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Fuzzy Based FOPID for Improvement of Power Quality by using Unified Power Flow Controller

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ABSTRACT

Electricity is viewed as the foundation of the industrial revolution and needs to be transmitted at a greater distance in order to meet both industrial and domestic needs. Something flexible needs to be adapted to pave the way for the electricity as well as regulate the problems that are affecting the power system in a cascading fashion. In terms of the analysis of the performance of the power system, flexible alternate current transmission systems (FACTS) have been seen as promising. This study presents a thorough analysis of the UPFC, a FACTS device known as the Unified Power Flow Controller. In light of this, a controller based on a fractional order proportional integral derivative (FOPID) and fuzzy logic controller (FLC) is used to perceive the UPFC for various instances. The MAMDANI approach was used to construct the fuzzy logic-based FOPID controller, which is introduced and replaces FOPID controllers on transmission lines under various power system operating situations. The controller network was outlined using MATLAB/SIMULINK. In terms of reducing power quality concerns including voltage sags, swells, and damping, it was found that the UPFC with the Fuzzy logic-based FOPID control technique performed better than the UPFC with the FOPID controller. One could get theconclusion that the fuzzy logic based FOPID controller (FFOPID) is effective in reducing power quality problems.

KEYWORDS: Flexible Alternating current transmission systems (FACTS), Unified Power .Flow Controller (UPFC), Proportional integral fractional order proportional integral derivative (FOPID), fuzzy logic, MATLAB/SIMULINK, Power system, Power Quality, Voltage sag, Voltage swell.

1. INTRODUCTION

The demand for electricity has been rising dramatically in recent years to keep up with the constantly expanding demand. With this demand, the electric power system is constantly stressed by the regular interruption of the electric flow caused by faults, its dynamic character, and due to the non-linear loads also resulting in unacceptable voltage and frequency conditions. Additionally, the installation of transmission lines is necessary to accommodate this development, which exacerbates the interference issue in the transmission system. The FACTS technology was recently used to alleviate such situations by regulating the power flow along the transmission lines and improving the power system in terms of dampening oscillations[1].

The Power System Stabilizer (PSS), one of the most often used stabilisers, was widely utilised before the FACTS device was seldom considered. These PSS play a significant function in reducing the automated VAR generator's negative voltage. These PSS had a problem in that they didn't offer enough dampening between the producing units in a transmission line[2].

The implementation of the FACTS has emerged as an exciting strategy for assisting in the relief of numerous power system issues, such as inter-area oscillations and managing all damping and important bus voltages on a transmission line[3]. A more efficient transfer of power between regions under control and dampening of power system oscillations are two benefits of the flexible AC, which is designed in accordance with HVDC and THYRISTORS development. UPFC is one of these Facts devices that is adaptable among the others. The voltage frequency line impedance, amplitude, and phase angle are controlled individually or in succession by this UPFC, a solid-state controller based on high power electronics. The controller that is built into the device and its design, however, play a significant influence in preventing device failure. Additionally, the ineffective power flow regulation and disregarding the dynamic performance of this capacitor dc connection were just restrictions. In terms of delivering transient stability and robust performance, the FOPID controller that was used with the FACTS device was insufficient. Due to these governing parameters' hiccupping under various operating situations, this drawback was noticed.

This study introduces the fuzzy with FOPID controller-based UPFC to get beyond these limits and progress the power quality network, which was being held back by theFOPIDcontroller. Fuzzy with FOPID logic controllers provide both reliable performance and efficient dynamic power flow management[12]. In order to execute the simulation with a quicker and more consistent performance, MATLAB/SIMULINK is employed.

The arrangement of the paper is as follows: Basic structure of UPFC is discussed in Section 2. In Section 3, UPFC's with the both additional shunt and series converter controllers are analysed. fuzzy logic system analysis is made in section 4. Section 5 has covered the fractional order PID controller. fuzzy with FOPID controlleris discussed in the section 6. In section 7, UPFC with fuzzy and FOPID controllers are analysed.MATLAB simulation models and simulation results are discussed section 8 and section 9.

