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Performance of Fuzzy logic Based UPFC for Power flow Control

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Abstract

A new concept of Flexible AC Transmission system (FACTS) brought radical changes in the power system operation and control. A new technique using FACTS devices linked to the improvements in semiconductor technology opens new opportunities for controlling power and enhancing the usable capacity of existing transmission lines. The Unified Power Flow Controller is devised for the real time control and dynamic compensation of transmission systems, providing multifunctional flexibility required solving many of the problems facing the power delivery industry. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively all the parameters affecting power flow in the transmission line and this unique capability is signified by the adjective “unified” in its name. UPFC can independently control both active and reactive power in the line. A transformer-less UPFC based on an innovative configuration of two cascaded multilevel inverters (CMIs) has been proposed recently, which is suitable for power flow control between two interconnected synchronous AC grids. The active power as well as the reactive power can be independently controlled by the new transformer-less UPFC. The controlled signal for the multi level inverter is fed by using fuzzy logic controller (FLC). This project is carried out using MATLAB simulink software.

Keywords: Flexible AC transmission systems (FACTS), multilevel inverter, unified power flow controller (UPFC), Fuzzy Logic Controller (FLC).

INTRODUCTION

The unified power flow controller (UPFC) is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (i.e., voltage magnitude, impedance, and phase angle). The conventional UPFC consists of two back-to-back connected voltage source inverters that share a common dc link, as shown in Fig. 1. The injected series voltage from inverter-2 can be at any angle with respect to the line current, which provides complete flexibility and controllability to control both active and reactive power flows over the transmission line. The resultant real power at the terminals of inverter-2 is provided or absorbed by inverter-1 through the common dc link. As a result, UPFC is the most versatile and powerful flexible ac transmission systems device. It can effectively reduce congestions and increase the capacity of existing transmission lines. This allows the overall system to operate at its theoretical maximum capacity.

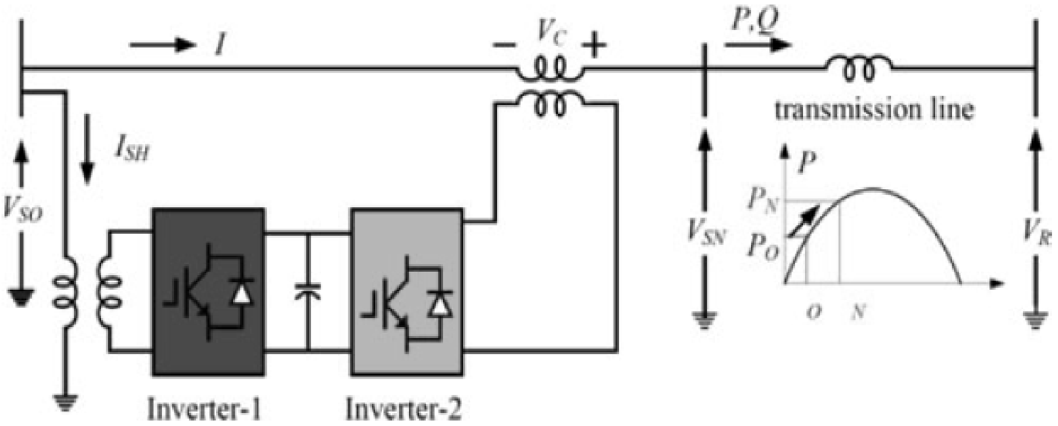

Figure 1: Conventional UPFC

The conventional UPFC has been put into several practical applications, which has the following features: 1) both inverters share the same dc link; 2) both inverters need to exchange real power with each other and the transmission line; 3) a transformer must be used as an interface between the transmission line and each inverter. In addition, any utility-scale UPFC requires two high-voltage, high-power (from several MVA to hundreds of MVA) inverters. This high-voltage, high-power inverters have to use bulky and complicated zigzag transformers to reach their required VA ratings and desired voltage waveforms. The zigzag transformers are: 1) very expensive (30–40% of total system cost); 2) lossy (50% of the total power losses); 3) bulky (40% of system real estate area and 90% of the system weight); and 4) prone to failure. Moreover, the zigzag transformer based UPFCs are still too slow in dynamic response due to large time constant of magnetizing inductance over resistance and pose control challenges because of transformer saturation, magnetizing current, and voltage surge.

Recently, there are two new UPFC structures under investigation: 1) the matrix converter-based UPFC and 2) distributed power-flow controller (DPFC) derived from the conventional UPFC. The first one uses the matrix converter replacing the back-to-back inverter to eliminate the dc capacitor with ac capacitor on one side of the matrix converter. The DPFC employs many distributed series inverters coupled to the transmission line through single-turn transformers, and the common dc link between the shunt and series inverters is eliminated. The single-turn transformers lose one design freedom, thus making them even bulkier than a conventional transformer given a same VA rating. In summary, both UPFCs still have to use the transformers, which inevitably cause the same aforementioned problems associated with transformers (such as bulky, lossy, high cost, and slow in response).

