Comparison and Simulation of Open Loop System and Closed Loop System Based UPFC used for Power Quality Improvement

S.Muthukrishnan, A.Nirmalkumar

Abstract*—This paper deals with digital simulation of power system using open loop system and closed loop based UPFC to improve the power quality. The UPFC is capable of improving transient stability in a power system. It is the most complex power electronic system for controlling the power flow in an electrical power system. The real and reactive powers can be easily controlled in a power system with a UPFC. The circuit model is developed for UPFC using rectifier and inverter circuits with the help of IGBT and MOSFET. The control angle of the converters is varied to vary the real and reactive powers at the receiving end. The Matlab simulation results are presented to validate the model. The experimental results are compared with the simulation results.

***Index Terms*— UPFC, Power Quality, Statcom, Compensation and matlab simulink**

I. INTRODUCTION

The power-transfer capability of long transmission lines are usually limited by large signals ability. Economic factors, such as the high cost of long lines and revenue from the delivery of additional power, give strong incentives to explore all economically and technically feasible means of raising the stability limit. On the other hand, the development of effective ways to use transmission systems at their maximum thermal capability has caught much research attention in recent years. Fast progression in the field of power electronics has already started to influence the power industry. This is one direct outcome of the concept of flexible ac transmission systems (FACTS) aspects, which has become feasible due to the improvement realized in power-electronic devices. In principle, the FACTS devices could provide fast control of active and reactive power through a transmission line. The unified power-flow controller (UPFC) is a member of the FACTS family with very attractive features. This device can independently control many parameter, since it has the combined properties of a static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) [1].

These devices offer an alternative mean to mitigate power system oscillations. Thus, an important question is the selection of the input signals and the adopted control strategy for these devices in order to damp power oscillations in an effective and robust manner. Much research in this domain has been realized [2]-[4]. This research shows that UPFC is an effective device for this purpose.

The UPFC parameters can be controlled in order to achieve the maximal desired effect in solving first swing stability problem. This problem appears for bulky power systems with long transmission lines.

Various methods to reference identification of the series part, in order to improve the transient stability of the system based on: “optimal parameters”[2], “state variables”[3], and also “injection model” were studied. The real and reactive power of the transmission line can be controlled with help of UPFC [13].

This paper is organized as follows. After this introduction, the principle and operation and of a UPFC connected to a network are presented. In section II, the control strategy for UPFC is introduced. Equivalent circuit of the UPFC system and their simulation are presented in Section III. The open loop and closed loop systems of the UPFC are simulated and their results are presented in Section IV. Hardware setups are described in Section V. section VI describes the conclusion.

II. UPFC SYSTEM

A simplified scheme of a UPFC connected to an infinite bus via a transmission line is shown in Fig.1.

UPFC consists of a parallel and series branches, each one containing a transformer, power-electric converter with turn-off capable semiconductor devices and DC circuit. Inverter 2 is connected in series with the transmission line by series transformer. The real and reactive power in the transmission line can be quickly regulated by changing the magnitude (V_b) and phase angle (δ_b) of the injected voltage produced by inverter 2. The basic function of inverter 1 is to supply the real power demanded by inverter 2 through the common DC link. Inverter 1 can also generate or absorb controllable power [5],[6].New method for improving transient stability is given in [7]. The modeling, interface, control strategy and case study of the UPFC in interconnected power system is described in [8].Enhancing transient stability using Fuzzy control is also discussed in [9].

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S.Muthukrishnan, Dept of EEE, Anna university/ Sri Eshwar College of Engg. Coimbatore, India, 9976079535 (e-mail: samkumar04@yahoo.co.in).

Dr.A,**Nirmalkumar** Dept of EEE, Anna university / Info College of Engg. Coimbatore, India (e-mail: ankhod@gmail.com).