2. BASIC STRUCTURE OF UPFC

A. Without controller of UPFC

The fundamental structure of UPFC is depicted in figure 2 below. Between the transmitting and receiving ends, this UPFC is linked, and its performance is evaluated. Under stable working circumstances, the transmission line parameters continuously flow from the sending end to the receiving end. 1. Converter 1 operates as a shunt converter. 2. Converter 2 operates as a series converter. The two converters—Converter 1, which conducts shunt compensation, and converter 2, which performsseries—are each given this. in each case, recompense. Using a shared capacitor DC connection, these two are joined.

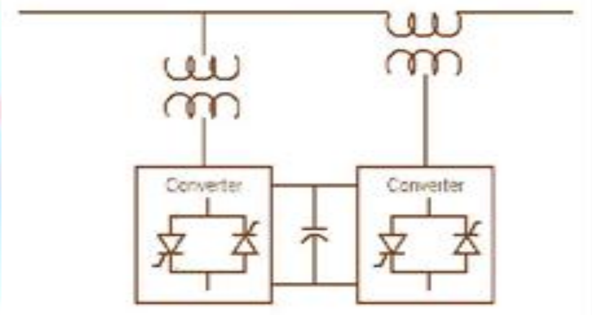

Fig 2: Structure of UPFC without controller

B. With controller of UPFC

Figure 3 below illustrates the fundamental composition of FOPID-based UPFC. The performance of this UPFC, which connects the transmitting and receiving ends, is examined. Shunt converter operation for Converter 1, series converter operation for Converter 2, FOPID-based controller, measurement block, and settings block are the other conversion methods. The transmission line parameters continuously flow from the transmitting end to the receiving end under stable operation circumstances. The Measurements block keeps track of the transmission parameters continually and reports its findings to the FOPID Controller.

This controller block evaluates the transmission line parameters in comparison to the nominal rated values. The setting block won't produce a pulse signal if the difference between these values is 0, and the converter section won't get any signal either. The FOPID Controller will produce an error during this procedure if there is a discrepancy between the values supplied by the measurement block and the nominal rated values that are really present. When there is a defect, the setting block sends a signal to the FOPID Controller block continually. This is sent to two converters, Converter 1 and Converter 2, with Converter 1 doing shunt compensation and Converter 2 performing series compensation, respectively.

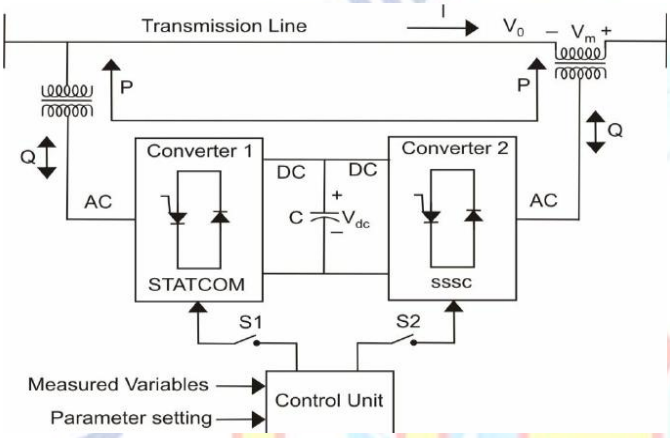

Fig 3: Structure of UPFC with controller

3. UPFCSHUNT AND SERIES CONTROLLERS

A. *Control Strategy for Shunt Converter.*

In below figure 4, depicts the shunt converter, which can be referred to as a STATCOM and typically handles shunt compensation, and which serves a crucial role in the operation of the UPFC system. [10] The AC and DC controllers on the STATCOM controller are responsible for controlling the reactive power and the active power, respectively. Reference currents for active power and reference are produced by the DC controller (Ip*). The reference reactive current, abbreviated Ir*, is produced by the AC controller. The measured value and the reference value are compared to produce Ep and Er. Ir* will be finite in this situation but Ip* will be zero. The Ip and Iq are represented as the corresponding Id and Iq components produced by the parts transformation. The capacitor injecting reactive power is yet another crucial component of this feature. The amplitude and phase angle of the compensating reference signals are produced from the Ep and Er values. The Real/Reactive Current Calculator uses the equation below to calculate current.

