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RESEARCH ARTICLE

USING SMART CONTROLLER WITH UPFC TO IMPROVE POWER QUALITY IN MEDIUM AND HIGH VOLTAGE GRIDS WITH HIGH WIND POWER PENETRATION

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ABSTRACT

With the growing demand of electricity, at times, it is not possible to add new power lines to meet the demand. The renewable energy sources, which are expected to be a promising alternative energy source, can bring new challenges when connected to the power grid. For example, the generated power from renewable energy sources is usually fluctuating due to environmental condition. In the same way, wind power injection into an electric grid affects the power quality due to the fluctuating nature of the wind. Power quality issues such as: voltage dip, harmonic distortion and reliability problems are among concerns in the grid caused by wind variations. Flexible AC Transmission Systems (FACTS) use Thyristor controlled devices and optimally utilizes the existing power networks. FACTS devices plays an important role in controlling the reactive and active power flow to the power network, and hence, both the system voltage fluctuations and transient stability. This paper proposes a smart controller for Unified Power Flow Controller (UPFC) as a power electronic-based device with a feed-back line which helps it to act in a smart and automatic way and be ableto control the power flow through the power line as well as improving the power and voltage stability. The smart controlhas the ability to control and increase the power quality of the network connected to the high wind power penetration by controlling the active and reactive power of the grid from far distances. **Copyright © IJSEE, all rights reserved.**

KEYWORDS: Power Quality, Facts, Smart Controller, UPFC, STATCO[1]

I. INTRODUCTION

The need to integrate the renewable energy, like wind energy, into power system needs to make it possible to minimize the environmental impact on conventional plant [1]. The integration of wind energy into existing power system presents technical challenges and requires considering voltage regulation, stability and power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network [3]. There has been an extensive growth and quick development in the exploitation of wind energy in recent years. The individual units can be of large capacity up to 2 MW, feeding into distribution network [2]. In the fixed-speed wind turbine operation, all the fluctuations in the wind speed are transmitted as fluctuations in the mechanical torque and electrical power on the grid and leads to large voltage fluctuations. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc. However, the wind

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[1] Static Synchronous Compensator

generator introduces disturbances into the distribution network. One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has inherent advantages of cost effectiveness and robustness. However; induction generator's power is varied due to wind and absorbed reactive power and terminal voltage of an induction generator can be significantly affected [3].

Many researchers have proposed different approaches of installing UPFC in power systems [4, 5, 6]. The concepts of characteristics have been broadly reported in the literature [7].The UPFC has been researched broadly and many research articles dealing with UPFC modelling, analysis, control and application have been published in the recent years. Mathematical models of UPFC has been developed to study steady state characteristics using state space calculations without considering the effects of converters and the dynamics of generator [8,9]. The performance of UPFC has been reported by designing a series converter with conventional controllers [10, 11]. Many power converter topologies have been proposed for the implementation of FACTS devices such as multi-pulse converter like 24 pulses and 48 pulses and multi-level inverters [12, 13, 14].The advantages and limitations of high power converters have been discussed [15]. In [16] the dynamic control of UPFC has been analyzed with six pulse converter using switching level model. In this paper by considering all the mentioned problems in above, feed-back line is considered in the controller to addthe ability to be smarter in sudden variation as well as being able to be controlled from distances. This paper is categorised as below, in II. Unified Power Flow Controller (UPFC) with its basic principle is explained, III. evaluates different types of the Flexible AC Transmission System (FACTS) and consequently in IV. problems caused by high wind power penetration to the power system is studied and finally V. presents the simulation and results for the presented controller.

II. UNIFIED POWER FLOW CONTROLLER

The Unified Power Flow Controller (UPFC) is the most versatile FACTS controller for the regulation of voltage and power flow in a transmission line. It consists of two voltage source converters (VSC), one shunt-connected and the other series-connected. The DC capacitors of the two converters are connected in parallel (Figure 1). If the switches 1 and 2 are open, the two converters work as STATCOM and SSSC[2] , controlling the reactive current and reactive voltage injected into the line in shunt and series, respectively. Closing switches 1 and 2 enables the two converters to exchange real (active) power flow between the two converters. The active power can be either absorbed or supplied by the series-connected converter [17].

