

# Application of Fuzzy and PI based UPFC in Electrical Power System

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**Abstract:** In a Power Systems the voltages drop to a very low magnitude when short circuit fault occurs. When voltage magnitude falls below the desired voltage called Voltage sag, which is one of the most severe problems to be dealt with as it causes severe disruptions and results in substantial economic loss. To control and compensate for the drop in voltage, Unified Power Flow Controller (UPFC) is used. UPFC is a FACTS device consisting of series and shunt converters where each is controlled by separate controllers. In this paper UPFC has been designed and incorporated in the system using MATLAB SIMULINK software. Fuzzy Logic Controller is designed for controlling the shunt converter. A simple test line is modeled and three phase to ground fault is applied on the system. The load voltage response with and without compensation is observed for the test system and compared to show that the voltage have been compensated as UPFC is implemented into the system and also the real and reactive power flow through the transmission line with and without compensation is observed which shows the efficient performance of UPFC.

**Keywords:** FACTS, UPFC, Fuzzy Logic Controller.

## I. INTRODUCTION

The electrical power system is mainly based on Alternating Current i.e. electric power is generated, transmitted and distributed in the form of AC. The generated power must possess certain electrical properties that allow electrical system to function their intended manner i.e. it can energizes all electrical equipment equally and satisfactorily. Due to various abnormal conditions of the power system network, the quality of the power changes and thus it becomes less suitable for any further applications. During abnormal condition voltage may fall below the desired value called voltage sag or it may rise from the desired value called voltage swell. When a short circuit fault occurs in a transmission system there is said to be a drop in the voltage, is one of the most wide and severe problem to be dealt with as it causes severe process disruptions and results in substantial economic loss. UPFC is one of the most widely used FACTS devices for power flow control, enhancement of transient stability and voltage regulation. In this paper the performance of UPFC on compensating the voltage sag in the line is examined with a control mechanism i.e. With Fuzzy PI controller. UPFC consists of series and shunt converters connected back to back. Both of these have different controllers. Shunt converter is connected through a shunt transformer and series converter is connected through a series transformer with the main transmission line. The shunt-converter is used primarily to provide the real power demanded by series converter through the common DC link terminal. Also, it can generate or absorb reactive power independently of the real power, it can be used to regulate the terminal voltage; thus, shunt converter regulates the voltage at the input terminals of the UPFC. The series converter controls the active and reactive

powers flow through transmission line by adjusting the magnitude and phase angle of the series injected voltage. The shunt converter controls the dc voltage and the bus voltage at the shunt converter transformer. In today due to the development of voltage-sensitive load equipment in diverse industries, such as automatic production lines, high-precision processing, computer centres, hospital equipments, and so on, their processes have also become much more vulnerable to degradation in the quality of power supply. Voltage quality problems in the form of voltage sags, voltage harmonics, and voltage swells can cause severe process disruptions, resulting in substantial economic and data losses. Faults at either the transmission or distribution line may cause voltage sag and swell in the entire system or a large part of it. Voltage sags, sudden decrease of supply voltage, can occur at any instant of time with amplitudes ranging from 10-90% and a duration lasting for half a cycle to one minute. Voltage swell, on the other hand is defined as a sudden increasing of supply voltage up 110% to 180% in rms voltage at the network fundamental frequency with duration from 10ms to 1 minute. Voltage sag and swell can cause sensitive equipment to fail, or shutdown, as well as create a large current unbalance that could blow fuses or trip the breakers. These effects can be very expensive for the customer ranging from minor quality variations to production downtime and equipment damage. Many efforts have been undertaken to fulfill consumer requirement i.e. to maintain a level of voltage higher than the level provided by modern networks of electricity. There are many different methods to mitigate voltage sags and swells but use Unified Power Flow Controller (UPFC) is considered to be one of the most efficient methods.

This paper composed of additional five sections. In section II configuration and operation of UPFC is explained. In section III control mechanism and simulation details of UPFC are provided. In section IV Analysis of the results of the test system are illustrated. In the last section, some conclusions are drawn

## II. CONFIGURATION AND OPERATION OF UNIFIED POWER FLOW CONTROLLER

The UPFC is the combination of two voltage-source converters; one converter is connected to the power system through a shunt transformer, whereas the other converter is inserted into the transmission line through a series transformer [1]. The converters are connected by a common DC-link where the capacitor is coupled and it allows a bi-directional real power flow between the output terminal of shunt converter and the input terminals of series converter. The basic system configuration of UPFC structure is shown in Figure. 1.

