited and shunt devices mainly serve other purposes. For example, the voltage support provided by a shunt device at the midpoint of a long transmission line can boost the power transmission capacity.

STATCOM

A static synchronous compensator (STATCOM) is basically a Voltage Source Converter (VSC) that is connected between a grid and the ground through a coupling inductance as shown in Fig.2. The STATCOM acts as an AC voltage source and has characteristics similar to a synchronous condenser (a synchronous generator that is running idle and used for reactive compensation). The STATCOM injects an AC current in Quadrature (leading or lagging) with the grid voltage and imitate capacitive or inductive impedance at the point of connection.

If the voltage generated by the STATCOM is less than the grid voltage, it will act as an inductive load and withdraw reactive powers from the system. When the STATCOM voltage is higher than the grid voltage, it will act as a capacitor load and provide reactive power to the grid. Compared to the synchronous condenser, the STATCOM is a Power Electronic based device without inertia and therefore has a faster dynamic response. It consists of a three-phase current-fed converter, whose outputs are connected to a three-phase full-bridge diode rectifier through a delta-delta wound three-phase transformer.

The three-phase current-fed converter is divided into a three-phase full-bridge converter configured as six main MOSFET switches (S_1–S_6) for three-phase DC/AC conversion, one auxiliary MOSFET switch (S_c) and clamp capacitor C_c for the active clamp and a DC boost inductor L_{dc} acting as a current source.

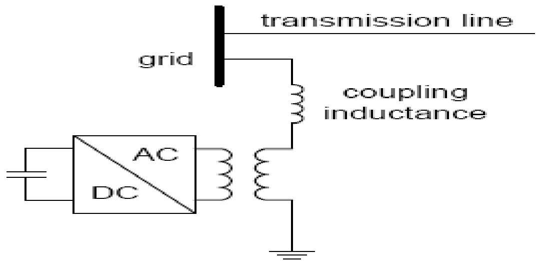

Fig. 2. STATCOM configuration

The DC Voltage Source Converter is the most common type of converter that used for the STATCOM and the DC voltage source can be a capacitor. By using a multi-level, multi-phase or

Pulse-Width Modulated (PWM) converter, the current distortion of the STATCOM outputs can be sufficiently reduced and the STATCOM may even require no filtering. Fig.3 shows the waveforms of a voltage generated by a five-level STATCOM and the corresponding current.

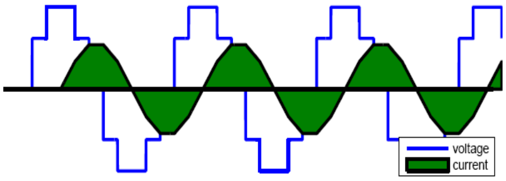

Fig. 3. Voltage and current waveforms generated by a five-level STATCOM

Unified Power Flow Controller

Unified power flow controller (UPFC) is a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are coupled through a common DC link, to allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC is an angularly unconstrained series voltage injection and control of the transmission line voltage. Impedance and angle in real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation. The operation of the UPFC from the standpoint of conventional power transmission based on reactive shunt compensation, series compensation and phase shifting, the UPFC can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage V_{inj} with appropriate amplitude and phase angle.

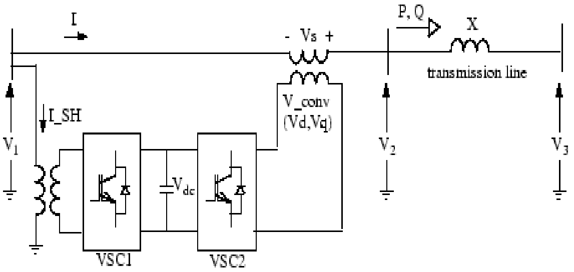

Fig. 4. UPFC System

Fig. 4 shows an combination of Shunt and Series controller action is works as a unified power flow controller (UPFC) is used to control the power flow in a 500 kV transmission system. The SSSC and STATCOM located at the left end of the 75-km line L_1, between the 500 kV buses B_1 and B_2 is used to control the active and reactive powers flowing through bus B_2 while controlling voltage at bus B_1. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B_1 and one connected in series between buses B_1 and B_2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L_2. This pair of converters can be operated in three modes: Unified Power Flow Controller (UPFC) mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available. Shunt converter operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus B_1 Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current.

Dynamic Performance of the STATCOM

The STATCOM device operation can be illustrated by the phasor diagrams shown in Fig. 5. When the secondary voltage (V_S) is lower than the grid system bus voltage, the STATCOM acts like an inductance absorbing reactive power from the grid bus. When the secondary voltage is higher than the bus voltage, the STATCOM acts like a capacitor generating reactive power to the grid bus. In steady-state operation, the bus voltage always leads the inverter AC voltage by a very small angle to supply the required small active power losses.