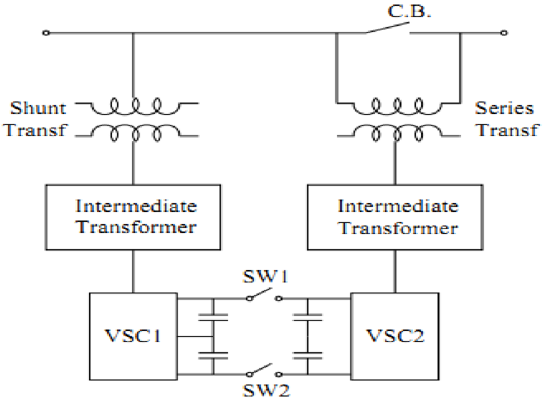

Fig. 1: A UPFC schematic

The series converter executes the main function of the UPFC by injecting a voltage, with controllable magnitude and phase angle, in series with the transmission line. It is controlled to provide concurrent active and reactive series compensation without an external energy source. By means of the series voltage injection without angular constraint, the UPFC is able to control, concurrently or selectively, the transmission angle, impedance and line voltage, or alternatively, active and reactive power flow through the line. The voltage injected by the series converter is generated internally by the series converter (like SSSC), and the active power is supplied by the shunt converter that is transported through the DC link. The basic function of the shunt converter is to supply or absorb the active power demanded by the series converter. The shunt converter controls the voltage of the DC capacitor by absorbing or generating active power from the bus, therefore it acts as a synchronous source in parallel with the system. Similar to the STATCOM, the shunt converter can also independently provide

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[2] Static Synchronous Series Compensator

controllable reactive compensation for the bus. Considering its control capability, the UPFC can have the following functions:

- Voltage regulation by continuously varying in-phase/anti-phase voltage injection that is similar to a tap-change transformer,
- Series reactive compensation by injecting a voltage that is in quadrature to the line current. Functionally, this is similar to an SSSC that can provide a controllable inductive and capacitive series compensation,
- Phase shifting by injecting a voltage with an angular relationship with respect to the bus voltage. By varying the magnitude of this voltage, the phase shift can be controlled.

The listed functions of the UPFC can be executed simultaneously, which makes the UPFC the most powerful PFCD [18].

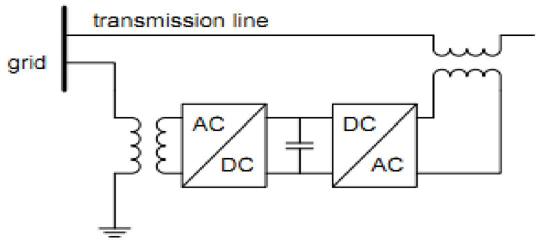


Fig. 2. UPFC configuration

Thus, unlike other FACTS controllers which have only one degree of freedom, a UPFC has three degrees of freedom by means of controlling three features simultaneusly or selectively. The concept of combining two or more converters can be extended to provide more flexibility and additional degrees of freedom [17, 19].

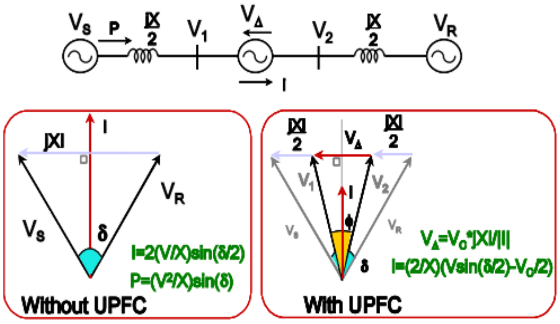


Fig. 3. UPFC operation

III. FELEXIABLE AC TRANSMISSION SYSTEM COMPARSION

In Table 1 [20], a comparison between UPFC and STATCOM is done and it is easy to compare the benefits of these two devices. Items which are reviewed in this table are the capability of generation or absorption of reactive power, SSR mitigation, phase jump reduction, active power generation or absorption, voltage control, voltage stability improvement, power flow control, power oscillation damping, rotor angle stability improvement, flicker mitigation, harmonics reduction, and in all of these functions UPFC has the best results. This eminence is the basic reason why the UPFC has been chosen in this paper. The other reason is that the UPFC has more degrees of freedom for better controlling action, compared to other simple FACTS devices such as SSSC, SVC and STATCOM. The only feature in UPFC that causes its limitation on output is the current rate. This new device offers utilities the ability to control voltage magnitude in the system, on predefined corridors, allowing secure loading of transmission lines up to their full thermal capability. A summary of different FACTS controllers is given in Figure 4 [17].