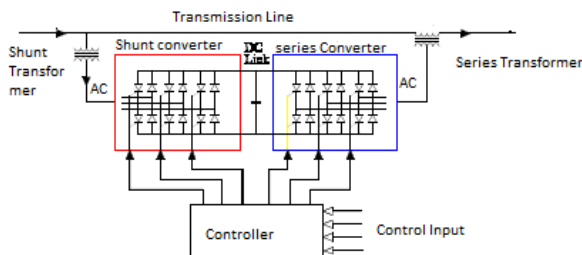


Fig 1-UPFC Configuration

### Shunt converter:

The shunt branch of UPFC comprised of a DC Capacitor, Shunt converter. It can absorb or generate only reactive power because the output current is in quadrature with the terminal voltage. The shunt-connected branch is used primarily to provide the real power demanded by series converter through the common DC link terminal. Also, it can generate or absorb reactive power independently of the real power, it can be used to regulate the terminal voltage at the sending end; thus shunt converter regulates the voltage at the input terminals of the UPFC. Another important role of the shunt branch of UPFC is a direct control of the DC capacitor voltage, and consequently an indirect regulation of the real power required by the series UPFC branch. The amount of real power required by the series converter plus the circuit losses have to be supplied by the shunt converter. Real power flow from the series converter to shunt converter is possible and in some cases desired, in this case, the series converter would supply the required real power plus the losses to the shunt converter. The shunt converter controls the dc voltage and the bus voltage at the shunt converter transformer. In this paper, the shunt converter is used to control the sending-end bus voltage magnitude by locally generating and absorbing reactive power.

### B. Series converter:

The series branch of UPFC is comprised of a DC Capacitor, series converter and a series connected transformer. It can act as a voltage source injected in series

to the transmission line through series connected transformer. The real power transferred from series converter to shunt converter and vice versa, and hence it is possible to introduce positive or negative phase shifts between voltage at the source and at the load respectively. The series injected voltage ( $V_{se}$ ) can have any phase shift with respect to the terminal voltage at the source. Therefore, the operating area of the UPFC becomes the circle limited with a radius defined by the maximum magnitude of  $V_{se}$ , i.e.,  $V_{se,max}$ . The series converter controls the active and reactive powers flow through transmission line by adjusting the magnitude and phase angle of the series injected voltage. The series converter directly controls real power of the line by controlling the magnitude of the series injected voltage. The series converter is used to generate the voltage and phase shift at the fundamental frequency. This voltage is added in series with the transmission line by the series connected coupling transformer. The transmission line current passes through the series transformer, and in the process exchanges real and reactive power with the series converter.

## III. CONTROLLERS OF UPFC

### Shunt controller

The controller which is used to control shunt converter called shunt controller. The shunt converter has two duties, namely to control the voltage magnitude at the sending-end bus by locally generating or absorbing reactive power, and to supply or absorb real power at the dc terminals as demanded by the series converter. It is possible to achieve real power balance between the series and shunt converter by directly controlling the dc voltage  $V_{dc}$ , as any excess or deficit of real power will tend to increase or decrease the dc voltage, respectively. By varying the magnitude and angle of the shunt converter output voltage the real and reactive power flow in and out of the shunt converter is controlled. The PI bus voltage regulator sets the reactive current reference and PI dc voltage regulator sets real current. The shunt converter controls the bus voltage by injecting reactive current in quadrature with sending-end voltage.

The shunt converter is operated to draw a controlled current from the line. One component of this current is automatically determined as a requirement real power to meet the losses in the converters and to balance the real power of the series converter [2]. However, the net real power is used to maintain the dc voltage and to provide the reactive power compensation without an external-electric-energy source to the system independently [3]. This component of current is calculated by finding the differences between reference value and instant value of DC bus voltage in this study. The result is used as an angle in the sinus block of control mechanism. The other component is reactive part of current and it can be set to any desired reference level (inductive or capacitive) within the capability of the converter. This component is calculated in the same way with the other component by finding the differences between reference voltage and instant value of bus voltage. The result is used as a magnitude to multiply with sinus block. Hence, the reference signals are calculated to use in the PWM

techniques. PI controller based and fuzzy controller based control mechanisms of shunt converter are given as separately in figure 2.

