Asian Journal of Water, Environment and Pollution, Vol. 15, No. 3 (2018), pp. 19–26.
DOI 10.3233/AJW-180039

Transient and Voltage Stability Investigation of Integrated Wind Farm Fed to a Power Grid through Generalized Unified Power Flow Controller (G-UPFC)

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Received March 7, 2018; revised and accepted April 5, 2018

Abstract: This paper reveals investigated result of an integrated wind farm fed to a power grid through a generalized unified power flow controller (G-UPFC), to synchronously achieve voltage-fluctuation mitigation as well as stability improvement. The performance of the considered wind farm is simulated by an equivalent 9 MW doubly-fed induction generator (DFIG). An IEEE 14 bus system is also connected with the system for load flow analysis. A fault is deliberately created at a bus. This integrated power system has been simulated with and without G-UPFC and simulation result of voltage waveform at different buses is captured with respect to time. The results illustrate that the G-UPFC is very effective in voltage fluctuation mitigation and transient stability improvement.

Key words: Doubly fed induction generator (DFIG), FACTS device, G-UPFC, integrated power system, renewable energy system, electric power system.

Introduction

The steady-state operation of a multi-terminal unified power flow controller was performed by Mwinyiwiwa et al. (2000). The M-UPFC has been implemented as it has an advantage over UPFC of high level of service. In order to enhance the transient as well as voltage stability, a coordinated excitation controller and UPFC is designed on a single-machine with single-load power system (Chen et al., 2002).

A method is proposed to achieve optimal dimension for multi converter VSC-based FACTS controllers in (Fardanesh, 2004). This method helps in finding the comparisons for the steady-state performance of all one, two, and three converter controllers in attaining desired objectives. A hybrid flow controller (HFC) is introduced as a novel flexible ac transmission system (FACTS) controller for steady-state performance of power transmission lines (Niaki et al., 2008). A hybrid flow controller, as the name suggests, will provide both series and shunt compensation. Hydro-Quebec network is analyzed for its steady state performance due to the effect of various kinds of FACTS devices (Ghahremani et al., 2014).

The performance of the network is analyzed with and without FACTS devices. Results show that UPFC is the most efficient FACTS device in case where increase in network load-ability and reduction of network losses are required. A linearized Phillips-Heffron model of power system in which UPFC is installed is designed (Wang, 2000). This linearized Phillips-Heffron model has two main benefits: (1) It helps in studying the effect on power system oscillation stability due to UPFC DC voltage regulator. (2) It helps in designing the UPFC

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damping controller by selecting most effective damping control signal. For multi machine power system, a hybrid fuzzy logic proportional with conventional integral controller for UPFC is designed (Dash et al., 2000). This controller is capable in delivering gain with extensive variation in a nonlinear manner. This controller is very effective in damping out multi model power system oscillations. The applications of UPFC on transmission system of Taiwan power system for redistribution of power flow over unbalanced parallel corridors and enhancing the low voltage level has been presented by Chang et al. (2002).

The controller of UPFC is designed using a dynamic generator model to achieve most accurate controller parameters. A damping controller is also designed in order to enhance the damping of low frequency oscillations. A controller based on H∞ mixed sensitivity in linear matrix inequality (LMI) framework for UPFC is designed to provide adequate damping of inter-area oscillation (Pal, 2002).

In this paper, the problem is defined so as to construct a stabilized controller that stratifies a variety of constraints. Dynamic response of system exhibits the effectiveness of the controller to damp out the inter-area oscillation. Tambey et al. (2003) have done a detailed designing of UPFC as a power flow controller, dc voltage regulator and damping controller. The impact of UPFC's control signal is examined to damp out the low frequency oscillation. In this paper a dual damping controller is proposed which modulates the UPFC's control signals. A method to select the control signal of UPFC has been proposed (Farsangi et al., 2004).