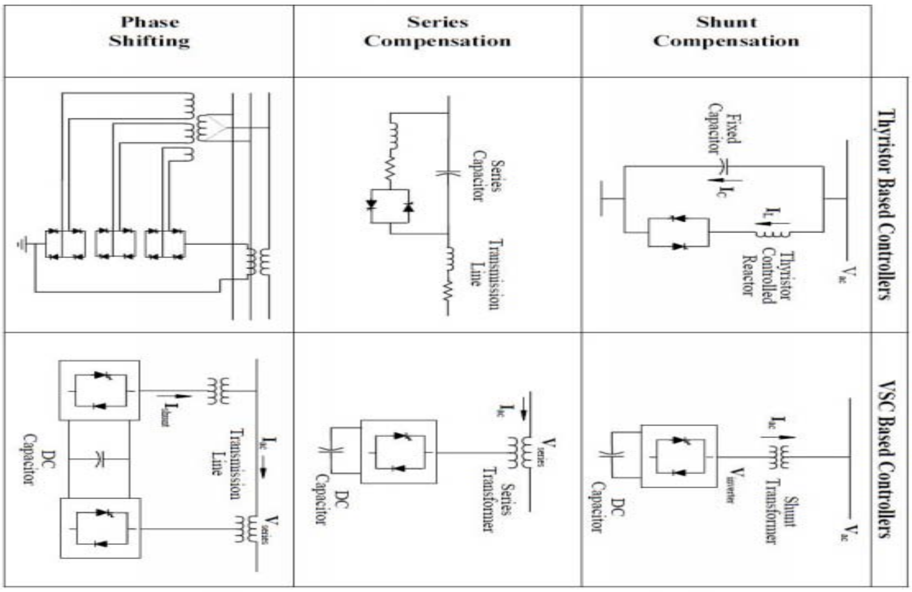


Fig. 4. Summary of different FACTS Controllers

Table 1. Comparison of some FACTS devices

FACTS Service	SVC	STATCOM	STATCOM+ ES	UPFC
Reactive Power Generation and Absorption	🟩	🟥	🟥	🟥
Active Power Generation and Absorption			🟥	
Voltage Control	🟩	🟥	🟥	🟥
Voltage Stability Improvement	🟩	🟥	🟥	🟥
Power Flow Control	🟨	🟨	🟨	🟥
Power Oscillation damping	🟨	🟩	🟩	🟥
SSR mitigation				🟥
Phase jump reduction				🟥
Rotor angle stability improvement	🟨	🟨	🟩	🟥
Flicker mitigation	🟩	🟥	🟥	🟥
Harmonics reduction		🟩	🟩	🟥
Inertia emulation			⬛	
Curtailment			⬛	
Primary, Secondary, tertiary reserve			⬛	
Frequency Stability Improvement			⬛	

Performance	**Excellent**	**Good**	**Limited**	**Dependent**
Indicator	🟥	🟩	🟨	⬛

IV. HIGH WIND POWER PENETRATION IN POWER SYSTEM

Over the last 30 years, wind power has emerged as the most promising renewable resource due to its rapid developments in disciplines such as aerodynamics, structural dynamics and mechanics, as well as power electronics. In spite of the phenomenal growth and development in the last decades, the WT industry keeps moving forward in order to increase the efficiency and controllability of the wind turbines and to improve the integration to the power grid [20]. Off-shore wind farms have emerged as major contributors of power generation in European countries. This power is being generated far from the point of consumption. In the past, wind energy used to contribute a very small fraction of the electrical power system network. Today, this has changed dramatically with more wind energy penetrating the conventional power network [20]. In the next ten years, the produced wind energy will be comparable with the energy produced from conventional steam, hydro and nuclear systems so that any adverse effect of wind generation integration can jeopardize the control schemes of the system [20]. The main begins by introducing high wind power to the system. Due to the fluctuation and unpredictable characteristics, wind variation has enormous effect on power system. The main motivation behind this work is to utilize mitigate these variation quickly and without need to any type of manual controller. The controller is also able to send the monitoring data to any far locations. Whole project simulated bythyristor-based FACTS devices for mitigation of SSR. Figure 5 shows the global wind power projection [20].