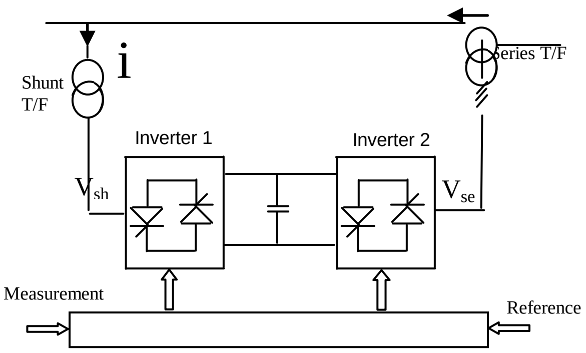

Fig1. UPFC Installed in Transmission Line

The above literature does not deal with UPFC system employing closed loop system. Evaluation of shunt and series power conditioning strategies for feeding sensitive loads is given [11]. The author is unaware of the use of five level inverter for the application of UPFC. In the present work, closed loop system is proposed in the UPFC and the comparison is made and also employing IGBT and MOSFET are used as a switching devices for the inverter circuit to make examine of THD values.

III. SIMULATION RESULTS

Two bus system without compensation is shown in Fig 2.1. Sag is produced when an additional load is added. Voltage across loads 1 and 2 are shown in Fig 2.1(a).The real and reactive power waveforms are shown in figures 2.1(b)3 and 2.1(c) respectively. Equivalent circuit of UPFC is shown in Fig 2.2. In this equivalent model of unified power flow controller a voltage source is connected in series with the transmission line for representing series converter and a current source is connected in shunt for representing shunt converter. The series capacitive compensation works by increasing the voltage across the impedance of the given physical line which in turn increases the corresponding line current and the transmitted power.

The equations for determining the power is given by,

Active Power,

$$P = \frac{V^2}{X^2+R^2}[X\sin\delta - R(1-\cos\delta)]$$

Reactive Power,

$$Q = \frac{V^2}{X^2+R^2}[R\sin\delta + X(1-\cos\delta)]$$

Therefore from the above equations it is evident that by altering the value of line voltage, V, and Phase Angle, δ, the active power (P) and the reactive power (Q) can be controlled.