METHODOLOGY

According to the IEEE definition, FACTS is defined as “The Flexible AC Transmission System(FACTS) is a new technology based on power electronic devices which offers an opportunity to enhance controllability, stability and power transfer capability of AC Transmission Systems”.

Power systems today are highly complex and the requirements to provide a stable, secure, controlled and economic quality of power are becoming vitally important with the rapid growth in industrial area. To meet the demanded quality of power in a power system it is essential to increase the transmitted power either by installing new transmission lines or by improving the existing transmission lines by adding new devices. Installation of new transmission lines in a power system leads to the technological complexities such as economic and environmental considerations that includes cost, delay in construction as so on. Considering these factors power system engineers concentrated the research process to modify the existing transmission system instead of constructing new transmission lines. Later they came up with the concept of utilizing the existing transmission line just by adding new devices, which can adapt momentary system conditions in other words, power system should be flexible.

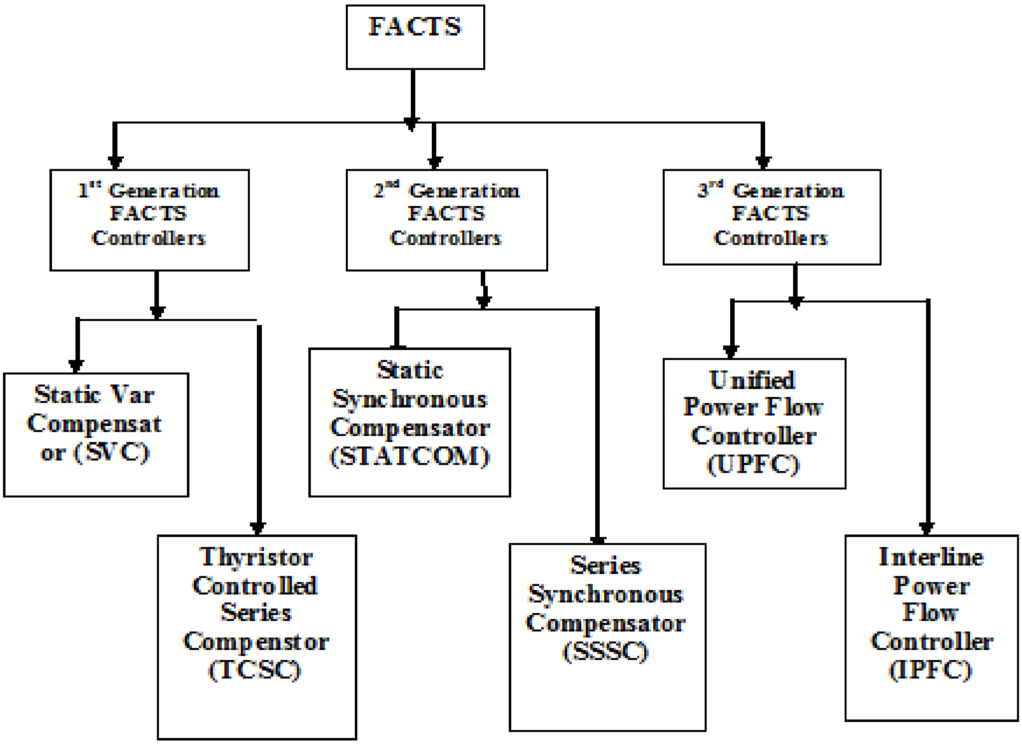

Figure 2: Block Diagram of FACTS Controllers

CONTROL TOPOLOGY

The Unified Power Flow Controller (UPFC) was devised for the real-time control and dynamic compensation of ac transmission systems, providing multi-functional flexibility required to solve many problems facing the power delivery industry.

UPFC is a generalized synchronous voltage source (SVS), represented at the fundamental frequency by voltage phasor Vpq (0<=Vpq<=Vpqmax) and angle P(0<=P<=2π), in series with the transmission line, as illustrated for an elementary two-machine system. In this arrangement the SVS generally exchanges both reactive and real power with the transmission system. Since, by definition, an SVS is able to generate only the reactive power exchanged, the real power must be supplied to it, or absorbed from it, by a suitable power supply or sink. In the UPFC arrangement the real power the SVS exchange is provide by one of the end buses, as indicated in the figure.