In this paper, a comparison is done for achieving the best damping for inter-area oscillation between static var compensator (SVC), static synchronous compensator (SSSC), and UPFC. This comparison is done by analyzing divergent input-output controllability that is used to select the most suitable stabilizing signal. The stabilizing signals are used for UPFC in order to damp out the inter-area oscillations. An improvement in damping of power swing of nonlinear power system has been done by using UPFC (Januszewski et al., 2004). The state-variable control strategy is derived using the application of direct Lyapunov method and implemented. This local control is used to damp out the power swings if both series and shunt branch of UPFC are controlled.

A Newton type current injection based model of UPFC was deviced by Son et al. (2004). This model is effective for studying the low frequency oscillations. The effectiveness of this model is checked for designing damping controller. Kumar et al. (2007) proposed a set of controllability indices in order to achieve the optimal location of UPFC for improving the system stability by damping of small signal oscillations. Controllability indices to find the optimal location corresponding to a critical inter-area modes for the systems having 39- bus and 68-bus.

A method for investigating the first swing stability of power system in which UPFC is installed was proposed by Haque (2008). This method also helps in generating the dynamic response for the power system. In this method, UPFC and the transmission line to which it is connected are represented as π-circuit model. A method for investigating the first swing stability of power system in which UPFC is installed is proposed in (Guo et al., 2009). This method also helps in generating the dynamic response for the power system. In this method, UPFC and the transmission line to which it is connected are represented as π-circuit model.

Zarghami et al. (2010) state a multistage control approach using multiple UPFCs for damping the inter-area oscillation for a large power system. This multistage control approach is used for marking the level of voltage in terms of voltage and magnitude at both sending end as well as the receiving ends of UPFC. These marked voltage signals are translated into switching command signals which can control the UPFC. Shojaeian et al. (2012) focused on adaptive input-output feedback linearization control (AIFLC) based approach to damp out the low frequency oscillation for multi UPFCs in multi machine system. A comparison is made between conventional PI controller and AIFLC controller for their behaviour for damping the low frequency oscillation. Simulation result shows that the PI controller is not capable for damping the low frequency oscillation for multi machine power system.

Shotorbani et al. (2013) states an algorithm that proves UPFC is capable of rapid control of transmission line parameters. This is proved by a study based on the direct Lyapunov stability theory for finite time convergence and chattering free characteristics in order to improve the damping of power oscillation using UPFC. The results of improvement of stability and power fluctuation mitigation for an onshore power grid fed through a UPFC from an integrated farm (offshore wind farm OWF and seashore wave farm SWF) were examined by Wang et al. (2013).

These examinations are done by simulating a model using 100 MW doubly fed induction generator and 60 MW squirrel cage induction generator considered for OWF and SWF respectively. This model is used with a damping controller based on modal control theory based for UPFC. This result of simulated model shows that the inherent power fluctuation injected to the power system can effectively remove as well as integrate OWF and SWF which can stabilize under various disturbances using this damping controller. A paper analyzed the performance of distance relay under power swing condition for uncompensated and compensated line with UPFC installed (Moravej et al., 2014).

The main results achieved in this study are: (1) the impendence seen by the distance relay for UPFC installed line under first power swing is analyzed, (2) UPFC's impact on line constant are extracted, (3) the radius of impedance locus is increased in STATCOM and SSSC (inductive mode) operation modes and decrease in SSSC (capacitive mode) operation mode in comparison to uncompensated lines and (4) no impact on the impedance locus under the power swing condition for different reference value of UPFC. This state-of-the-art work i.e. implementation of G-UPFC was done by Sharma et al. (2017). In their article's outcomes authors suggested to focus to implement the G-UPFC and use of G-UPFC for integrated system.

In this paper, a 9-MW wind farm comprising six 1.5 MW wind turbines linked to a 25 kV distribution system transmit power to a 120 kV grid via a 30 km, 25 kV feeder. A 2300 V, 2 MVA plant comprising a motor load and of a 200 kW resistive load are attached on the same feeder at bus B25. A fault is created on B25. A FACTS device named G-UPFC is used to mitigate system stability issues. An IEEE 14 bus system is also connected with the system for load flow analysis. The system is simulated in two stages: (1) without G-UPFC and (2) with G-UPFC. The graphical results of system stability investigation and numerical result of load flow analysis are recorded for both stages. The organization of this paper is done in such a way that the next Section describes the power transmission system with phasor model of G-UPFC and M-UPFC. The third Section comprises the simulation result in details. The last Section focuses on conclusion.