$$\begin{bmatrix} \mu d \\ \mu q \\ \mu o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \\ -\sin(\omega t) & -\sin(\omega t - \frac{2\pi}{3}) & -\sin(\omega t + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} ua \\ ub \\ uc \end{bmatrix}$$

$$\mathrm{Va} = \mathrm{Vm} \sin \omega t$$

$$\mathrm{Vb} = \mathrm{Vm} \sin(\omega t - \frac{2\pi}{3})$$

$$\mathrm{Vc} = \mathrm{Vm} \sin(\omega t + \frac{2\pi}{3})$$

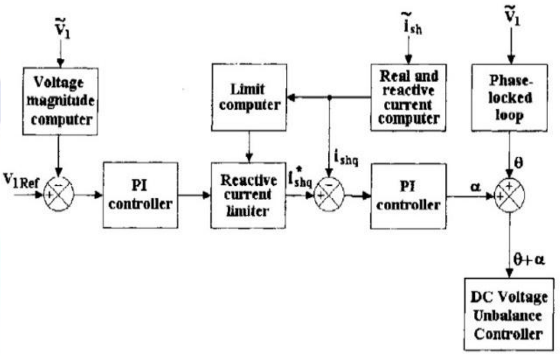

Fig 4.Shunt converter of UPFC

B. *Control Strategy for Series Converter.*

The basic goal of UPFC is achieved by the series converter, as indicated in fig 5. The series converter analyses the amplitude and phase angle values of the series-injected voltage to create the desired real and reactive power flow in the transmission line[11]. The restriction is that the operation must be identical to a shunt converter with the relaxation that Q* is treated as zero and in the place of E because both $\alpha = \beta$ are in series.

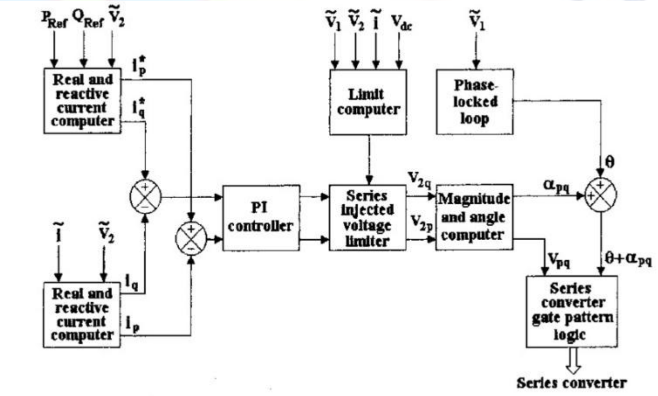

Fig 5: series converter of UPFC

IV. FUZZY LOGIC SYSTEM ANALYSIS

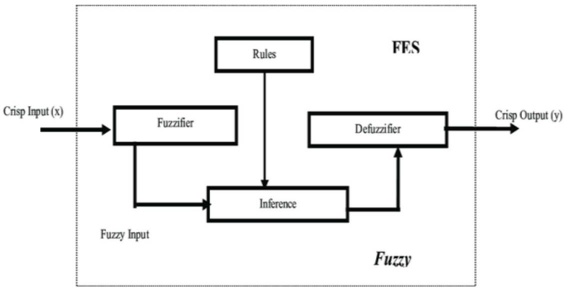

Fig. 6: Simplified model of FUZZY logic controller

The fuzzy logic controller's fundamental working model for any device to be applied in is illustrated in figure 4 above. 1. Fuzzifier is the fundamental component of our fuzzy logic controller. 2. Rules-based 3. A comparison tool 4. Defuzzied. Additionally, a full analytical description of the fuzzy is provided [12].