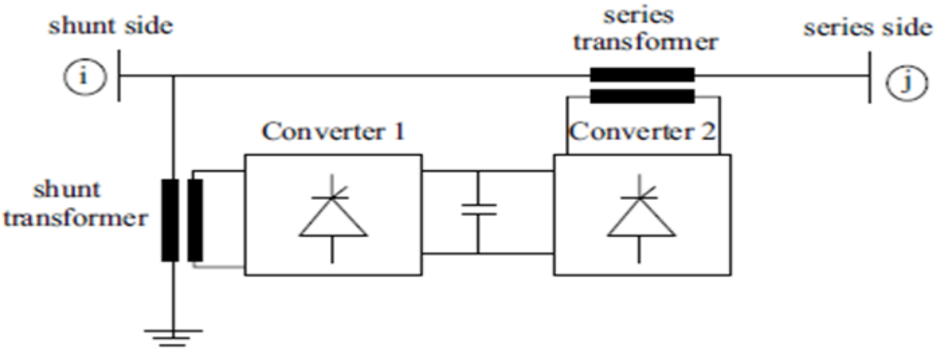

Figure 3: Circuit Diagram of Unified Power Flow Controller (UPFC)

The capability of unrestricted series voltage injection together with independently controllable reactive power exchange offered by the circuit structure of the two dc-coupled converters facilitates several operating and control modes for the UPFC. These include the option of reactive shunt compensation and the free control of series voltage injection according to a prescribed functional approach selected for power flow control. The UPFC circuit structure, also allows the total de-coupling of the two converter (i.e., separating the dc terminals of the two converters) to provide independent reactive shunt compensation (STATCOM) and reactive series compensation (SSSC) without any real power exchange.

A. Dynamic Models of UPFC System

The equations derived from the phasor diagram in Section II are limited to steady-state operation analysis. In order to design the vector-oriented control for the proposed transformerless UPFC with considering both steady-state and dynamic performance, the dynamic modules are necessary. The models are based on synchronous (*dq*) reference frame. The phase angle of original sending-end voltage V_{s0} is obtained from a digital phase-locked loop, which is used for *abc* to *dq* transformation. The dynamic models for the whole system shown in Fig. 2 will be divided into several parts. First, we can get the dynamic model from the new sending-end bus to receiving-end bus.

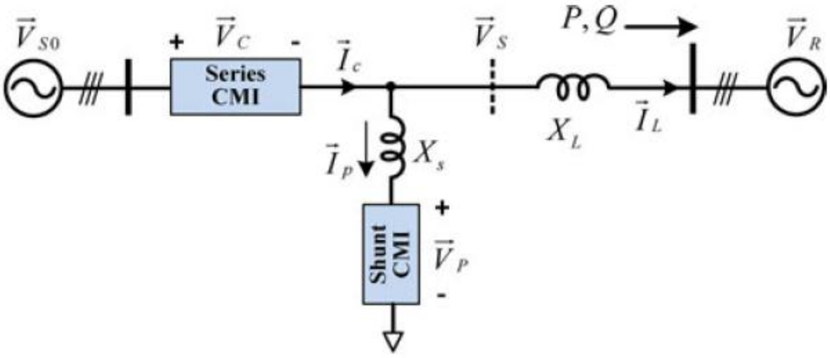

Figure 4: System configuration of Transformerless UPFC

$$\begin{cases} V_{sd} = R_L i_{Ld} + L_L \frac{di_{Ld}}{dt} - \omega L_L i_{Lq} + V_{Rd} \\ V_{sq} = R_L i_{Lq} + L_L \frac{di_{Lq}}{dt} + \omega L_L i_{Ld} + V_{Rq} \end{cases} \quad (1)$$

$$\begin{cases} V_{sd} = R_s i_{Pd} + L_s \frac{di_{Pd}}{dt} - \omega L_s i_{Pq} + V_{pd} \\ V_{sq} = R_s i_{Pq} + L_s \frac{di_{Pq}}{dt} + \omega L_s i_{Pd} + V_{pq} \end{cases} \quad (2)$$

B. Power Flow and Overall DC Voltage Control

It is desired to design a control system, which can independently regulate the active power P and reactive Q in the line, at the same time, maintain the capacitor voltages of both CMIs at the given value. Fig. 5 (a) shows the overall control system, which is divided into three stages, i.e., stage I to stage III.

Stage I: the calculation from $P*/Q*$ to $V*C0$ and $I*p0$. As mentioned before, the $V*C0$ is the voltage reference for series CMI, which is generated according to the transmission line power command, while $I*p0$ is current reference for shunt CMI, which is used to keep zero active power for both CMIs. Note that instead of calculating $V*C0$, an alternative way is shown in Fig. 5 (b). Here, the line current reference $I*Ld/I*Lq$ is calculated out of the $P*/Q*$ reference, then the d- and q-axis components of series voltage $V\ *C0d$, $V\ *C0q$ are calculated according to (3), where the dynamic model is included. The line current is controlled in a way of decoupling feed forward control, thus better line current dynamic response could be achieved.

$$\begin{cases} V^*_{C0d} = V_{S0d} - V^*_{Sd} = \\ \quad V_{S0d} - \left(R_L I^*_{Ld} + L_L \frac{dI^*_{Ld}}{dt} - \omega L_L I^*_{Lq} + V_{Rd} \right) \\ V^*_{C0q} = V_{S0q} - V^*_{Sq} = \\ \quad V_{S0q} - \left(R_L I^*_{Lq} + L_L \frac{dI^*_{Lq}}{dt} + \omega L_L I^*_{Ld} + V_{Rq} \right) \end{cases} \quad (3)$$

Stage II: overall dc-link voltage regulation. With the $V*C0$ and $I*p0$ given in stage I, the dc-link voltage cannot be maintained due to the following three main reasons: 1) the CMIs always have a power loss, 2) the calculation error caused by the parameter deviations, 3) the error between reference and actual output.