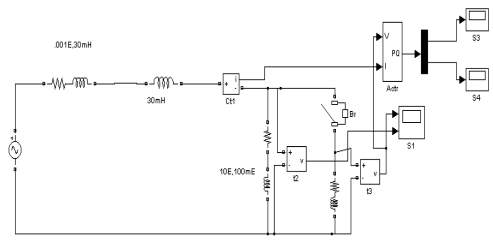

Fig 2.1 Line model with out compensation circuit

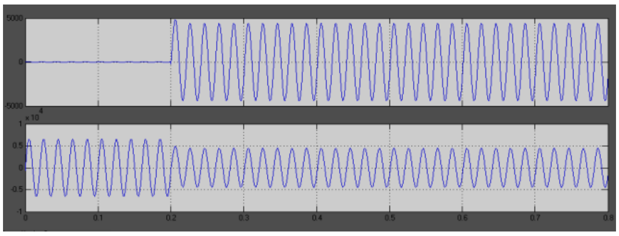

Fig 2.1(a) Voltage across Load 2 and Load 1

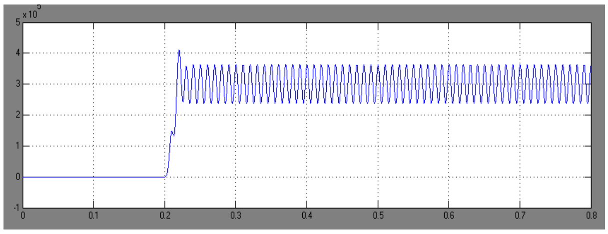

Fig 2.1(b) Real Power

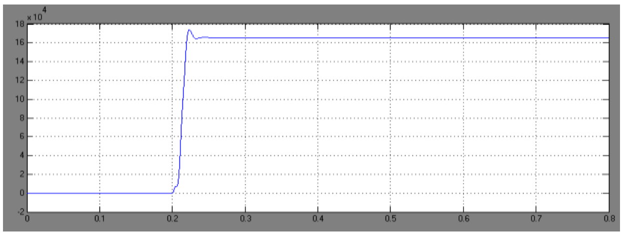

Fig 2.1(c) Reactive Power

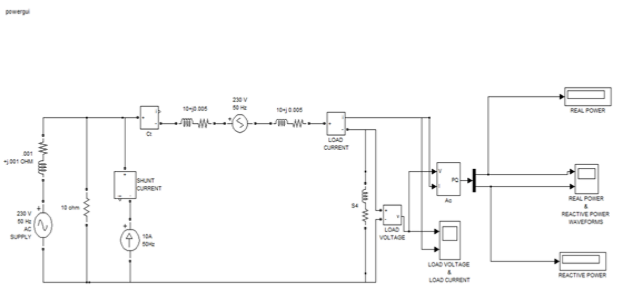

Fig 2.2 Equivalent Model of Unified Power Flow Controller

Fig 2.2a Load voltage and Load current at δ=0^0

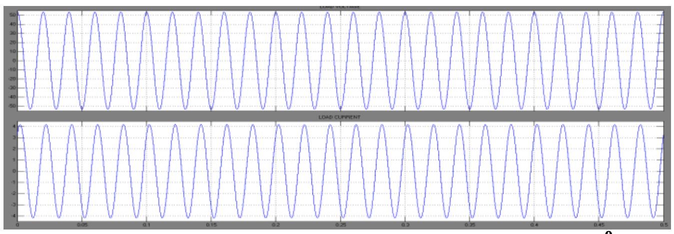

Fig 2.2b Load voltage and Load current at δ=180^0

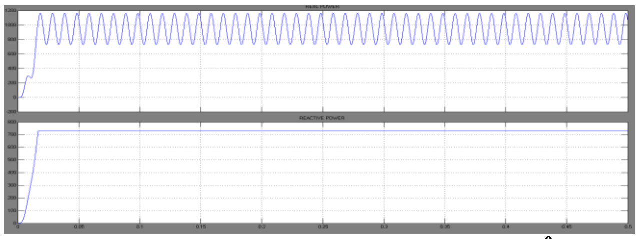

Fig 2.2c Real and Reactive power at δ=0^0

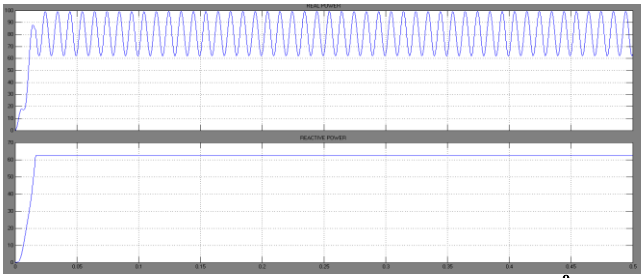

Fig 2.2d Real and Reactive power at $\delta=180^0$

Table 1.1 Variation of real and reactive power with change in phase angle of injected voltage (V_2)

S.No	Angle (δ) of injected Voltage (V_2) in degree	Active Power , P (Watts)	Reactive Power ,Q (VAR)
1	0	48.79	32.91
2	30	151.4	96.11
3	45	275.4	177.2
4	90	286.2	271.3
5	180	1572	1073
6	270	610.2	540.1
7	300	302.2	283.5

From the waveforms Fig (2.2a-2.2d) obtained through the simulation of the equivalent model of Unified power flow control and the tabulated results as shown in Table 1.1, it is evident that the real and reactive power of the power system can be controlled by controlling the phase angle of the series injected voltage.