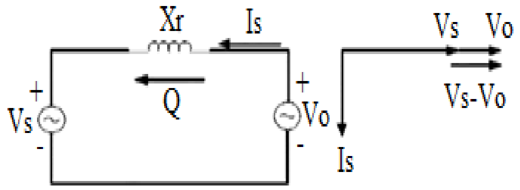

Fig. 5(a). STATCOM Induction Operation

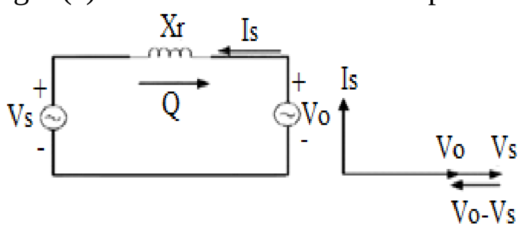

Fig. 5(b). STATCOM Capacitive Operation

The voltage source converter or inverter (VSC or VSI) scheme is the building block of any STATCOM device and other FACTS devices. A simple inverter produces a square voltage waveform as it switches the direct voltage source ON and OFF. The basic objective of a good VSI converter scheme is to produce a near sinusoidal AC voltage with minimal wave form distortion or excessive harmonics content. Three basic techniques can be used for reducing the harmonics produced by converter switches are harmonic neutralization using magnetic coupling, harmonic reduction using multilevel converter configurations and novel pulse-width modulation (PWM) switching techniques. The 24 and 48 pulse converters are obtained by combining two or four (12-pulse) VSI respectively, with the specified phase shift between all converters. For high-power applications with low distortion, the best option is the 48-pulse converter, although using parallel filters tuned to the 23^{rd}–25^{th} harmonics with a 24-pulse converter could also be adequately attentive in most applications, but the 48-pulse converter scheme can ensure minimum power quality problems and reduced harmonic resonance conditions on the interconnected grid network.

Result and discussions

This type of converter is used in high-power Flexible AC Transmission Systems which are used to control power flow on transmission grids. It can be used to fabricate a model of shunt or series static compensator (STATCOM or SSSC), a combination of shunt and series devices known as Unified Power Flow Controller (UPFC) as shown in figure 6.

Each three level inverter generates three square wave voltages which can be $+V_{dc}$, 0, $-V_{dc}$. The duration of the $+V_{dc}$ or $-V_{dc}$ level can be adjusted between 0 and 180^0 from the Sigma input of the Firing Pulse Generator block as shown in figure 7. Each inverter uses a 3 Level Bridge block power electronic devices and Ideal Switches. In this model each leg of the inverter uses three ideal switches to obtain the 3 voltage levels as shown in figure 8.

