Performance of generalised unified power flow controller in transmission system

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Abstract: This paper focuses on innovative dynamic performance of power electronics based on generalised unified power flow controller (PFC). The GUPFC is a voltage source converter (VSC) based flexible AC transmission system (FACTS) controller used to provide series and shunt compensation among the multi transmission line systems of a substation. GUPFC improves the performance of power quality issues, active and reactive power oscillations in multiple transmission lines. This paper proposes a complete replica comprising of 48-pulse gate turn-off (GTO) thyristor based VSC which examines the dynamic operation of control scheme for shunt and two series VSC for voltage stabilisation and active and reactive power compensation by using POD controller among the transmission lines of the grid network. It is able to control injected voltage, at the same time as keeping injected voltage in quadrature with current within the power system is completely modelled in MATLAB/SIMULINK.

Keywords: 48-pulse; generalised unified power flow controller; GUPFC; power oscillation damping; POD; power quality.

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1 Introduction

Many FACTS devices such as thyristor controlled series capacitor (TCSC), static var compensator (SVC), static synchronous series compensator (SSSC), static compensator (STATCOM), unified power flow controller (UPFC) and interline power flow controller (IPFC) (Hingorani and Gyugyi, 2000) have their own control capabilities among all the devices generalised unified power flow controller (GUPFC) is treated as the most powerful FACTS device and offers better control capabilities compared to other controllers. The accessibility of gate turn-off (GTO) thyristor switching devices with high-power managing capability and the development of the other types of power electronic devices such as IGBTs have been lead to the advance of quick controllable reactive and active power sources utilise power electronic switching and converter technology. The demand of power has been increasing day to day, in order to meet the demand the many power stations are installed due to this reason severe environmental problems are occurs. Due to the interconnection between power systems low frequency oscillations are developed in the system within the range of 0.2–3.1 HZ (Wang, 1999a, 1999b). In order to eliminate the effect of loss of synchronism this oscillations keep on increasing in magnitude. when a group of generators in an area move together and associated with other group in an another area then the most vulnerable oscillations gets
appear in the system (Larsen et al., 1995). In order to overcome these vulnerable oscillations power system stabilisers (PSSs) are used. Due to these interconnections of system networks some of the power oscillations like active and reactive power oscillations arises in transmission lines and also power quality problems like sag, swells. Finally in order to overcome all these drawbacks flexible AC transmission systems (FACTS) devices are employed. A new power flow controlling device (PFCD) so called GUPFC is employed which offers same control capabilities as that of distributed power flow controller (DPFC) with a reduced cost and with improved reliability.

2 Analysis of GUPFC

In order to maintain the voltages in the system within the limits FACTS devices are employed, in these devices voltage-sourced converters are used so as to inject controllable voltages in series or in shunt with the line. While injecting the voltages into the transmission line it requires an exchange of real and reactive power among the devices. Up to now most of the FACTS devices use no more than two converters. A new PFCD so called GUPFC is employed in the FACTS family, mainly it comprises of three converters that is one shunt and two series converters (Fardanesh et al., 2000). One of the converters is connected in shunt with the transmission line and the other two converters are allied in series with the two lines. The two series converters are placed in each transmission line as shown in Figure 1. Here Vs and Vr be the sending as well as receiving end voltages and Vsh be the shunt converter voltage, Vse represents the voltage across the series converter (Lubis et al., 2011). The GUPFC enlarges the conception of the voltage control as well as power control further than that attainable through the UPFC and IPFC controllers which are referred as two controller FACTS devices (Gyugyi et al., 1999, 1995).

Figure 1  Schematic diagram of GUPFC (see online version for colours)
This device is competent of controlling the voltages at the buses as well as it independently controls the power flow through the transmission lines consequently it controls the power system quantities such as bus voltages, transmission angles, line impedances etc. The two converters placed in series with the lines are capable of exchanging active power to meet the objectives of reactive power flow control and also they inject voltages in series with the line. Similarly to meet the objectives of real power flow control the reactive power is exchanged among the lines. And the shunt converters are used to inject the currents in shunt with the transmission lines. The consequences of these multi-use converters have to be taken into account; mainly they depend upon Mega volt-ampere (MVA) rating of the hardware elements.

3 Power quality improvement in GUPFC

Electrical power system comprises of generation, transmission and distribution, so due to its complexity when the electrical energy is moving from one point to other point it combines with deviations in weather, demand and some other factors due to which the power quality problems occurs. Due to the interconnections between the power systems sometimes short circuit between two devices, overloading of the motors may arise, when this type of conditions arises suddenly there will be a drop or rise in the voltage. When the value of voltage gets reduced it is termed as voltage sag. Similarly when the voltage value increases it is called as voltage swell.

In order to eliminate these power quality problems FACTS controllers are used. A new PFCD so called GUPFC is employed in the FACTS family, mainly it comprises of three converters that is one shunt and two series converters. By using this device these problems can be eliminated in turn the power transfer capability gets increases. Here SSSC acts as a series converter (Gyugyi et al., 1997). And the STATCOM behaves as a shunt converter. Both the converters are voltage sourced converters (Fardanesh et al., 1998).