IV. UPFC - OPEN LOOP SYSTEM

Two bus system with UPFC (open loop) is shown in Fig 3.1 UPFC is represented as a subsystem. The details of subsystem are shown in Fig 3.2 Voltage across loads 1 and 2 are shown in Fig 3.2a when the firing angle of the inverter is 0^0. Real and reactive powers are shown in Fig 3.2b. Load2 which is initially in OFF condition and it is switched on at t=0.3 sec. The shunt branch of UPFC is always in ON condition whereas the series branch of UPFC is switched ON at t=0.4 sec

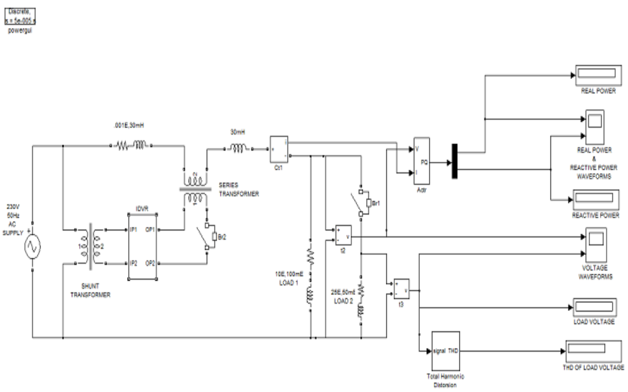

Fig 3.1 Power System with UPFC – Opel loop system

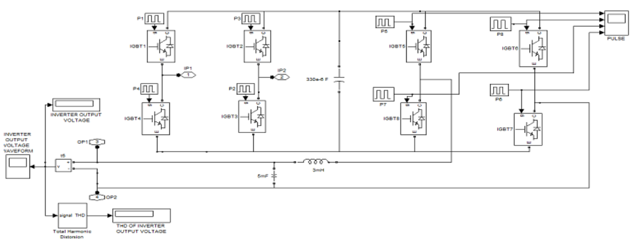

Fig 3.2 Converter – Inverter Circuit

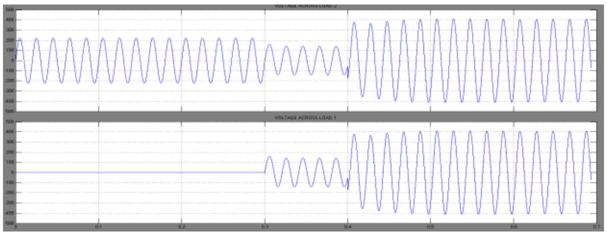

Fig 3.2a Voltage across load1 and load2

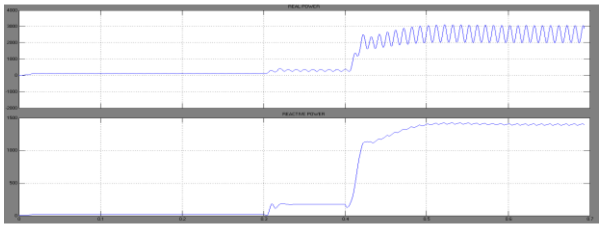

Fig 3.2b Real and reactive power

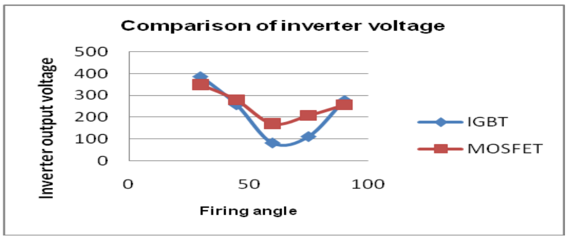

Fig 3.3 Comparion of inverter voltage

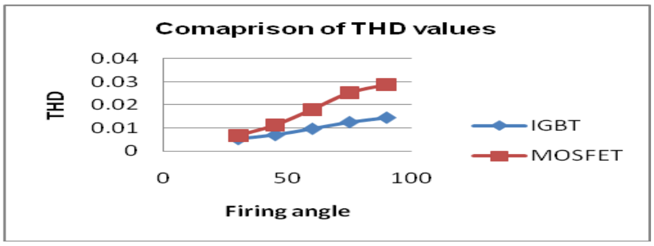

Fig 3.3a Comparison of THD values

From the figures 3.3 and 3.3a, it is evident that we can infer that the voltage THD values of the inverter output voltage is better when an IGBT is used instead of a MOSFET for the inverter circuit.