Model Description

Power System Model with G-UPFC

One 9 MW wind farm comprising six 1.5 MW wind turbines is linked to a 25 kV distribution system transmit power to a 120 kV grid via a 30 km, 25 kV feeder. A 2300 V, 2 MVA plant comprising a motor load and a 200 kW resistive load are attached with the same feeder at bus B25. The protection system of wind turbine as well as the motor load includes tracking of voltage, current and machine speed. The DC link voltage present at the common link of RSC and GSC of the DFIG is also observed. Wind turbines/doubly-fed induction generator (DFIG) set contains a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter.

The stator winding of DFIG is coupled directly to the 60 Hz power grid while the rotor is supplied at variable frequency via the AC/DC/AC converter. The DFIG technology permits to take out maximum permissible energy from the wind at lower wind speeds by adjusting the turbine speed, while reducing mechanical stresses on the turbine blades during squalls of wind. The optimized turbine speed produces maximum permissible mechanical energy for a given wind speed and is relative to the wind speed. The benefit of the DFIG technology is that it provides, generates or absorbs reactive power because of the use of power electronic converters. So it will abolish the need of installation of capacitor banks in case of squirrel-cage induction generators. The model uses a graphical user interface (GUI) as phasor solver which permits transient stability type studies. In this MATLAB/Simulink model, the system is observed during 10 seconds. A fault is introduced at five second.

Power System Model with G-UPFC

In this model as shown in Figure 2, all the power system components are same as in the previous model except G-UPFC model. A novel method is used for designing the G-UPFC in MATLAB/SIMULINK. The designing is based on controlled current scheme (CCS). G-UPFC

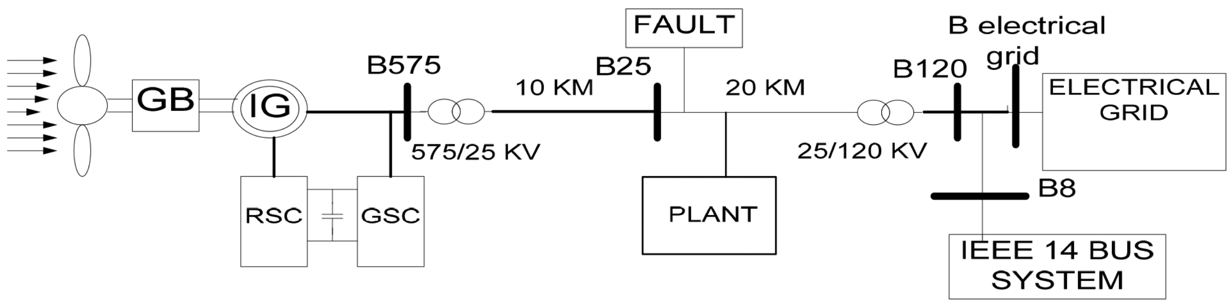

Figure 1: Line diagram of power system model without G-UPFC stage 1.