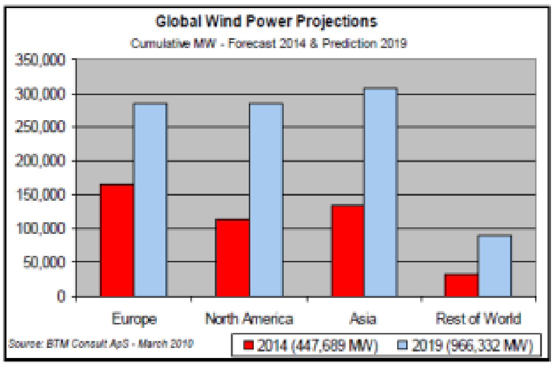


Fig. 5. Global wind power projection

V. SIMULATION AND RESULTS

As it is illustrated in Figure 7, the output of wind turbine is connected to two Y-Y grounded transformers for mitigating the 3rd harmonic which is made by wind fluctuations. Then, there is the UPFC on the transmission line which controls the power flow (active and reactive). The generator used in this Simulink simulation is an induction type, so it needs reactive power for magnetization. This reactive power will be provided by the UPFC. The UPFC in simulation is used to control the active and reactive power of the 3rd bus. This bus is the load bus. As the generated active power by the wind turbine becomes oscillatory due to wind fluctuations, the terminal voltage of the induction generator will be affected. In this paper, a step pulse is used to model the wind variation and it is activated on t=5s. At this time, the UPFC takes action and the output power has to pursue the main power for stability (Figure 10). The UPFC must be use in bilateral mode. So, it can take the power line voltage by one of its transformers which is used in parallel in the power line, and the other transformer which is used in series on the power line for its current. This way, the power of the transmission line can be controlled. After the fluctuations are applied, the outputs of the oscilloscopes showing the output reactive and active power of the generator, the injected Vdc, the injected Ib and Iq and the injected Vb and Vq can be compared to observe the differences between the absence and the presence of the UPFC in the network.