4 GUPFC-power oscillation damping (POD)

Another one of the most important power quality problem is low frequency inter-area power oscillations takes place among mob of rotating power generators, interrelated by a light or heavily loaded AC interties. This type of oscillations are caused due to sudden changes in the load, line faults etc. The range of these oscillations lies below 2.5 Hz. If these are damped out from the system then the power transmission capability gets increased (RajaReddy et al., 2016).

4.1 Dynamic modelling

GUPFC has many applications and it can be applied to a multi-machine power system, GUPFC arrangement can be done from UPFC configuration by adding a single series of voltage source converter (VSC). The first step in the dynamic modelling is presenting the complete model of GUPFC. It has already been known that GUPFC mainly consists of three converters they are a single shunt and two series converters. The series controllers
are placed in two different transmission lines. Here VSC are considered to act as the shunt as well as series converters. So that totally three VSC’s are required for the GUPFC arrangement. Second step is implementing the power-system network near to the installing of the GUPFC, and subsequently the parameters of GUPFC have to be categorised the parameter network (Hadi, 2011). Third step is to develop a linear-model of a synchronous machine. At last, to design the control blocks for the device two blocks are necessary they are PSS and POD for GUPFC. With the help of lead lag compensation method these two control blocks are designed. The complete model of the system is written in state-variable form so as to get suppleness in order to analyse power-system dynamics.

4.2 Design of POD controller

In order to eliminate the oscillations present in the system, POD controller is used in the GUPFC model (Sadikovic, 2006; Wang and Swift, 1992). From Figure 2 $T_{\text{lag}}$ and $T_{\text{lead}}$ are the time constants for both lag as well as lead compensators and $T_{\text{w}}$ be the gain for the wash-out block and $K$ represents the gain for POD controller. The arrangement of GUPFC-POD controller is represented in the following Figure 2 this arrangement is analogous to PSS controller. A single amplification block and two lead lag compensators and a wash out block is present in the POD controller. In order to overcome the DC components present in the POD controller wash out block is used. And also this block is provided with a very large time-constant in the range of 6 sec to 11 sec. In order to eliminate the variation among the input and output variables lag lead compensators are used in the GUPFC model. By considering the POD design, the values of time constants for lag lead compensators and also the amplification gain $K$ are provided.

Figure 2  POD controller

5 Simulation results

Here analysing two type of networks, one is the single machine is connected to the infinite bus, in this network by analysing power quality issues (Jamshidi et al., 2012) and another one is 2-bus system, in this network by analysing power oscillation (Yuan et al., 2009).
In order to replicate the dynamic performance of the system, a 3-phase fault is created very close to the load. The fault existence period is between 0.07 sec to 0.11 sec. From Figures 3 and 4 it can be observed that in an uncompensated system voltage sag and current swell is noticed, the estimated value of the voltage sag and current swell is 0.5 p.u and 0.2 p.u respectively. The load harmonics are the most important power quality issues that occurs in the system, among all odd harmonics are the most dangerous harmonics, now the behaviour of the harmonics in an uncompensated line can be observed as shown in Figure 5.
After placing a compensator like GUPFC in the transmission line the power quality problems such as voltage sag, current swell can be overcome successfully as shown Figures 6 and 7. After placing the GUPFC in the line the odd harmonics are eliminated to some extent and also the values of THD are reduced from 55.07% to 0.23% shown in Figure 8.

**Figure 5** Total harmonic distortion without GUPFC (see online version for colours)

**Figure 6** 3-phase load voltage swell with GUPFC is replaced with 3-phase load voltage sag with GUPFC (see online version for colours)

**Figure 7** 3-phase load current swell without GUPFC (see online version for colours)
In this case suddenly fault occurs in generator side oscillation will be produced, in order to know the real and reactive power flows through the line, the simulation work is carried out using MATLAB/ SIMULINK software. The results without GUPFC-POD controller are represented in Figures 9 and 10.

**Figure 8**  Total harmonic distortion with GUPFC (see online version for colours)

**Figure 9**  Without GUPFC-pod active power (see online version for colours)

**Figure 10**  Without GUPFC-POD reactive power (see online version for colours)
GUPFC-POD controller has excellent control capabilities in eliminating the low frequency oscillations and in controlling the real and reactive power flows in the transmission line. Hence it offers better performance characteristics compared to other controllers as shown in Figures 11 and 12.

Figure 11  With GUPFC-POD active power (see online version for colours)

![Active Power (W)](image)

Figure 12  With GUPFC-POD reactive power (see online version for colours)

![Reactive Power (Var)](image)

6 IEEE5-bus system

6.1 IEEE-5 bus tested by simulations

The test results observed that the performance results of 5-bus system is enhanced when compare with Hadi (2011). The active power and reactive power for test case is less oscillations with results of 0.02 sec. Voltage sag and current swell values for our system is 7 % and it is reduced by 10% when compare with Hadi (2011). THD for the system is 0.2%, it is reduced by 5% when compare with Hadi (2011).

7 Conclusions

Many efficient methods are introduced in order to develop the power-quality in the power system. GUPFC a new PFCD is presented in this paper, which offers same control capabilities as that of other devices with a low cost and with an increased reliability. This GUPFC device is placed in the transmission line in order to eliminate some of the power
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quality issues like voltage sag and current swell that are present in the system. Power oscillations are also one of the important phenomena which reduce the performance of the power system. So in order to overcome this drawback GUPFC-POD controller is used to damp the low frequency oscillations as well as multiple-frequency power oscillations in the similar time.

References