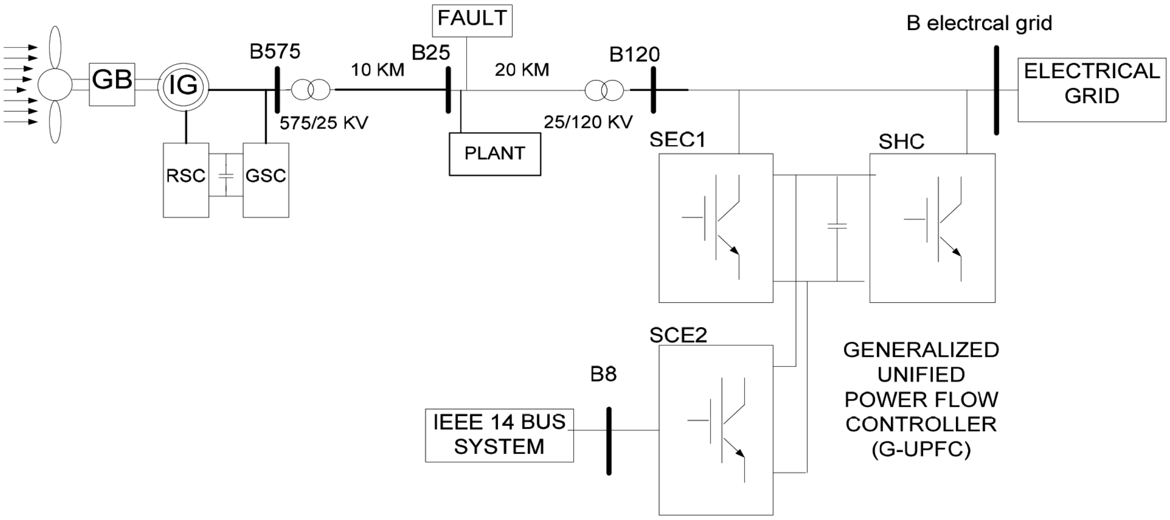

Figure 2: Line diagram of power system model with G-UPFC stage 2.

comprises one shunt converter and minimum of two series converters. As shown in Figure 2, G-UPFC consists of one shunt converter (SHC) and two series converters (SEC1 and SEC2).

Simulation Result

This section is further divided in subsections. First sub-section presents a detail investigation of system stability whereas second sub-section exhibits a detail comparison of result obtained with and without G-UPFC.

System Stability Investigation

The simulation result of the system under studies are recorded for with and without G-UPFC. The simulation results of stage 1 and stage 2 are comprised in 21 figures (Figures 3-23) for system stability investigation during faulty conditions. The simulation run time is 10 seconds. A three-phase fault is introduced at time = 5 seconds for 0.15 sec. This simulation result shows the effectiveness of the G-UPFC in attaining the system transient stability.

Simulation Results Without G-UPFC

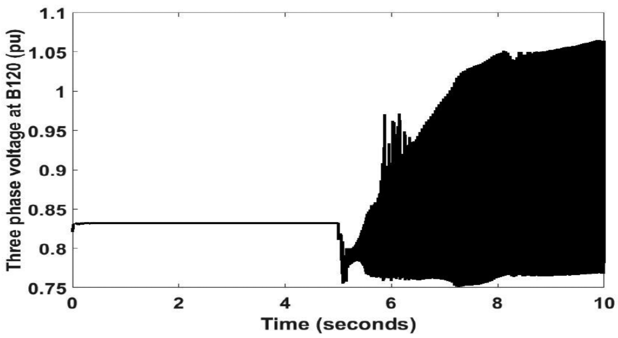

Figure 3: Voltage magnitudes at Bus no. 120 with respect to time without G-UPFC.

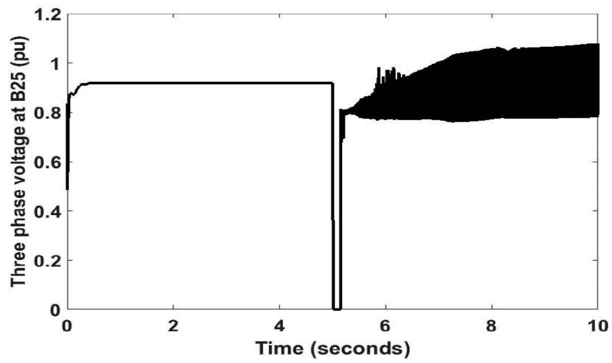

Figure 4: Voltage magnitudes at Bus no. 25 with respect to time without G-UPFC.

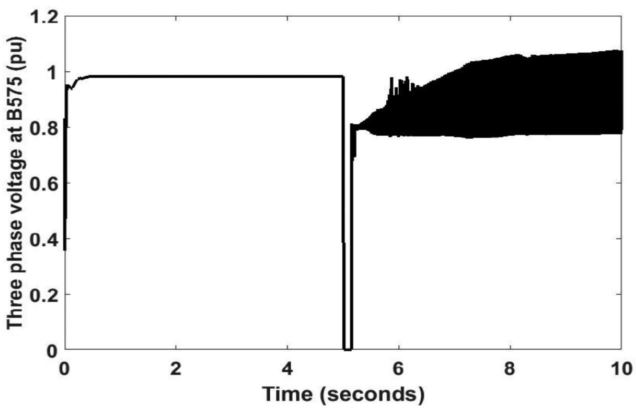

Figure 5: Voltage magnitudes at Bus no. 575 with respect to time without G-UPFC.