The mathematical model and detailed parameters design for the overall dc voltage control. Usually, the CMI should be considered as three single-phase inverters, therefore, the dc capacitor voltage will contain the 2ω (two times of the fundamental frequency) component. To keep the average dc track the command without being affected by the 2ω ripple, the bandwidth of current control loop and dc voltage control loop is designed to be differential. For example, the current control loop has been designed to have fast dynamic response (e.g., half cycle, 8 ms), while dc voltage control loop has been designed to have much slower dynamic response (e.g., ten cycles). In this way, the 2ω ripple can be suppressed in the voltage control loop.

Stage III: voltage and current generation for series and shunt CMI, respectively. For series CMI, output voltage could be directly generated from the reference *V*C* by FFM. While for shunt CMI, decoupling feedback current control is used to control output current to follow the reference current *I*P* , as shown in Fig. 5(c).

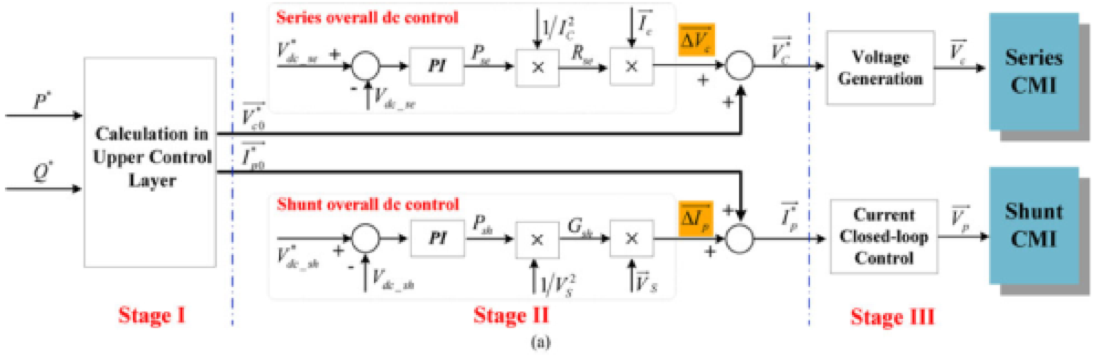

Figure 5: Control system for transformer less UPFC

(a) Overall control diagram for both power flow and dc capacitor voltage control, (b) detailed calculation from *P */Q** to *V*C* 0 and *I*p* 0 , and (c) current closed-loop control for shunt CMI.

FUZZY CONTROLLER INTRODUCTIUON

The main use of fuzzy control system is based on empirical rules is more effective. Fuzzy systems are easily upgraded by adding new rules or new features to improve performance. Fuzzy control can be used to improve existing traditional control systems by adding a layer of intelligence to the current control method. The fuzzy logic controller consists of Fuzzy Inference System Editor. The simulation of soft switching circuit is developed in this FIS editor. VCr and ICr are the inputs of the fuzzy controller. The output of the controller is crisp value. This Graphical User Interface consists of FIS Editor, Membership function Editor, Rule Editor, Rule Viewer and Surface Viewer.

A. FUZZY SET THEORY

(a) Definition of a fuzzy set: Assuming that X is a collection of objects, a fuzzy set A in X is defined to be a set of ordered pairs: $A = \{(X,\mu A(X))/X\epsilon X\}$ (1) Where $/\mu A$ (x) is called the membership function of x in *A*. The numerical interval *X* is called Universe of Discourse [5]. The membership function $\mu A(X)$ denotes the degree to which x belongs to *A* and is usually limited to values between 0 and 1.

(b) **Fuzzy set operation**: Fuzzy set operators are defined based on their corresponding membership functions. Operations like AND, OR, and NOT are some of the most important operators of the fuzzy sets. It is assumed that *A* and *B* are two fuzzy sets with membership. Functions $\mu A(x)$ *and* $\mu B(x)$ respectively. Then, the following operations can be defined.

(1) The AND operator or the intersection of two fuzzy sets: The membership function of the intersection of these two fuzzy sets ($C = A \cap B$), is defined by $\mu c\ (x) = \min\ \{\mu A\{x),\mu B\ (x)\},x\epsilon\ X$ (2)

(2) (2) The OR operator or the union of two fuzzy sets: The membership function of the union of these two fuzzy sets ($D = A \cup B$), is defined by

$\mu D(x)=\mathrm{Max}\{\mu A(x),\mu B(x)\},x\epsilon X$ (3)

(3) *The NOT operator or the complement of a fuzzy set* The membership function of the complement of A, *A'*, is defined by:

$$\mu A(x)=1-\mu A(x),x\epsilon\ X \quad \textbf{(4)}$$

4) Fuzzy relation: A fuzzy relation R from A to B can be considered as a fuzzy graph and characterized by membership function $\mu R(x,\ y)$, which satisfies the composition rule as follows: $\mu B(y)= \mathrm{Max}\ \{\min[\mu A(x),\mu B(x)]\}$ (5) $x\ \epsilon\ X$

B. Fuzzy Inference Diagram

The fuzzy inference diagram is the composite of all the smaller diagrams we’ve been looking at so far in this section. It simultaneously displays all parts of the fuzzy inference process we’ve examined. Information flows through the fuzzy inference diagram. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions [2]can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in the previous sections: membership functions, fuzzy logic operators, and if-then rules.