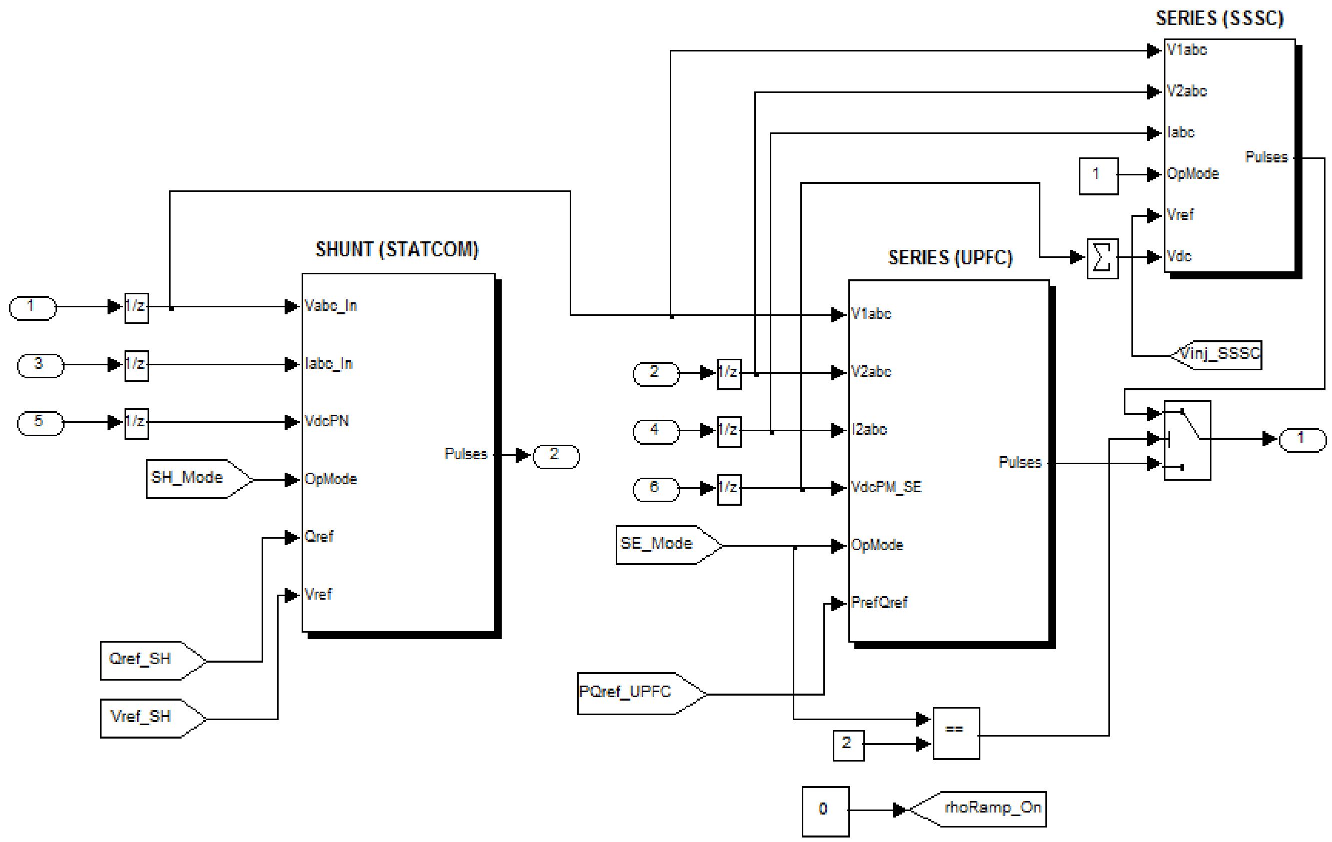

Fig. 6. Simulation Circuit for UPFC Controller

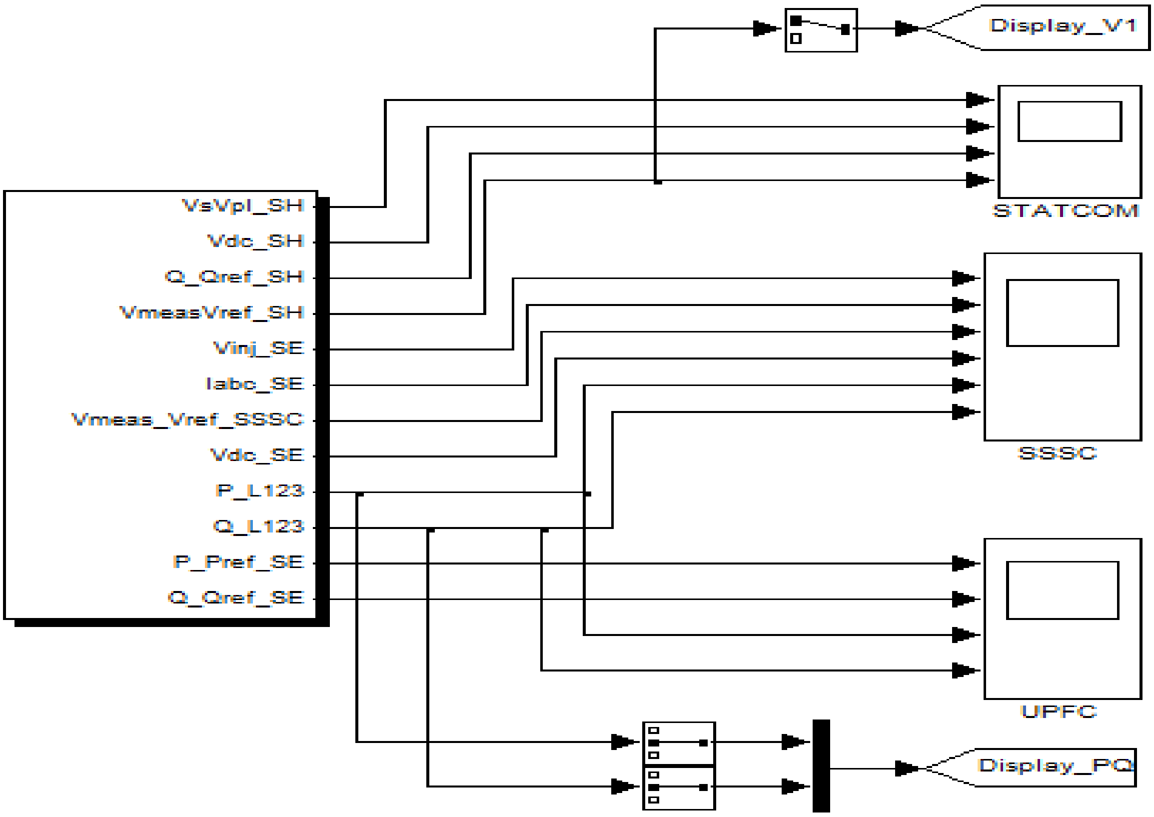

Fig. 7. UPFC Data Acquisition for STATCOM, SSSC & UPFC

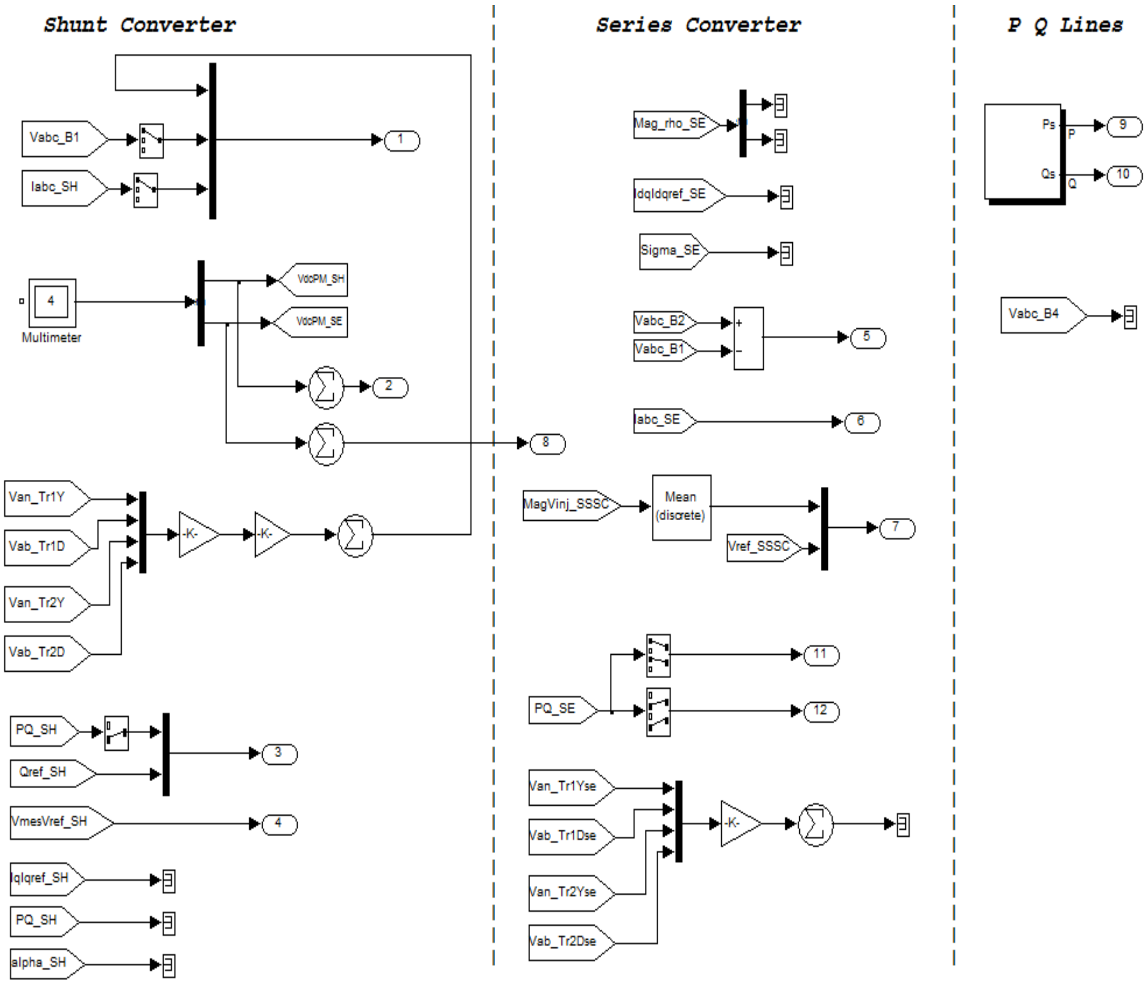

Fig. 8. Simulation Circuit for Shunt, Series Converter & PQ Line

The Static Synchronous Series Compensator is a series device of the FACTS family using power electronics to control power flow and improve power oscillation damping on power grids. The SSSC injects a voltage V_s in series with the transmission line where it is connected shown in figure 9. The abc to dq_0 transformation of Unified Power Flow controller as illustrated in figure 10. The four voltages generated by the inverters are applied to secondary windings of four zig-zag phase shifting transformers connected in star or delta. The four transformer primary windings are connected in series and the converter pulse patterns are phase shifted so that the four voltage fundamental components sum in phase on the primary side as shown in figure 11. The inverter is operated in open loop at constant DC voltage. During the first three cycles the inverter operates at no load using UPFC as shown in figure 12.