A).FUZZIFIER: A fuzzifier is a block that executes the process of decomposing a system's input and/or output into one or more fuzzy sets, which is known as fuzzification. The FUZZIFICATION process makes it possible to define the system's inputs and outputs in language terms, which makes it possible to apply rules to complicated systems in a straightforward way.

B).Inference Engine:

E/CE	**NB**	**NM**	**NS**	**EZ**	**PS**	**PM**	**PB**
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
EZ	NB	NM	NS	Z	PS	PM	PB
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z

Table 1. Fuzzy rule base

Language-based variables such as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (EZ), Positive Small (PS), Positive Medium (PM), and Positive Big are used to characterise the mistake and changes in the error (PB). values used as input by the fuzzy controller. The MAMDHANI technique makes it simple to establish a connection between input and output data.

C). DEFUZZIFIER:It is simpler to accept a crisp output that is represented as a single scalar quantity in many systems whose output is fuzzy. Defuzzification is the process of turning a fuzzy collection into a single crisp value.

5. FRACTIONAL ORDERPID CONTROLLER:

Year 1960, the application of FO calculus to dynamic systems was initiated. Since then, numerous engineering fields have benefited from research on FO control. A combination of fractional operators and controller gains make up the fractionalorder PID controller. The representation of the transfer function for the FOPID controller is

$$G_c(s)=\frac{u(s)}{e(s)} = K_p + K_I s^{-\lambda} + K_D s^{\mu},$$

G(s) stands for the controller transfer function, e(s) for error, and U(s) for output. For proportional, integral, and derivative terms, the profits are denoted by the letters K_P,K_I, and K_D. The fractional components of integral and derivative portions, respectively, are denoted by the terms λ and μ, respectively. The representation of the FOPID controller in the time domain is shown in

$$u(t) = K_P e(t) + K_I D^{-\lambda} e(t) + K_D D^{\mu} e(t).$$

Table 2: Controller parameters of fractional-order PID controller

K_P	K_I	λ	K_D	μ
6.22	0.09	0,91	0.33	1,33

It is clear that the parameters of integral order X and derivative-order Y should be taken into account in addition to the standard three parameters K_P, K_I, and K_D in FOPID controllers. In light of this, the FOPID controller design process entails solving five nonlinear equations using five system-related unknowns: K_P, K_I, K_D, X, and Y. However, the fractional order is mostly to blame for the five nonlinear equations' high complexity. In light of the challenges, designing the controller in MATLAB using the appropriate tool may be a better option. The best solutions are provided with the least amount of error by the MATLAB optimization toolbox.

6. FUZZY WITH FOPID CONTROLLER:

The rule-based fuzzy set theory offers more flexibility in system design and easier-to-understand language notation for expressing observations. In closed-loop control systems, particularly those having nonlinearity between their inputs and outputs, the fuzzy logic system also performs better when tweaking the controller settings. The proportional, integral, and derivative terms of the classical controllers, including the fractional order controller, are multiplied by a set gain value. As a result, the controller's performance falls short of what is reasonable for a complicated, nonlinear system. Instead of using a fixed gain, an attempt can be made to use a dynamic gain value for the proportional, integral, and derivative terms.

In a FOPID control scheme, dynamically changing the gain will improve controller performance and rapidly stabilise the system output during load variations and outside disturbances. This paper proposes a fuzzy logic and fractional-order control technique by taking these factors into account. The rule basis fuzzy control and the FOPID controller are combined to create the FFOPID controller. The scaling factor of the proportional, integral, and derivative components is determined by the FLC in this control scheme using system error and derivative error inputs.

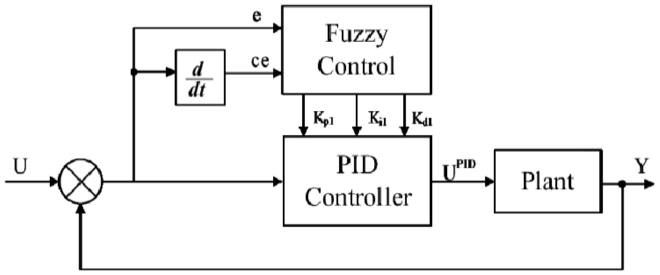

Fig.8 Block diagram of the fuzzy with fractional-order PID controller.