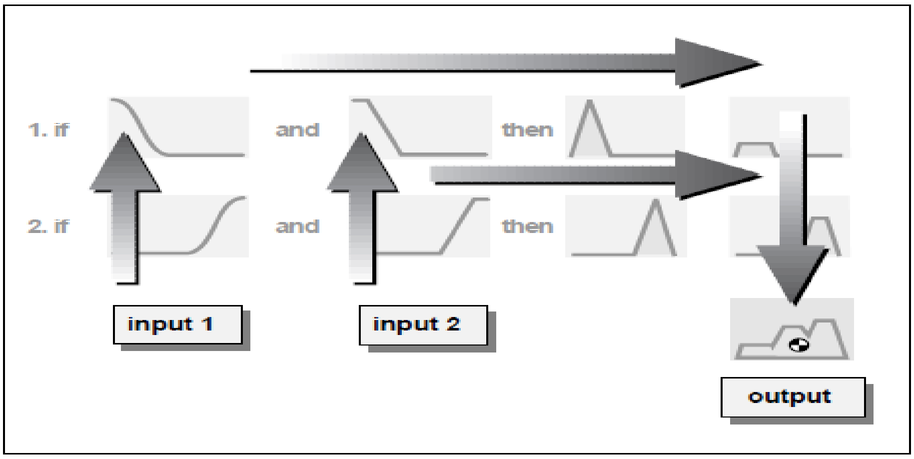

Figure 6: Fuzzy Inference Diagram

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory,fuzzy logic controllers, and simply (andambiguously) fuzzy systems.

A. Mamdani-Type Inference Method

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. Mamdani-type inference, as we have defined it for the Fuzzy Logic Toolbox, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It's possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a single ton [3]output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function. The flow proceeds up from the inputs in the lower left, then across each row, or rule, and then down the rule outputs to finish in the lower right. This is a very compact way of showing everything at once, from linguistic variable fuzzification all the way through defuzzification of the aggregate output.

Fuzzy logic controllers usually outperform other controllers in complex, nonlinear, or undefined [4]systems for which a good practical knowledge exists. Fuzzy logic controllers are based on fuzzy sets, i.e., classes of objects in which the transition from membership to non membership is smooth rather than abrupt. Therefore, boundaries of fuzzy sets can be vague and ambiguous, making them useful for approximation systems. The first step in the fuzzy controller synthesis procedure is to define the input and output variables of the fuzzy controller. This is done accordingly with the expected function of the controller. There are not any general rules to select those variables, although typically the variables chosen are the states of the controlled system, their errors, error variation, and=or error accumulation.[6]

Simulation circuit for PI Controller as Shown in the Fig.7.