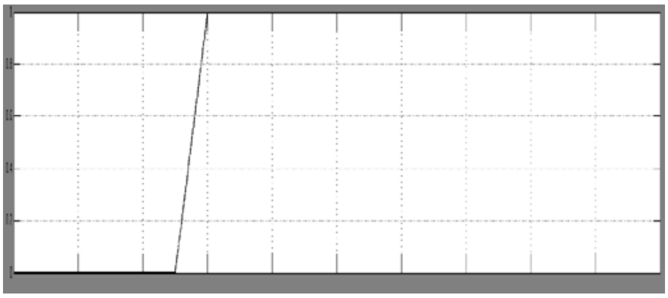


Fig. 6. Simulation of the wind by step pulse on t=5s

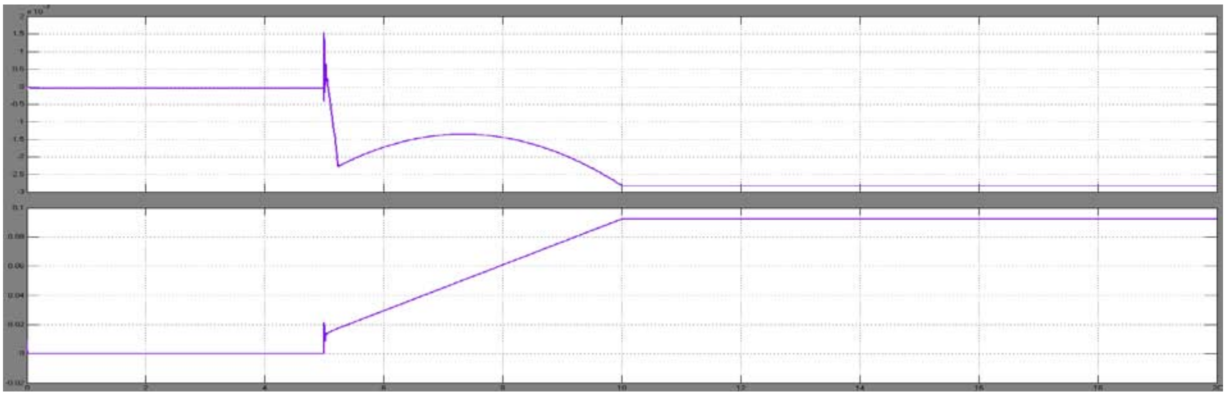


Fig. 7. From top to bottom: Vd and Vq of the series converter

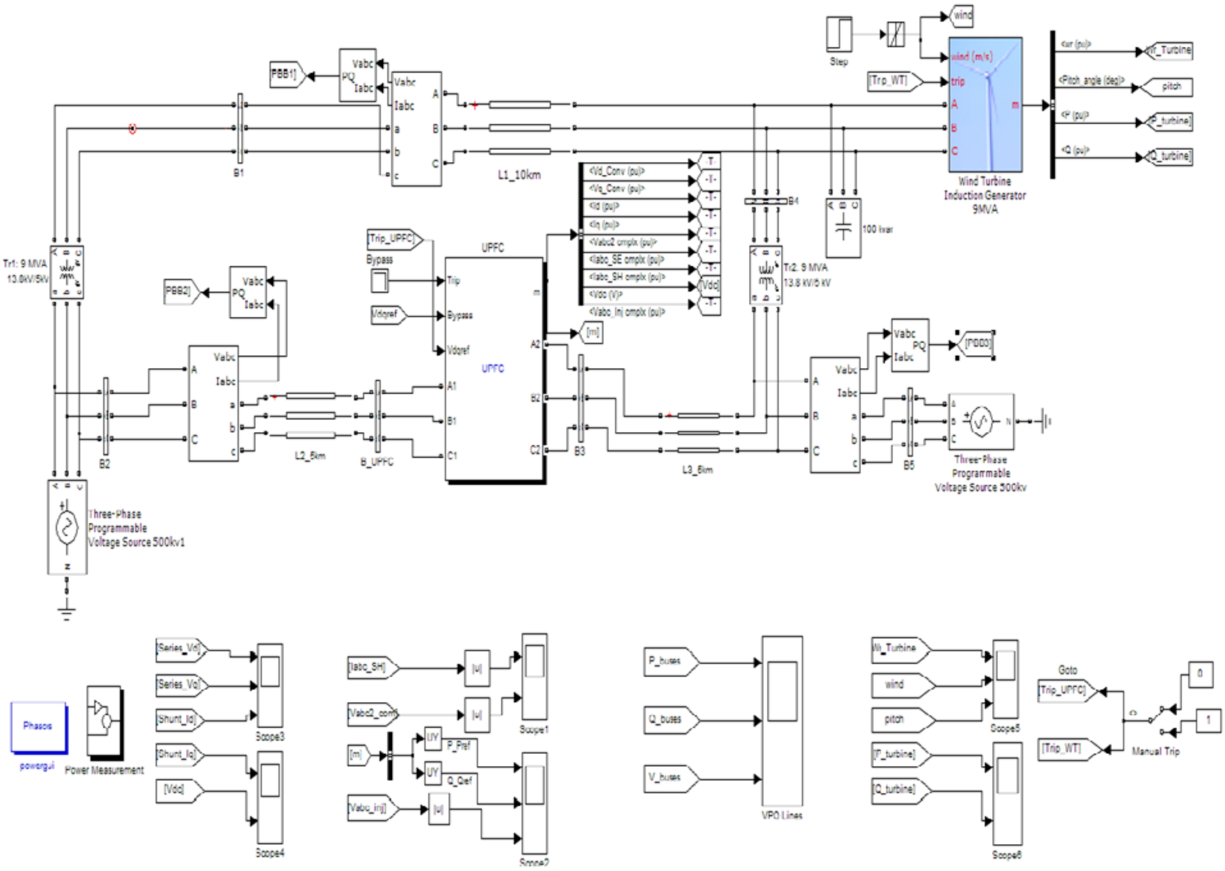
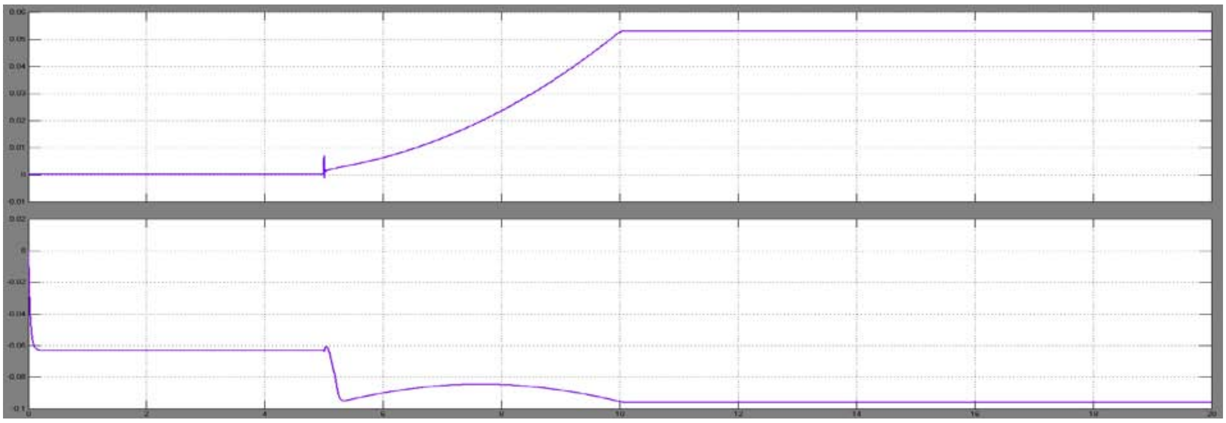