The amount of the controller gain will be changed every sample interval using these scaling parameters. As seen in Figure 8, the frame of a typical FFOPID control structure. In the suggested control structure, the FLC utilises the inputs for the error and its derivative to compute the scaling factor for the proportional, integral, and derivative terms. These results are then utilised to update the gain settings of the FOPID controller. In order to calculate the final gain values for the FOPID controller, the following formula is used to calculate K_P, K_I, and K_D.

$$k_P = K_P + \Delta K_P$$

$$k_i = K_I + \Delta K_I$$

$$k_d = K_D + \Delta K_D,$$

7. UPFC with FUZZY and FOPID CONTROLLERS:

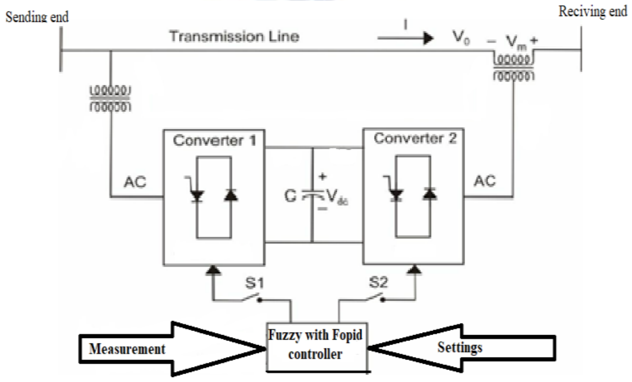

Fig.9 Block diagram of UPFC with FUZZY and FOPID controller.

The block diagram of the UPFC with the newly added fuzzy and FOPID controller is shown in basic form in Fig.9 above. The transmission line parameters continuously flow from the transmitting end to the receiving end under stable operation circumstances. The new FUZZY WITH FOPID CONTROLLER receives the transmission parameters from the Measurements block, which continually checks them. Voltage and current should be translated into intelligible values before being sent to the fuzzy block since the fuzzy logic system does not examine typical voltage and current values. The FUZZIFICATION block in this FUZZY block transforms the transmission line parameters' raw values into linguistic values. Depending on the input value that meets the rule, these values are then compared with the rules table listed in the inference block.The judgement is made by the fuzzy system's inference block, which provides a ZERO signal in accordance with the rule table displayed in Table 1. The FUZZY WITH FOPID block won't let the settings block to emit any pulses, and the Converter section won't receive any signal if there is no difference between these values.

In this procedure, an error is produced that identifies the fault state if there is a discrepancy between the data supplied by the measurement block and the specified nominal values included in the FUZZY WITH FOPID LOGIC Controller. The FUZZY WITH FOPID LOGIC controller block permits the settings block to create and give pulses to converters 1 and 2, which carry out shunt and series compensation, under this fault situation.The FUZZY WITH FOPIDLOGIC controller permits the pulses from the settings block up to and until the measurement block parameters and nominal rating values are tallied. Once these values are in agreement, the FUZZY WITH FOPID LOGIC controller stops sending pulses from the settings block to the appropriate controllers to switch off both series and shunt compensation.

8. MATLAB SIMULATIONMODELS:

To simulate the modelling of UPFC and the test system, MATLAB/SIMULINK is utilised. Essentially, the SIMULINK model is a transmission line network with loads and a five-bus system.

A. SIMULINK MODELING OF THE UPFC

The UPFC SIMULINK modelling is depicted in figure 10 below. The UPFC utilised in this study was created for the provided rating depicted in the picture. The reference active and reactive power are designed for the corresponding measurements in the picture below. The system network receives the trip signal. For waveform analysis from the axis of the relevant regulating parameters, a bypass is present on the UPFC. The supply network's individual input ports for the three-phase supply of the transmission system are designated as A1, A2, and A3, accordingly.