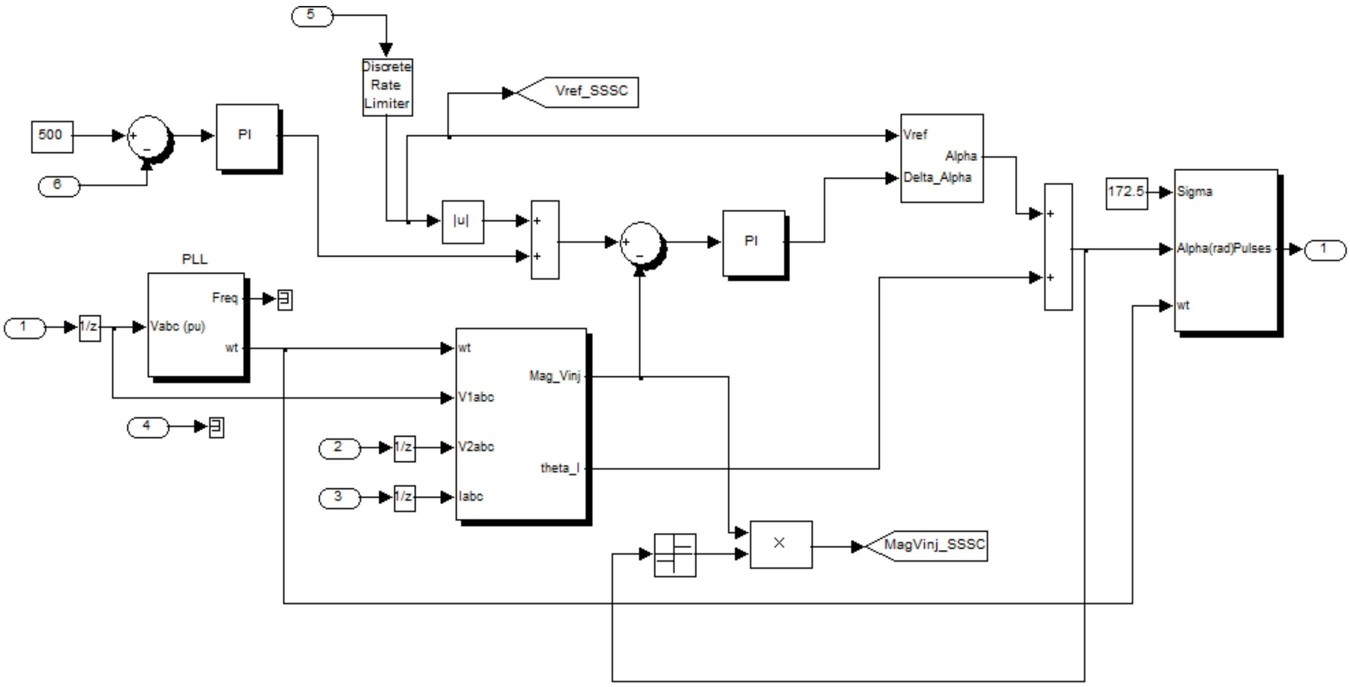

Fig. 9. Simulation Circuit for SSSC Controller Using PI

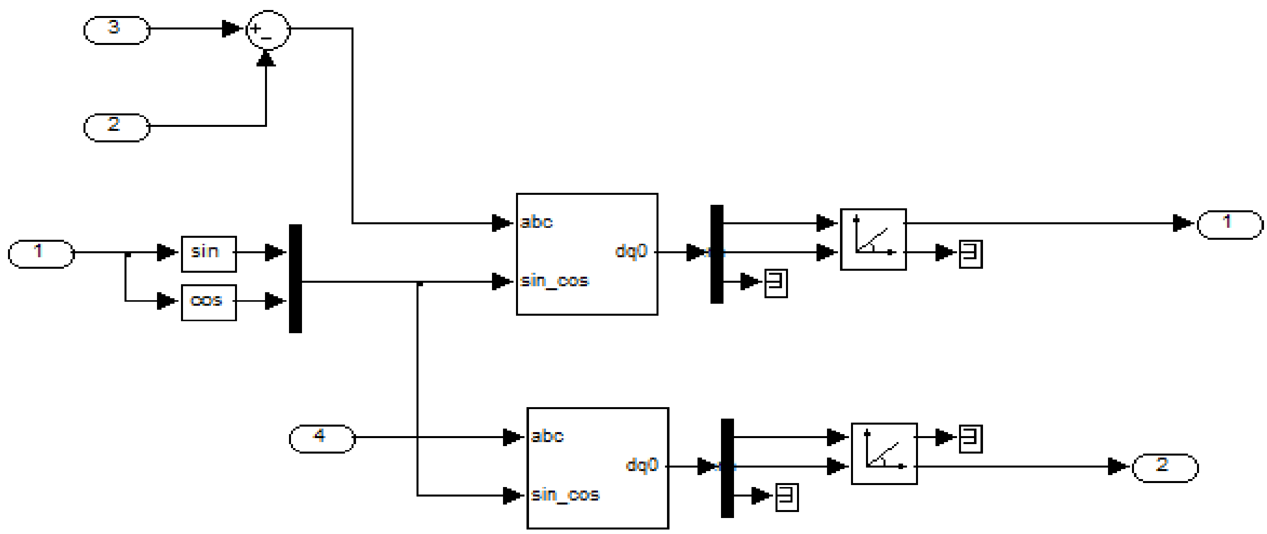

Fig. 10. abc to dq_0 Transformation of UPFC

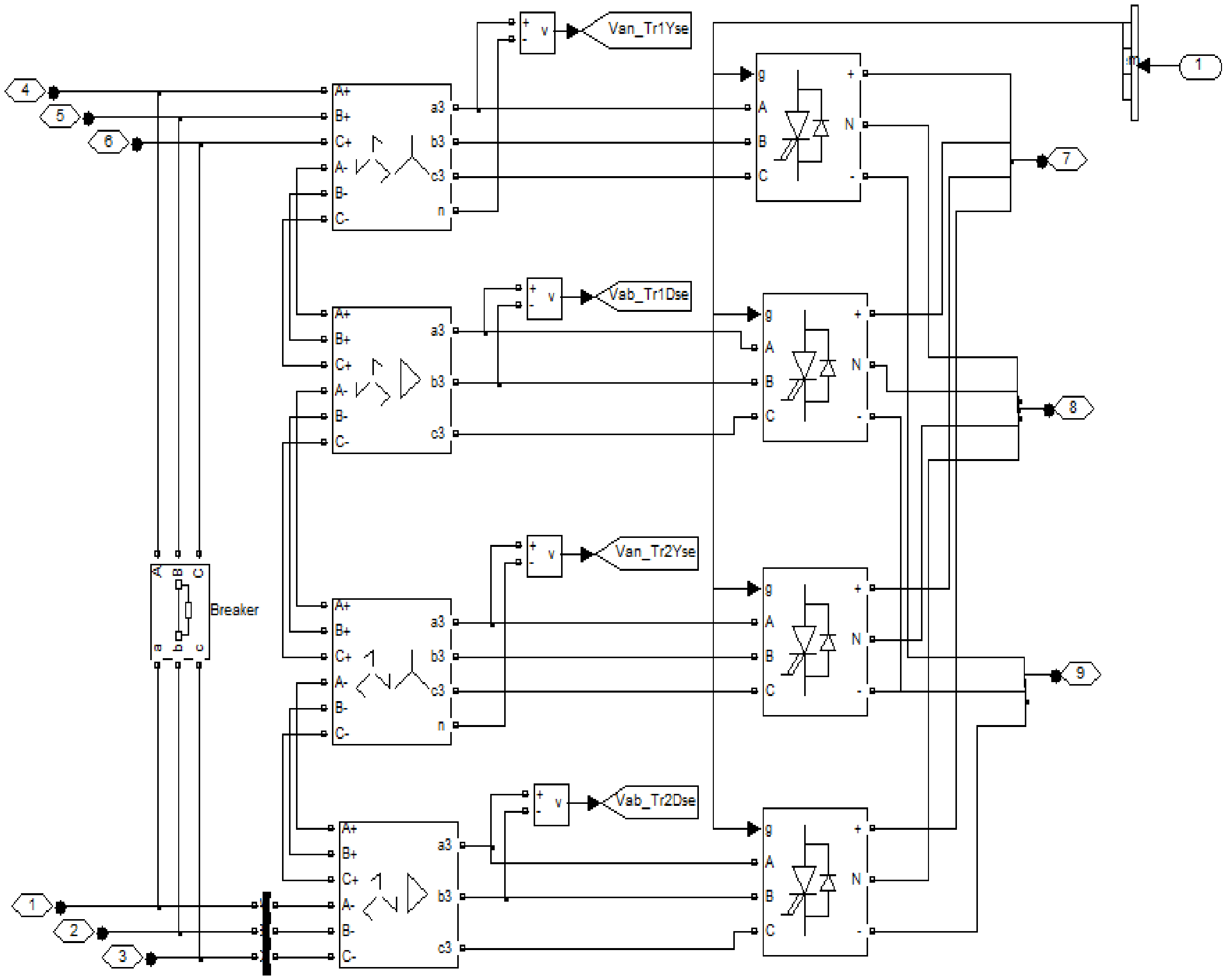

Fig. 11. 48-Pulse GTO Voltage Source Converter

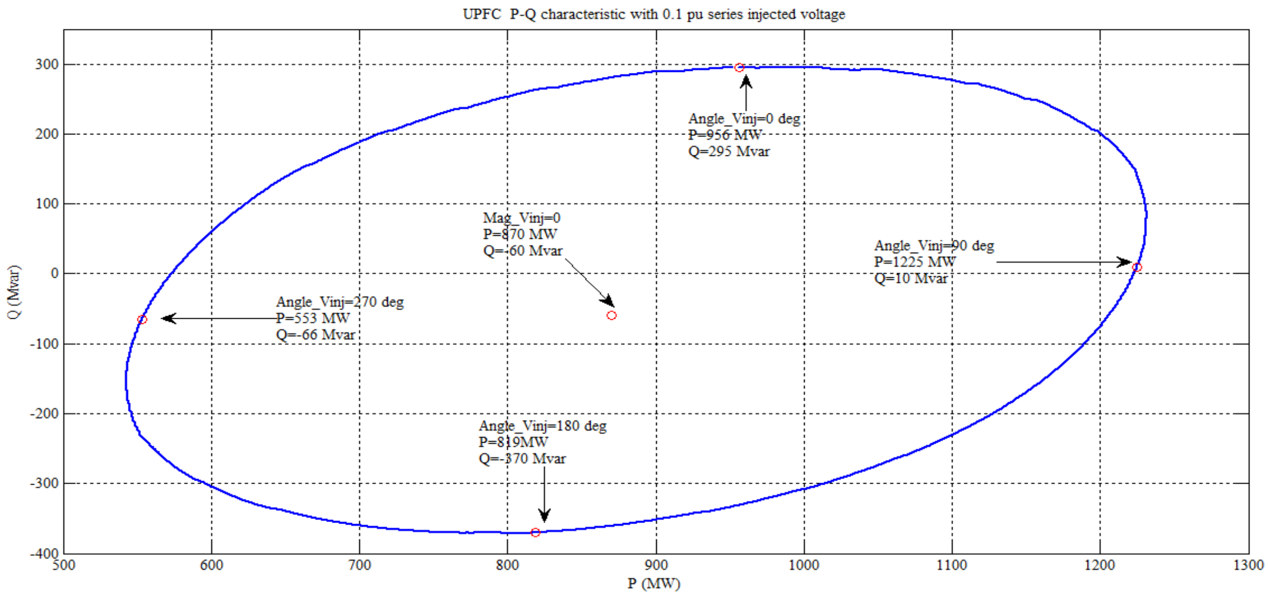

Fig. 12. Waveform for UPFC Controllable Region

The system has been tested and simulation results are shown in this section. This model has been implemented using MATLAB/SIMULINK environment with SIMPOWER system toolbox. Figure 13 shows the STATCOM output voltage and current waveform. The output describes the static synchronous series compensator of Voltage, Current, Real and Reactive Power waveform as given in figure 14 and Unified Power Flow controller waveform for Real and Reactive power is illustrated in figure 15.