Fig. 8. Simulation by MATLAB software package



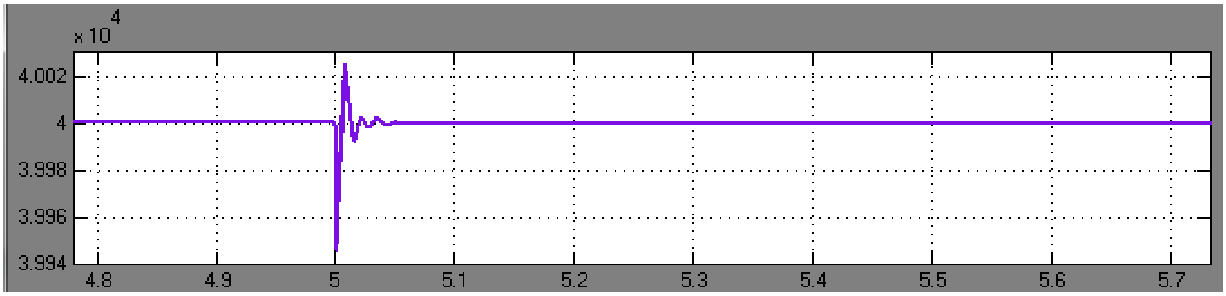


Fig. 9. From top to bottom: Iq, Id parallel and Vdc

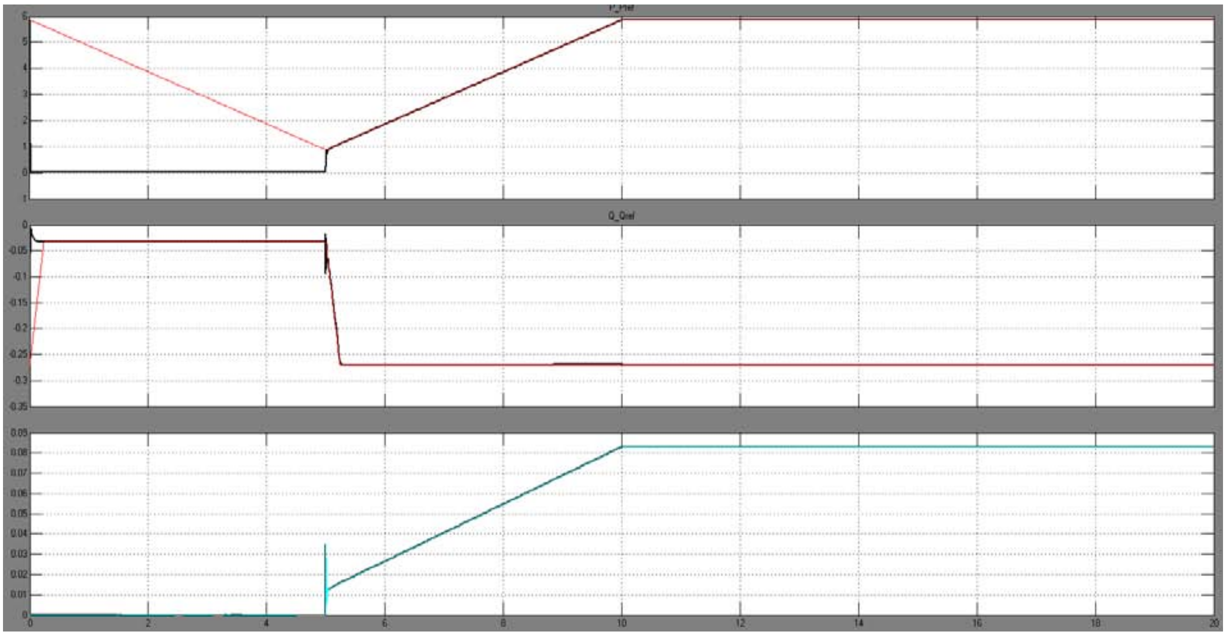


Fig. 10. From top to bottom: P and Pref., Q and Qref, and the injected Vabc

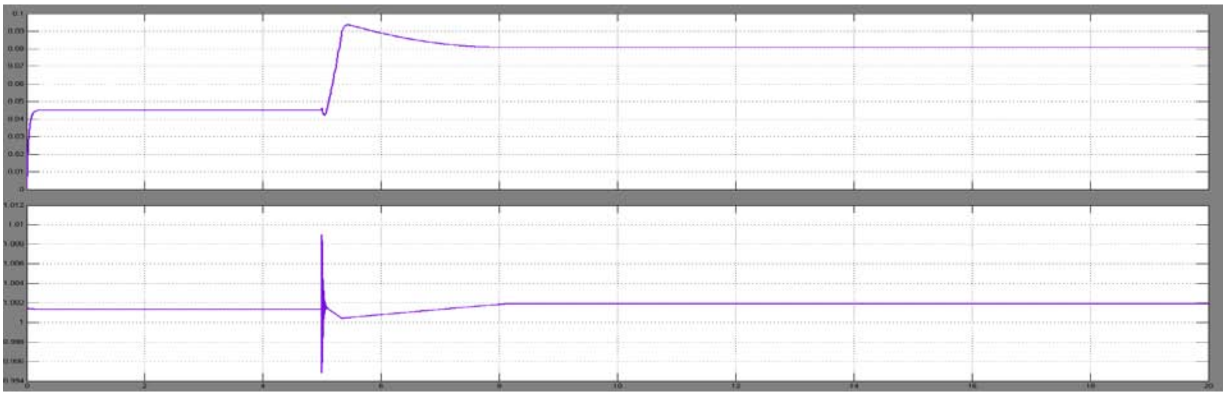