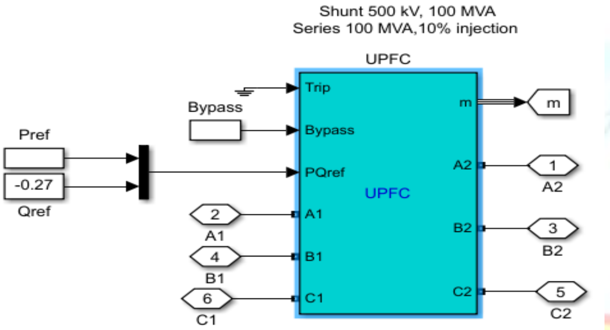

Fig:10 Modelling of the UPFC

B. SIMULINK MODELING OF THE FUZZY WITHFOPID CONTROLLER:

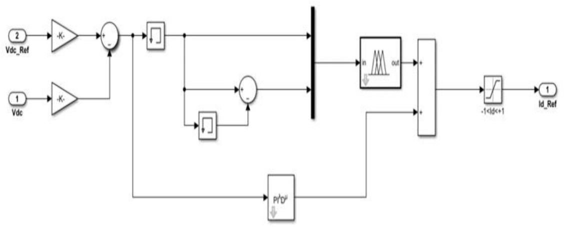

Fig.11modelling of the fuzzy with FOPID controller

The modelling of the fuzzy with FOPID controller is shown in figure 8. There are two input variables and one output variable for fuzzy controller.Every variable has seven membership functions, as was mentioned in table 1. As the controller operates according to the per unit scheme, the error variable is limited to values between -1 and +1. A crucial component of this design has shown that the mistake mostly changes between -0.01 and +0.01, or 1% of the inaccuracy. The 7*7=49 rule base that makes up this FIS's output is pre-compiled.The mistake that is produced is compared to the reference and measured VDCs. The calculation for the error change is = e(k)-e(k-1) where k is the measurement element.

C .SIMULINK MODELING OF THE UPFC WITH FUZZY AND FOPID CONTROLLER:

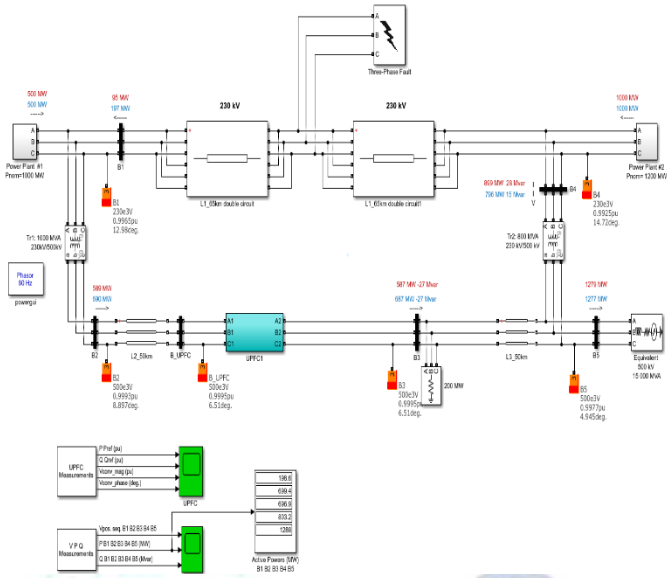

Fig.12 Modelling of the UPFC with fuzzy and FOPID controller

The SIMULINK model of the construction of the transmission line network is depicted in figure 12above. Figure 15 analyses both active and reactive power for the network with the UPFC on a transmission line parameter with the FUZZY AND FOPID CONTROLLER.