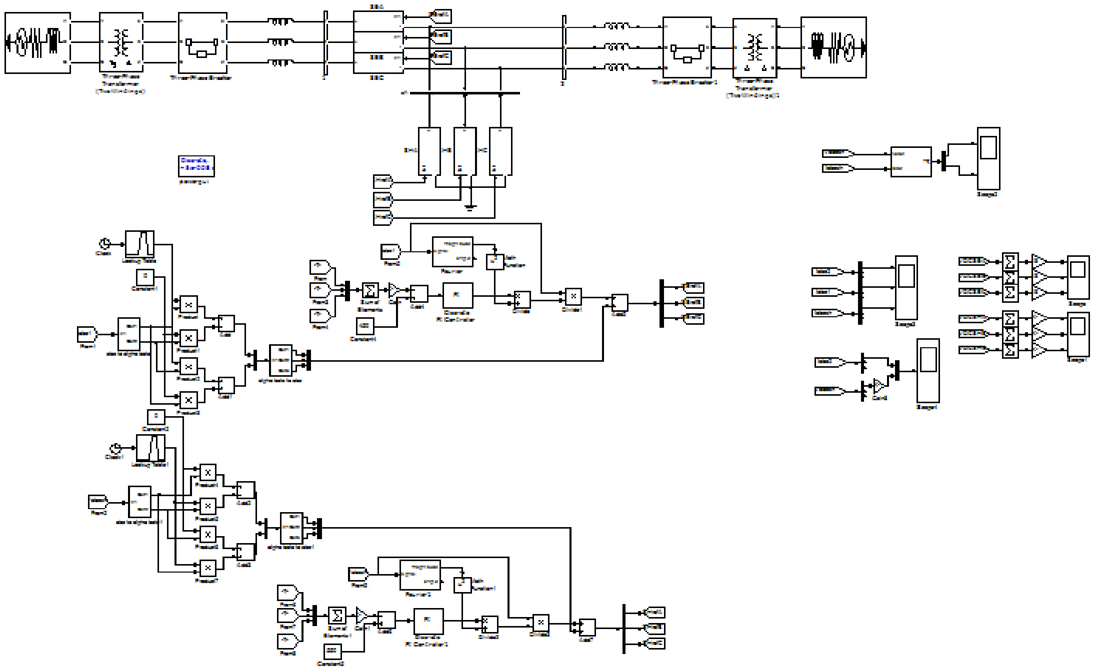

Fig. 7 : UPFC with PI Controller

The simulation circuit diagram for Fuzzy Controller as Shown in the Fig.8.

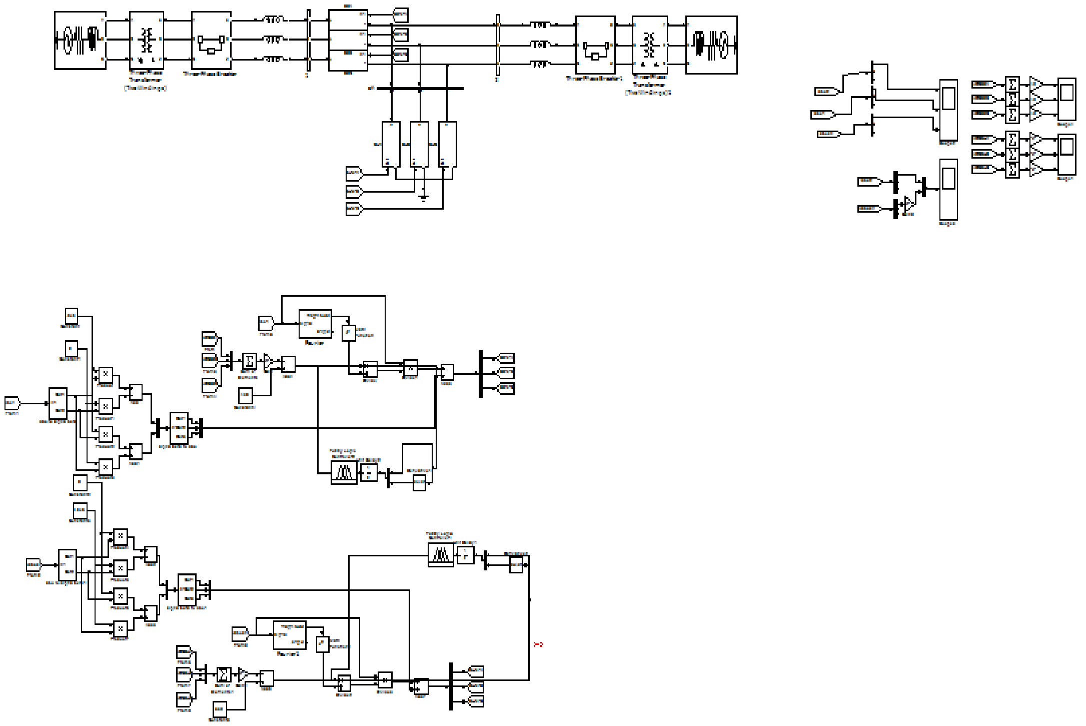

Figure 8: UPFC with Fuzzy Controller

SIMULATION RESULTS

The simulation circuits are simulated for the following test conditions and the results are observer as following:

Test- I: The Simulation circuit result for PI controller with source current is as shown in the Fig.9.

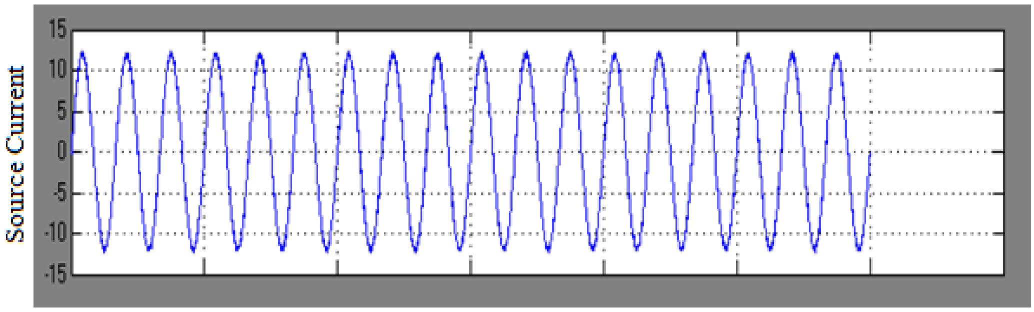

Figure 9: Output waveform of Source current for PI controller.