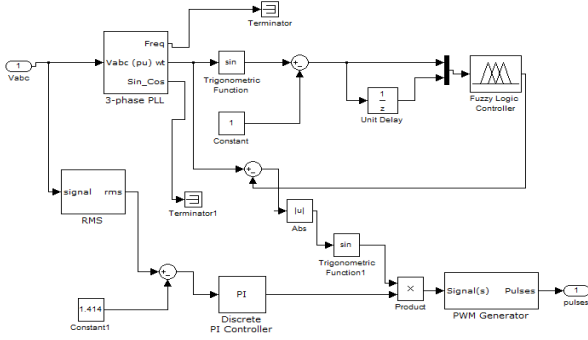


Fig. 2-Simulink model of Shunt controller

### Series controller

The main function of UPFC is actualized by the series converter. It controls the magnitude and the angle of the voltage injected in series with the line. This voltage injection is always intended to influence the power flow of the line [2]. The magnitude and the phase angle of series-injected voltage is calculated by control mechanism to provide the desired real and reactive power flow in the transmission line the series inverter will exchange real and reactive power with the line. The reactive power is electronically provided by the series inverter and the real power is transmitted to the dc terminals. The control mechanism of series converter is shown in Fig. 4. In the control mechanism, the receiving-end-generator voltage transforms into dq0 (Park) transform [4].

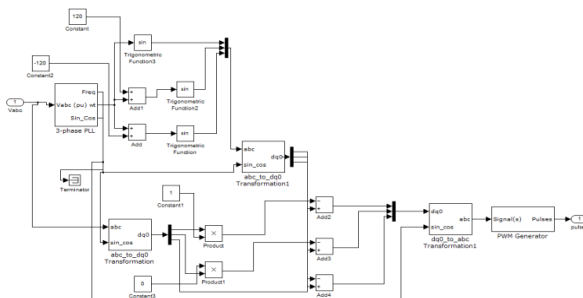


Fig. 3- Simulink model of Series controller

The dq0 components of receiving-end-voltage are multiplied with determined reference value of active/reactive powers. Hence, the signals desired by user are calculated. Then, the phase angle of transmission line is obtained by using PLL (phase locked loop). It is used to calculate the reference signals. These signals are transformed into dq0 form. The desired signals are subtracted from the reference signals and the results are transformed into three phase balanced system to use in the sinusoidal-pulse-width modulation (PWM). Thus, the firing angles of IGBTs (insulated gate bipolar transistors) are produce from the process of PWM technique.

### Fuzzy Logic Controller

The Controller that we used in our model is the Fuzzy Logic Controller (FLC). This tool was introduced in 1965 by LotfiZadeh. It is a mathematical tool that deals with

uncertainty. It provides us a basic technique to deal with imprecision and information granularity. Fuzzy logic (FL) controller is one of the most successful operations of fuzzy set theory. Its major features are the use of linguistic variables rather than numerical variables. This control technique relies on human capability to understand the systems behavior and is based on quality control rules. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FLC are formed by simple rule based on “If x and y then z”. These rules are defined by taking help from person’s experience and knowledge about the system behavior. The performance of the system is improved by the correct combinations of these rules [5] [6]. The general structure of FLC is represented in figure 4.

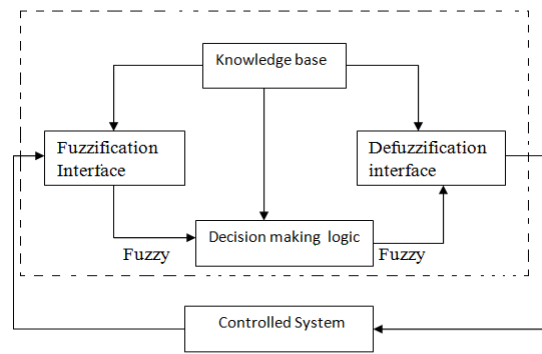


Fig. 4- Basic structure of Fuzzy Logic Controller

TABLE-1: Membership Functions

Error rate /Error	LP	MP	SP	VS	SN	MN	LN
LP	PB	PB	PB	PM	PM	PS	Z
MP	PB	PB	PM	PM	PS	Z	NS
SP	PB	PM	PM	PS	Z	NS	NM
VS	PM	PM	PS	Z	NS	NM	NM
SN	PM	PS	Z	NS	NM	NM	NB
MN	PS	Z	NS	NM	NM	NB	NB
LN	Z	NS	NM	NM	NB	NB	NB

## IV. OBSERVATION AND RESULTS

The simulation model of a simple test line in which UPFC is implemented is shown in figure 5. Simulation is done by applying three phase to ground fault for 100 ms (0.1-0.2 sec) duration.