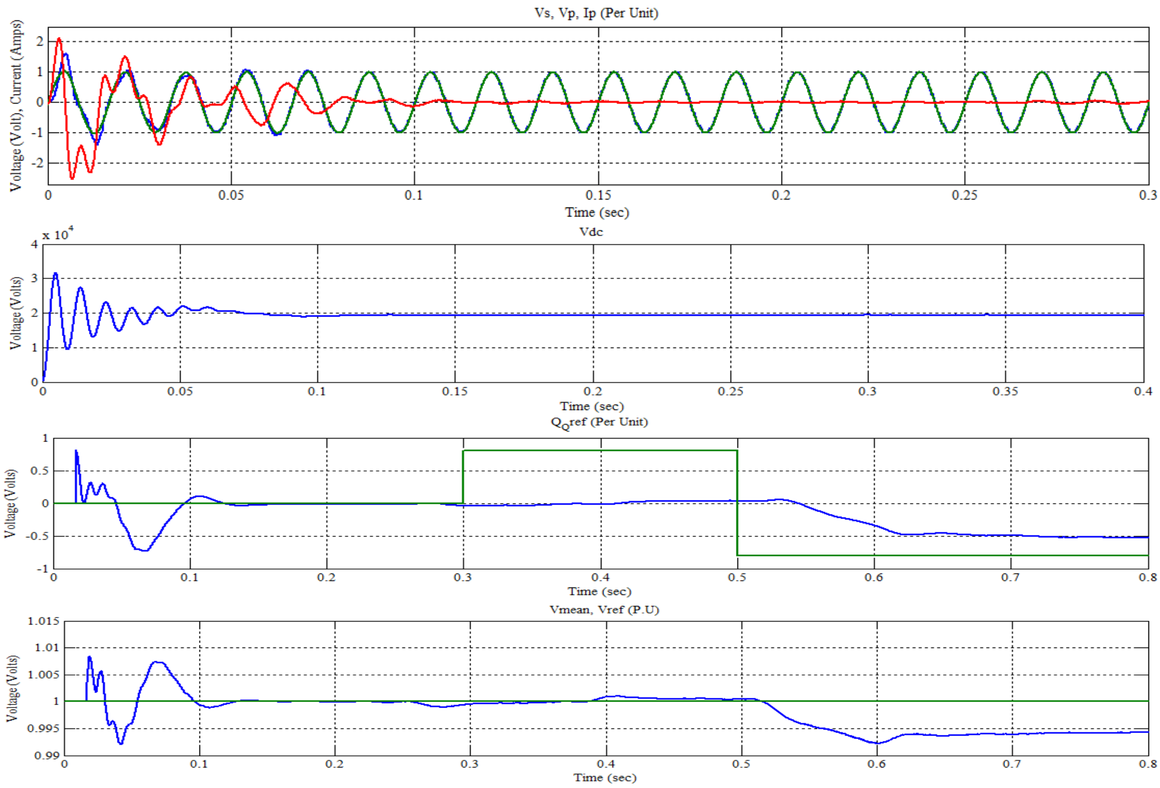

Fig. 13. Output Waveform for STATCOM

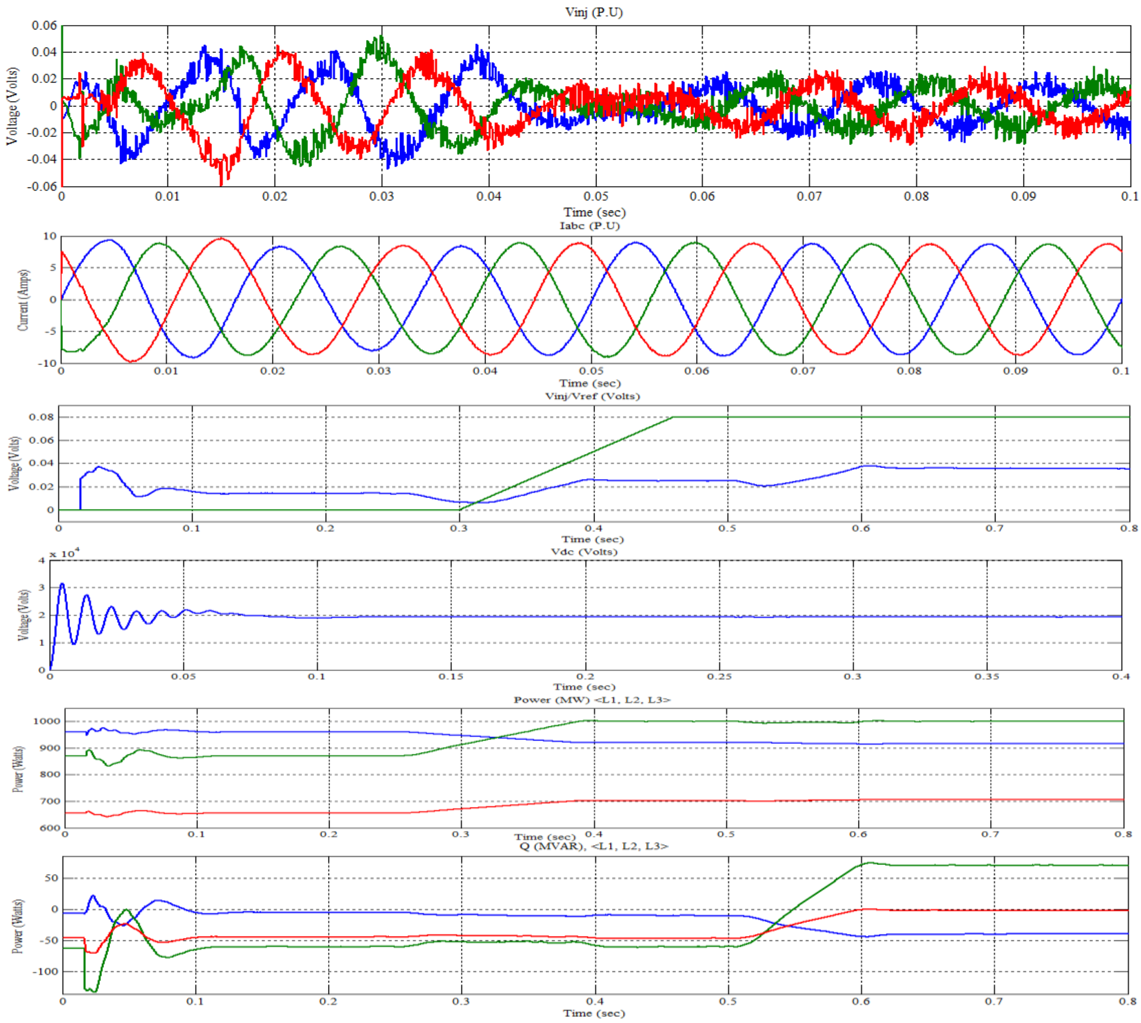

Fig. 14. Output Waveform for SSSC

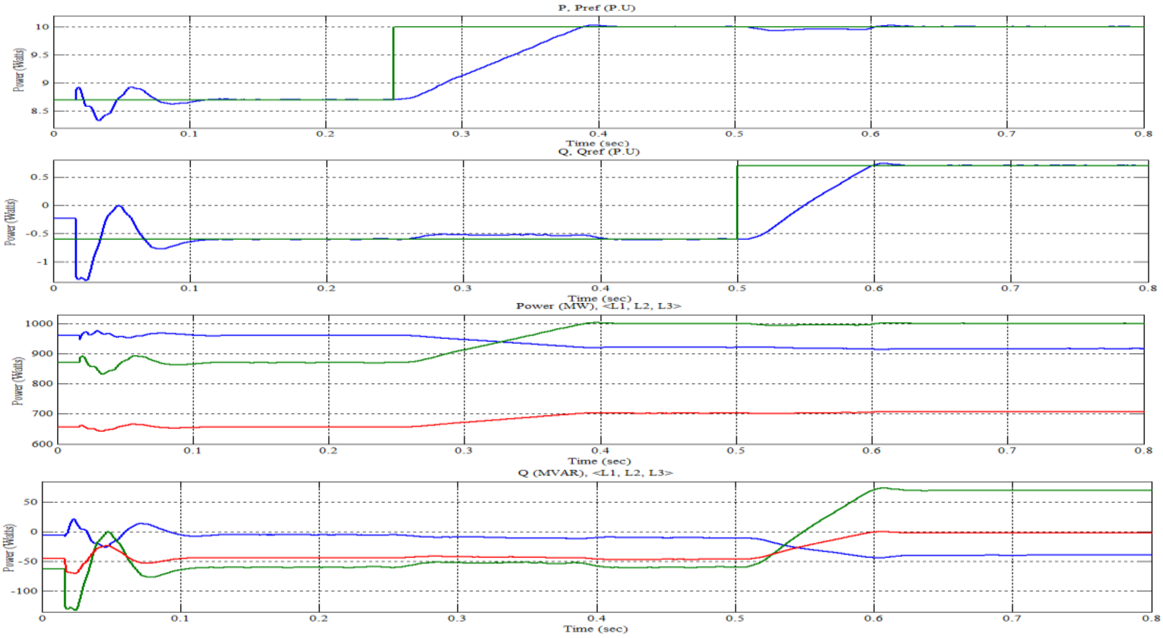

Fig. 15. Output Waveform for UPFC

Conclusions

This paper presents 48-pulse GTO voltage source converter of STATCOM, SSSC and UPFC FACTS devices. These full descriptive digital models are validated for voltage stabilization reactive compensation and dynamically power flow control using three novel decoupled current control strategies. The control strategies implemented by current control and auxiliary tracking control based on a pulse width modulation switching technique to ensure fast controllability, minimum oscillatory behavior and minimum inherent phase locked loop time delay as well as system instability reduced impact due to a weak interconnected AC system. Simulation results shows that GTO based controlled slightly increases the power flow control by increasing the damping rate and decreases the amplitude of low frequency oscillations. Results comparison between conventional PI controller and the proposed GTO based controller for UPFC indicates that the proposed GTO based controller has less settling time and less overshoot when compared with the conventional PI controller.

Conflict of interest

Authors declare there are no conflicts of interest.

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