Simulation Results with G-UPFC

Comparison of the Simulation Result with and without G-UPFC

In the section, a simulation result comparison is done. The comparison made very clear to understand the

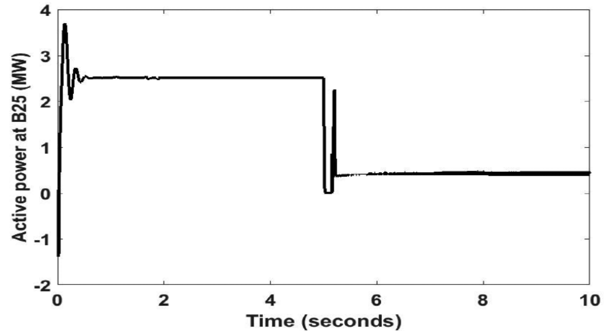

Figure 6: Active power at Bus no. 25 with respect to time without G-UPFC.

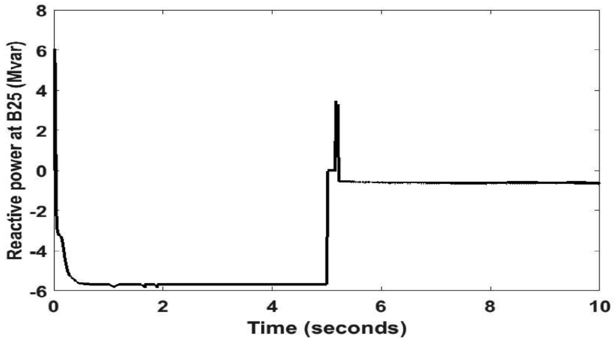

Figure 7: Reactive power at Bus no. 25 with respect to time without G-UPFC.

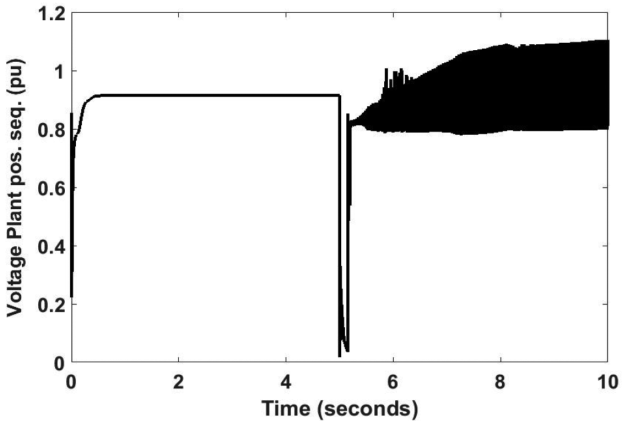

Figure 8: Positive sequence voltage magnitude at plant with respect to time without G-UPFC.

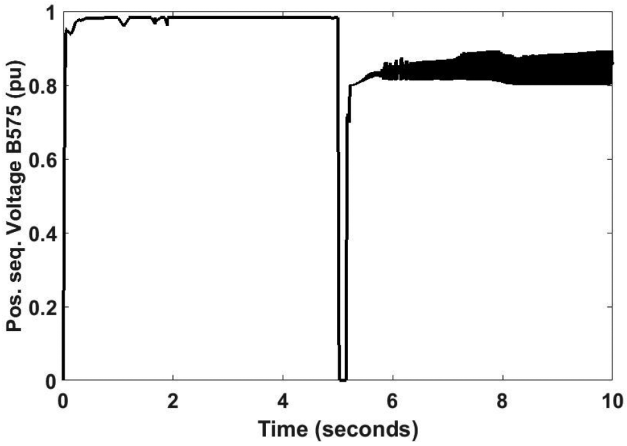

Figure 9: Positive sequence voltage magnitude at Bus no. 575 with respect to time without G-UPFC.