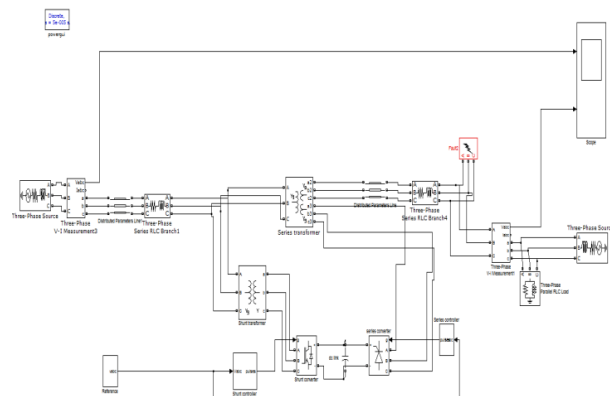


Fig. 5- Simulation model of transmission line with UPFC

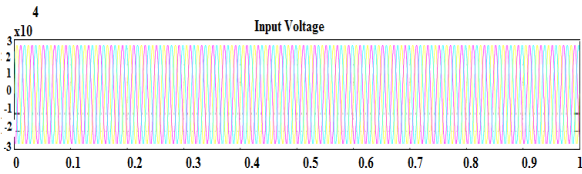


Figure 6- Input voltage waveform

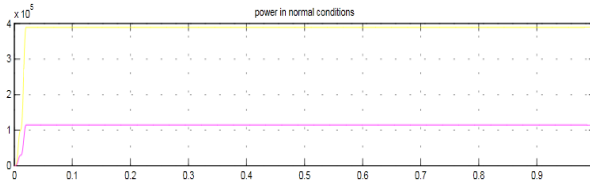


Fig. 7- Active and Reactive power through the line during normal condition

Figure 6 shows the input voltage which is fed to the three phase load. The peak value of the input voltage is 30 kV and Figure 7 shows Active and Reactive power flow through the line during normal condition i.e. without applying any fault on the system.

Figure 8 shows the load voltage waveform and Figure 9 shows Active and Reactive power through the line when fault is there on the line.

It is observed from the figures that during fault voltage magnitude reduce from its normal value to 10kV and active and reactive powers changes from its normal values.

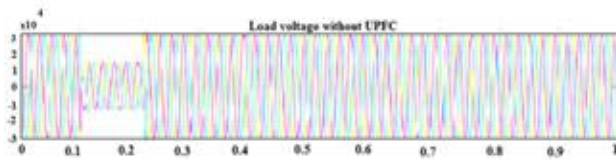


Fig. 8- load voltage during fault without UPFC

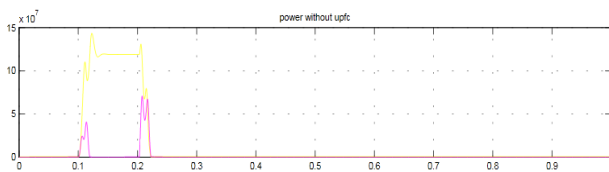


Fig. 9- Active and Reactive power through the line during fault

Last simulation is done for 0.5 second. From the figure-10 it is observed that during fault i.e. for 0.1-0.2 sec load voltage is almost same as the voltage during normal condition and from figure -11 it is also seen that active and reactive power are almost same as the power at normal condition.

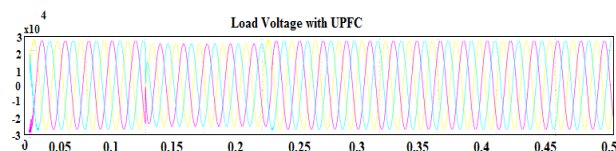


Figure 10- Load voltage waveform with UPFC

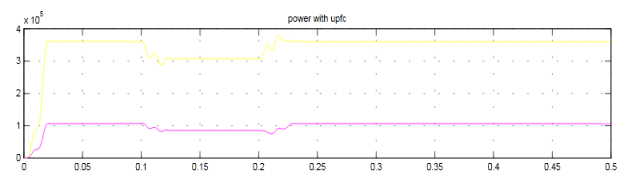


Figure 11- Active and Reactive power through the line with UPFC

## V. CONCLUSION

This paper presents description about designing and developing a simulation model of Fuzzy and PI based UPFC using MATLAB SIMULINK. Due to fault on the system, voltage fluctuates and this cause damage in both large and small scale. To improve power quality in the transmission system implementation of UPFC is highly recommended. In this paper the control and performance of UPFC using shunt and series controller is implemented. It is observed that during abnormal condition the voltage experience a large amount of fluctuation in comparison to the normal condition. The UPFC is connected to a three phase line and the results are compared. It is found that after implementation of the UPFC the load voltage has been compensated and improves the quality of power. The active and reactive power has also been compensated. The UPFC also has other advantages like reduce maintenance and ability to control real and reactive power through the line and limit the transients.

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