Test-II: The simulation circuit diagram for PI Controller with Load Current is as shown in the figure.10.

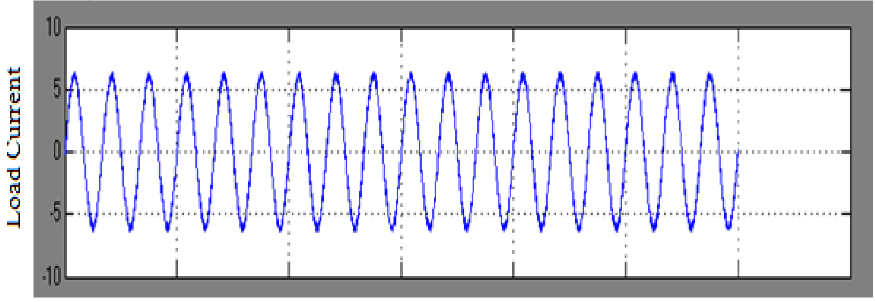

Figure 10: Output waveform of Load current For PI Controller.

Test-III: Result for Compensation current for PI Controller as Shown in the figure .11.

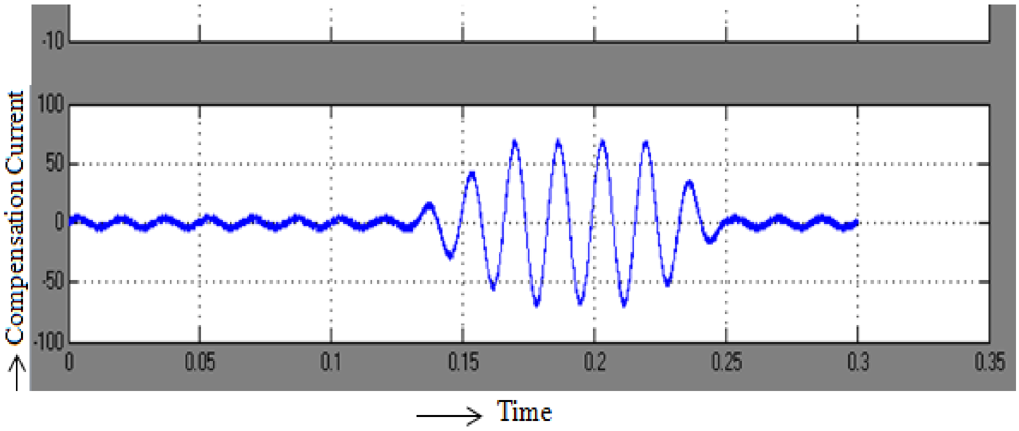

Figure 11: Output waveform of Compensation Current for PI Controller.

Test-IV: Simulation Result for Real Power of PI Controller as shown in The Fig.12

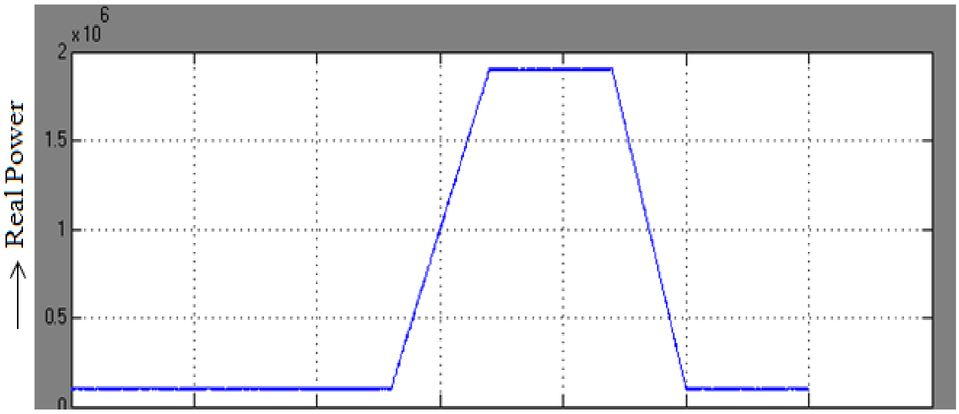

Figure 12: Output waveform of real power for PI Controller

Test-V: Simulation Result for Reactive Power of PI Controller as shown in The Fig.13