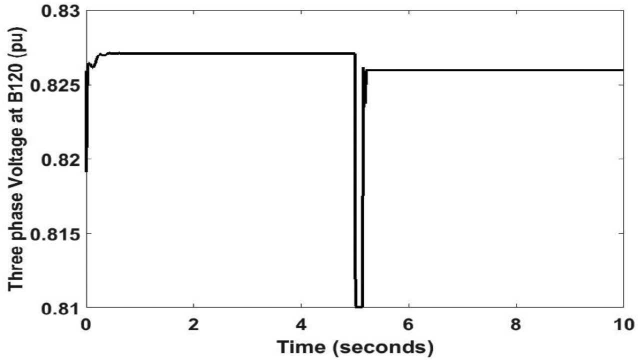

Figure 10: Voltage magnitudes at Bus no. 120 with respect to time with G-UPFC.

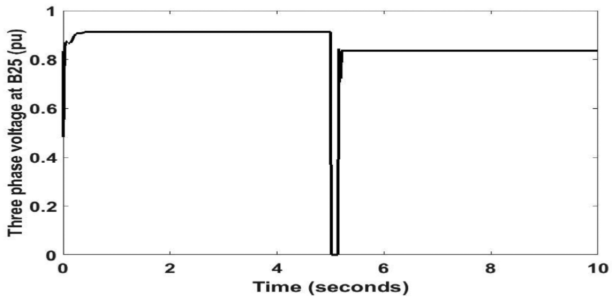

Figure 11: Voltage magnitude at Bus no. 25 with respect to time with G-UPFC.

effectiveness of the G-UPFC for providing the voltage stability as well as transient stability. Figures 17-23 show the comparison of Matlab/simulation results.

Conclusion

This research work has presented load flow analysis as well as transient stability enhancement of a grid-connected hybrid system containing a 9 MW wind farm comprising six 1.5 MW wind turbines linked to a 25 kV distribution system transmitting power to a 120 kV grid via a 30 km, 25 kV feeder using G-UPFC. A time-domain approach based on non-linear simulations under a three-phase short-circuits fault at bus B25 with change in wind speed is exhibited.

Simulation result of the studied system subject to a severe three-phase short-circuit fault at the B25 have verified the effectiveness of the proposed G-UPFC in

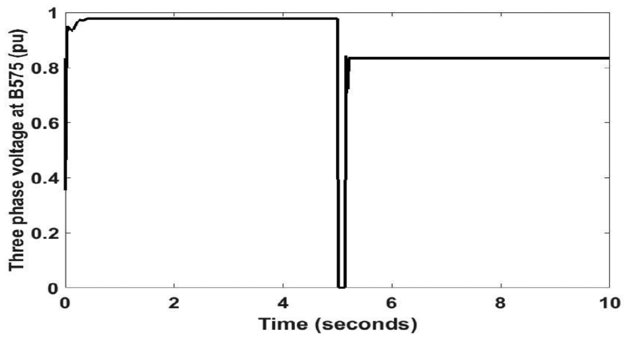

Figure 12: Voltage magnitudes at Bus no. 575 with respect to time with G-UPFC.

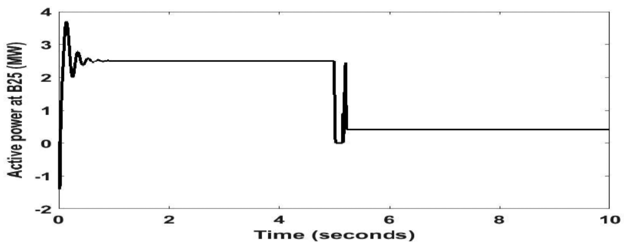

Figure 13: Active power at Bus no. 25 with respect to time with G-UPFC.