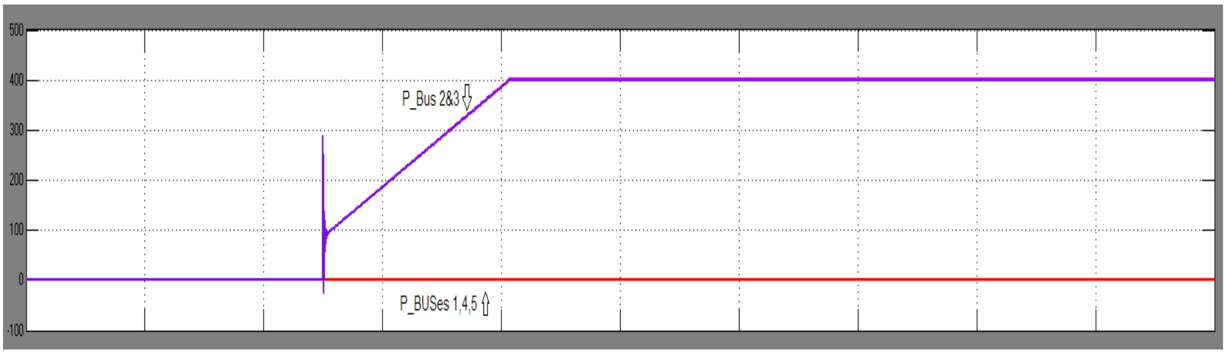


Fig. 11. From top to bottom: parallel Iabc and terminal voltages A2, B2, C2 of UPFC



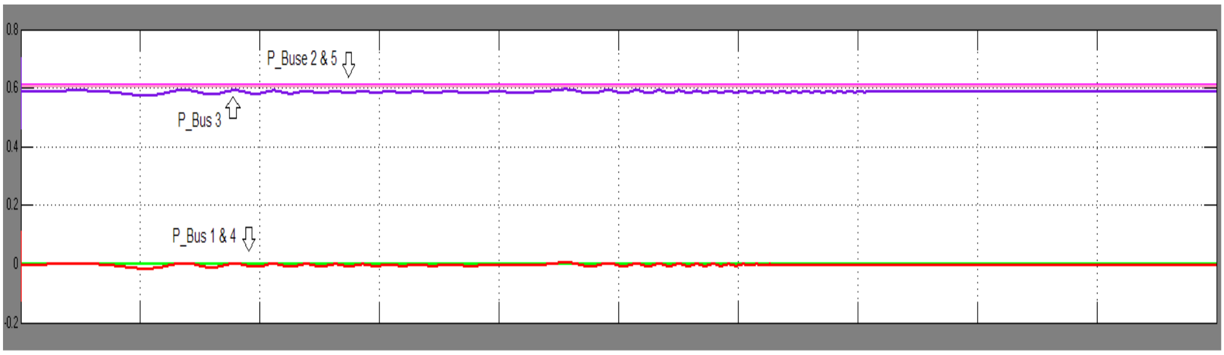


Fig. 12. The quantity of P on different buses. The top figure is for using the UPFC and the bottom one is the case without UPFC