9. MATLAB RESULTS:

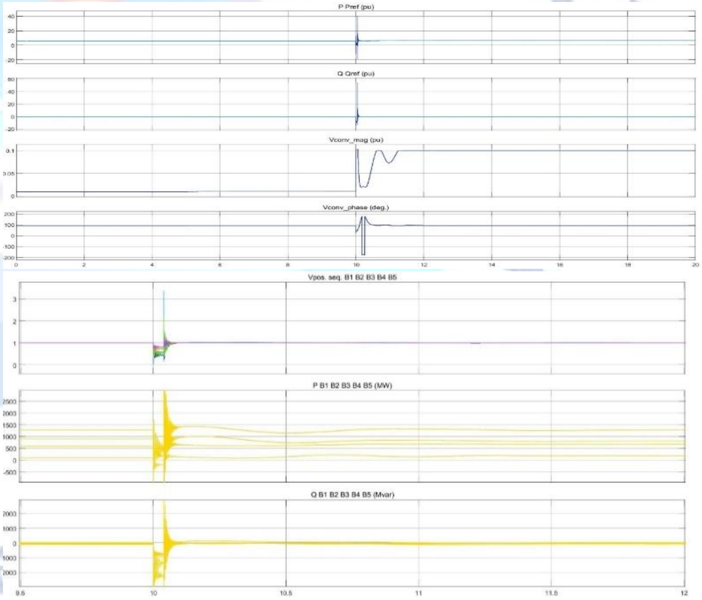

Fig .13 Simulation result of FOPIDbased UPFC

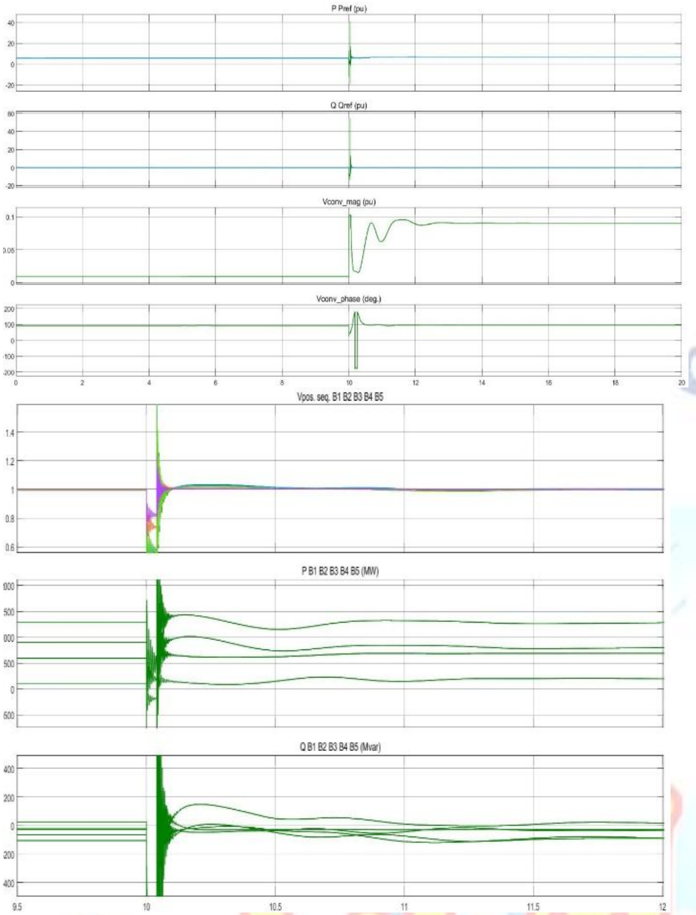

Fig .14Simulation result of fuzzy based UPFC

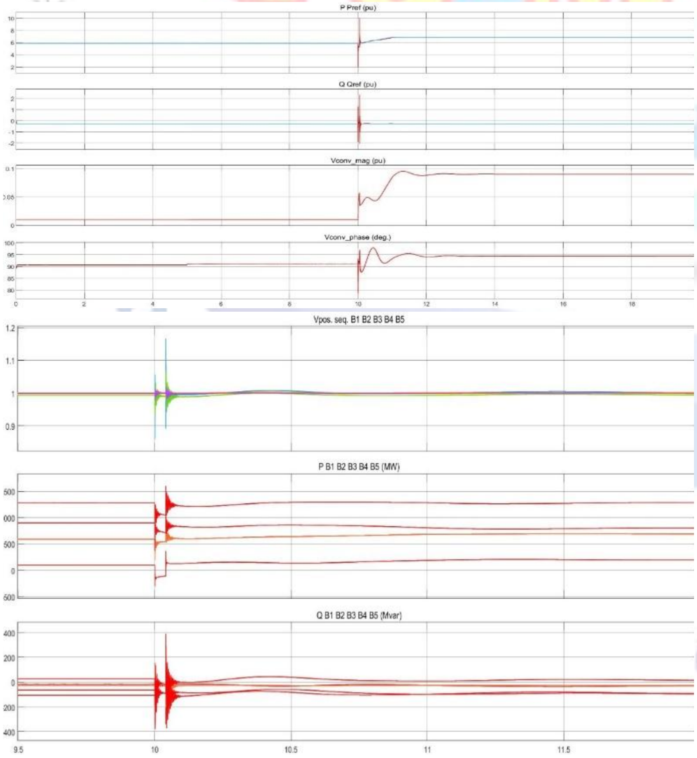

Fig.15 Simulation results of FFOPID based UPFC

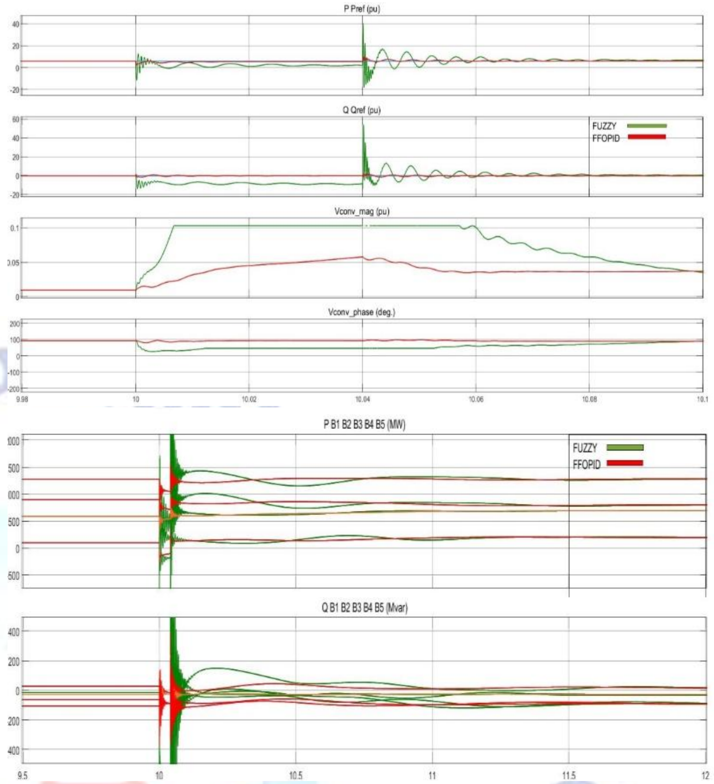

Fig:SIMULINK output of comparison between FUZZY AND FFOPID

10. CONCLUSION

In this paper, the significance of the FACTS device for the purposes of its analysis is noted. The UPFC (Unified Power Flow Controller), one of the MAJOR FACT devices, is examined along with the two compensations—series compensation and shunt compensation. Additionally, the effectiveness of the UPFC with the FOPID controller is researched. In this paper, a fuzzy logic-based FOPID controller is proposed along with a unified power flow controller, and its performance is examined.

A MATLAB/SIMULINK is used for this. Additionally, the compensating values are extracted from this output and compared to the UPFC that is based on the FOPID Controller.This suggests that the newly released fopid UPFC, which is based on a fuzzy logic controller, has superior compensatory values than the FOPID controller-based UPFC. Therefore, it might be argued that the fuzzy logic based FOPID controller is the best controller for reducing Power Quality problems.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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