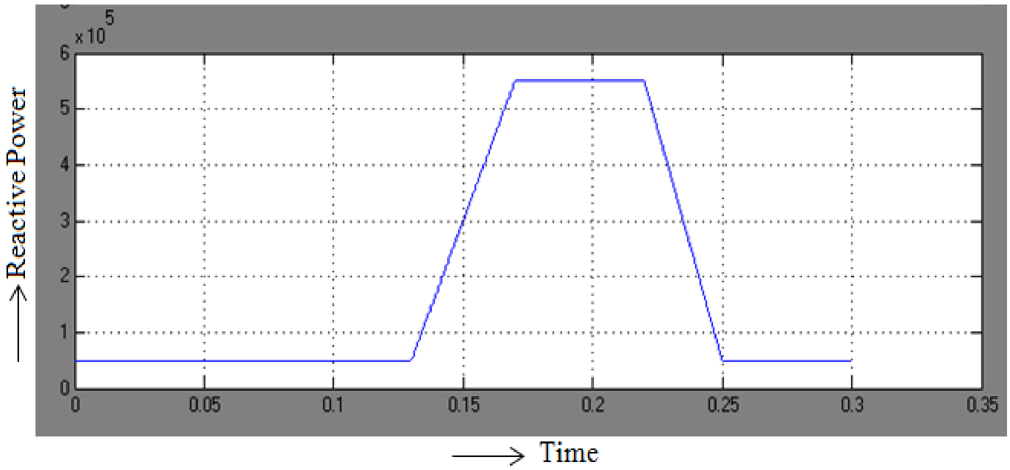

Figure 13: Outputwaveform of Reactive power for PI Controller

HARMONIC ANALYSIS

To observe the power quality improvement of the obtain voltage and Current levels, Harmonic analysis is conducted by using Powergui FFT analysis. Then the THD calculation results are observed as follows. By using Fuzzy Controller Technique Then The percentage of THD is decreasing.

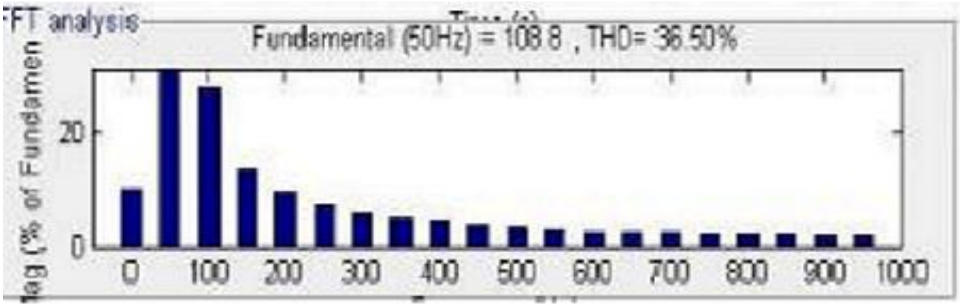

Figure 14: FFT Window of Output Voltage For PI controller Technique.

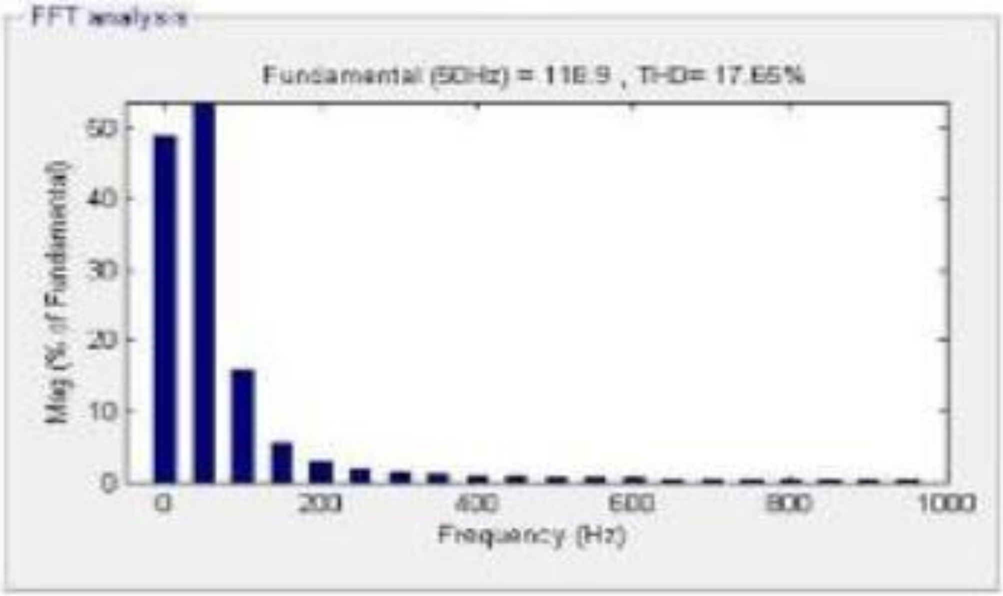

Figure 15: FFT Window of Output Voltage For PI controller after apply Fuzzy controller.

CONCLUSIONS

Fuzzy Logic based UPFC is mainly used For Power flow Control. Proposed for inter connection between two loads. One is series other one is Shunt Type UPFC. These two are connected in between Sending and Receiving end Side of the Transmission line. Active power as well as reactive power can be independently controlled by the new transformer-less UPFC. For different power flow control solutions have been investigated. In this there are mainly two Control techniques can be applied that is PI Controller and Fuzzy Logic controller when compared to PI Controller Technique Fuzzy Logic Controller is best to reduce The Harmonics and ripple contents in the Voltage and current waveforms. These converters can be used in high power and high/medium voltage applications.

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