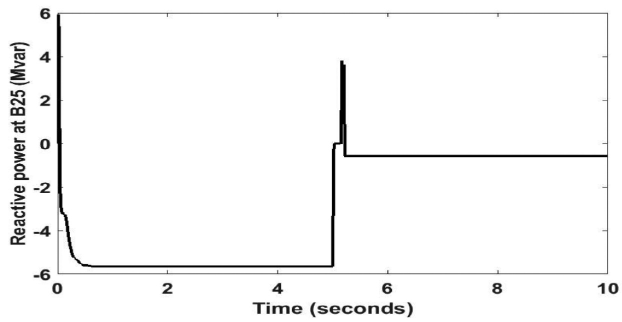

Figure 14: Reactive power at Bus no. 25 with respect to time with G-UPFC.

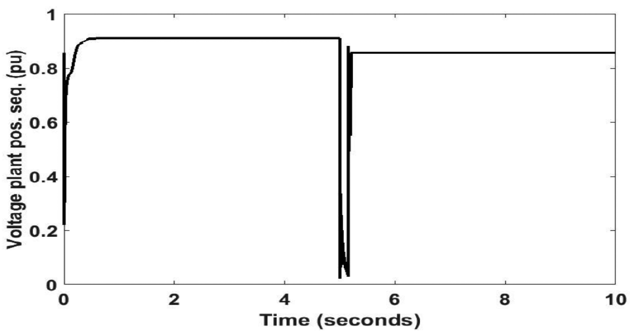

Figure 15: Positive sequence voltage magnitude at plant with respect to time with G-UPFC.

mitigating power fluctuations injected to the power grid of the studied system. A comparative study of using G-UPFC and without using G-UPFC on the

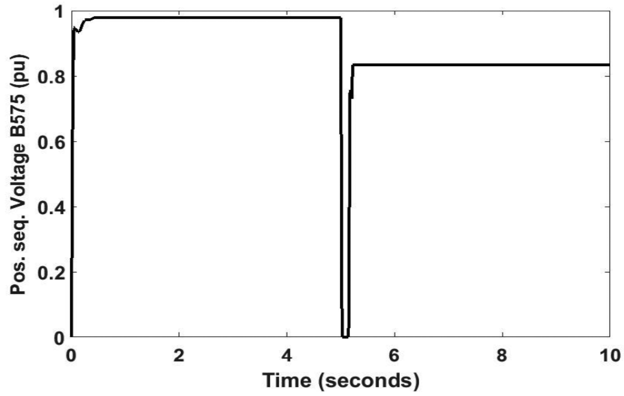

Figure 16: Positive sequence voltage magnitude at Bus no. 575 with respect to time with G-UPFC.

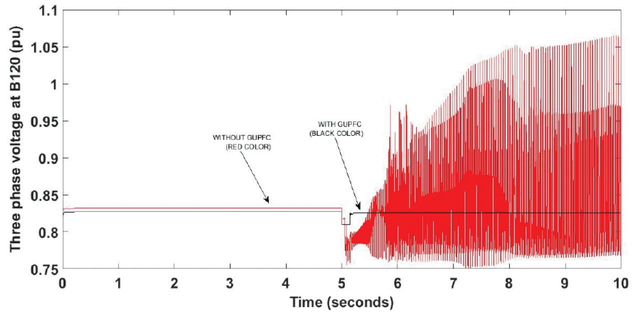

Figure 17: Comparison of simulation result with and without G-UPFC for three-phase voltage at B120.

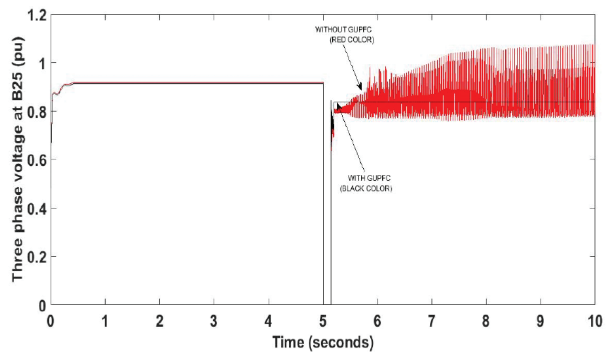

Figure 18: Comparison of simulation result with and without G-UPFC for three-phase voltage at B25.