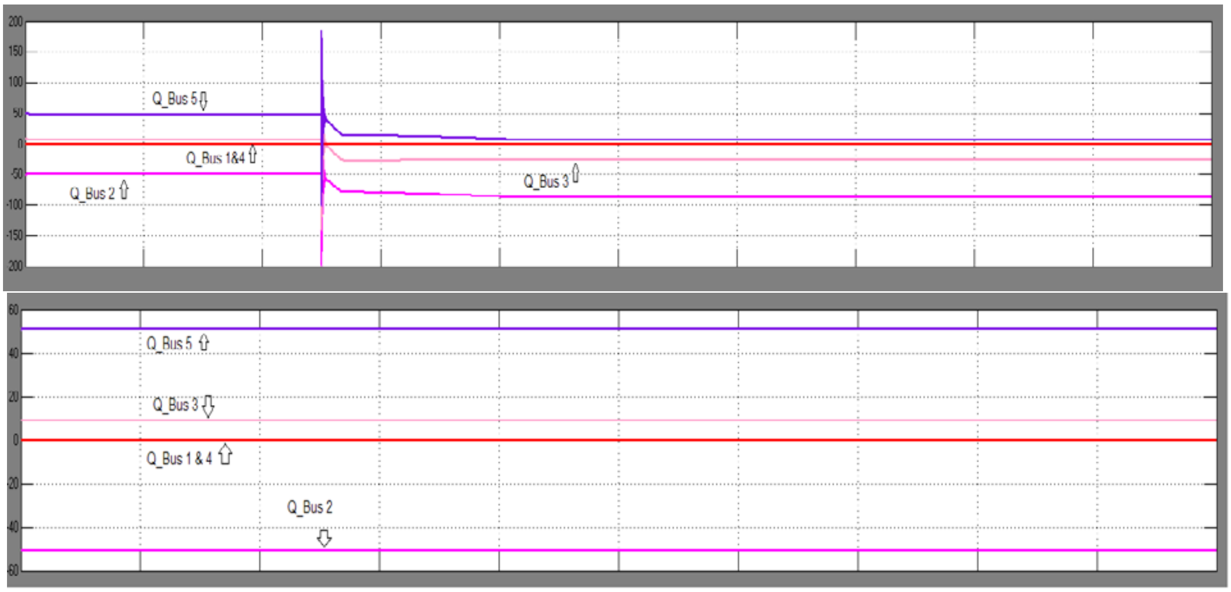


Fig. 13. The quantity of Q on different buses. The top figure is for using the UPFC and the bottom one is the case without UPFC

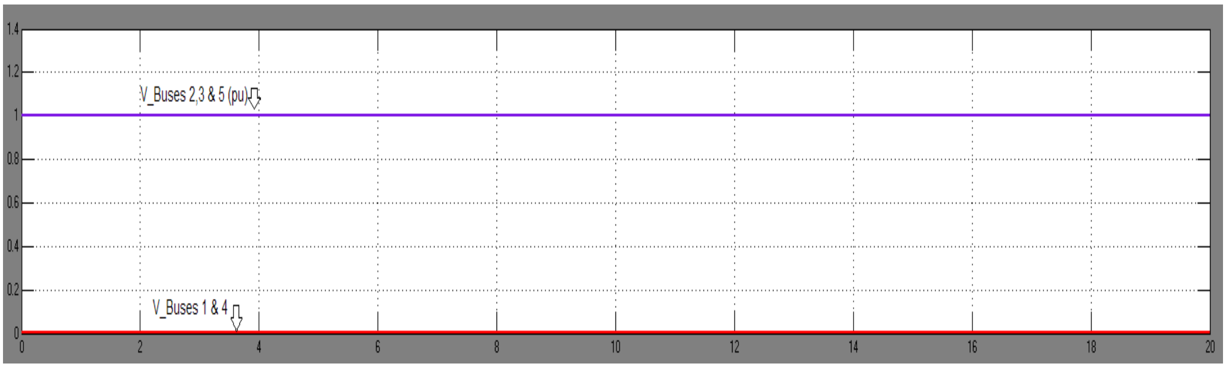


Fig. 14. The quantity of V on different buses. in using UPFC

VI. CONCLUSIONS

In this paper, by introducing a smart controller with a feed-back line forthe UPFC in MATLAB simulation environment, wind variations is applied to the system in order to illustrate the response from the smart controller.The presented controller is also capable of controlling and monitoring the system from far distances. By using the introduces controller for the UPFC, system is able to control the power flow (active/reactive) on power lines simultaneously or selectively as well as improving voltage stability margin.

VII. FUTURE WORKS

In future system with Concentrated Solar Power (CSP) in cooperation with off-shore wind power can be studied to find a proper siting and sizing for the different types of power quality improvement tools such as SVC[3], UPFC, TCSR[4] and STATCOM[5].

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[3] Static VAR Controller
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