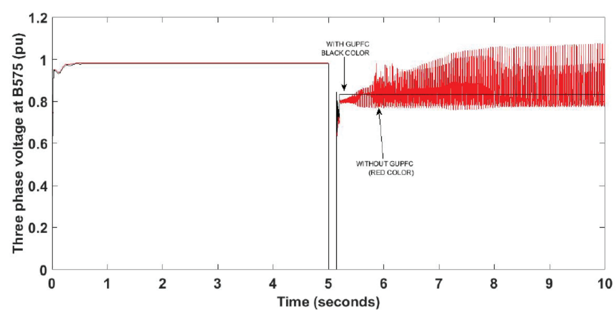

Figure 19: Comparison of simulation result with and without G-UPFC for three-phase voltage at B575.

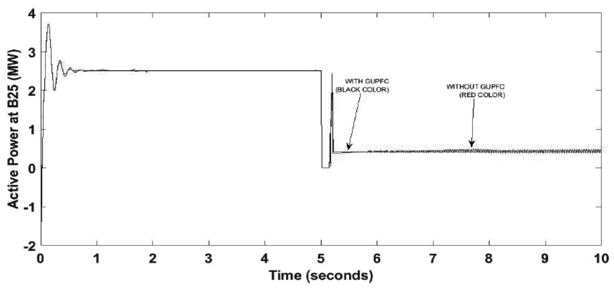

Figure 20: Comparison of simulation result with and without G-UPFC for active power at B25.

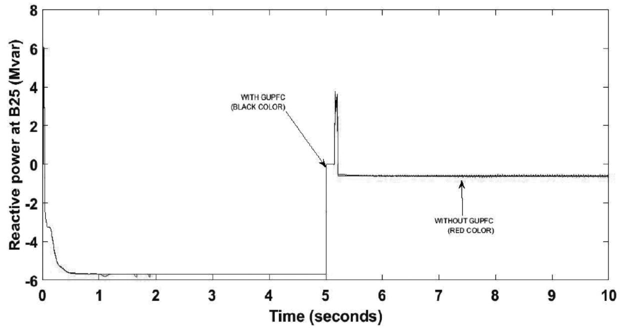

Figure 21: Comparison of simulation result with and without G-UPFC for reactive power at B25.

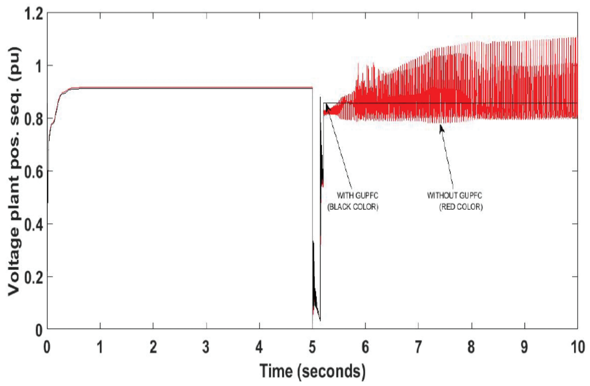

Figure 22: Comparison of simulation result with and without G-UPFC positive sequence voltage at plant.

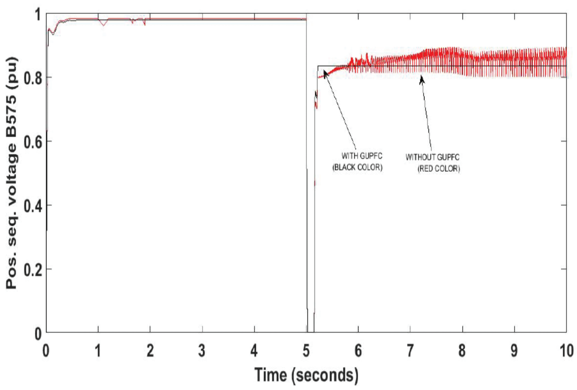

Figure 23: Comparison of simulation result with and without G-UPFC for positive sequence voltage at B575.

studied system shows the effectiveness of G-UPFC for achieving transient system stability and mitigating voltage fluctuation.

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