CONTROL ALGORITHM

The control algorithm is based on the active power filter reference current calculation method. Without UPFC shunt compensation, the line current, which is consisted of active and reactive components, is made up of the following terms: (neglecting the dc and harmonic components)

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$$
\begin{aligned}
i(t) &= i_p(t) + i_q(t) \\
&= I_p \sin(\omega t) + I_q \cos(\omega t)
\end{aligned} \tag{3}
$$

To regulate the voltage at bus connected to the shunt converter of the UPFC, the only component that this bus should supply is the active current component. Using eqn. (3), it can be noted that if the shunt converter of the UPFC supplies the reactive component, then the sending bus needs only to supply the active component. This can easily accomplished by subtracting the active current component from the measured line current.

$$i_q(t) = i(t) - I_P \sin(\omega t) \tag{4}$$

In eqn. (4), I_p is the magnitude of the in-phase current (to be estimated) and sin(ωt) is a sinusoidal in phase with the line voltage. The circuit shown in Fig. 3.3can accomplish this operation.

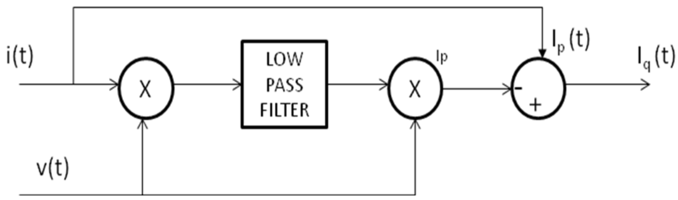

Fig 3.4 Open-loop system for calculating the UPFC shunt injected current

$$i(t).\sin(\omega t) = \frac{I_p}{2}[1 - \cos(2\omega t)] + \frac{I_q}{2}\sin(2\omega t) \tag{5}$$

V. UPFC - CLOSED LOOP SYSTEM

A series control algorithm is used for closed loop system based UPFC is shown in Fig 3.5.

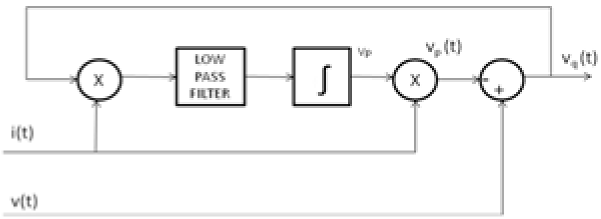

Fig 3.5 Closed-loop system for UPFC series injected voltage

Two bus system with UPFC (closed loop) is shown in Fig 3.6. UPFC is represented as a subsystem. The details of subsystem for converter – inverter is similar to open loop system and the control algorithm is shown in Fig 3.7

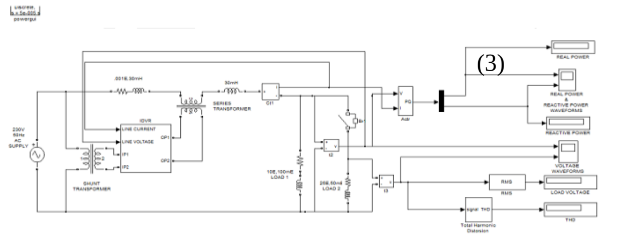

Fig 3.6 Power system with UPFC – closed loop system

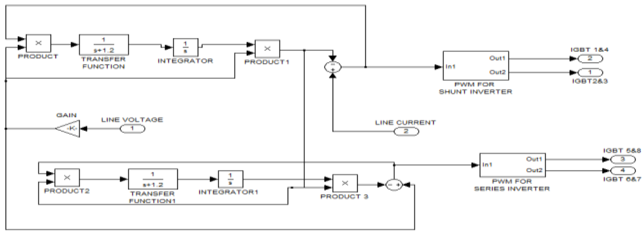

Fig 3.7 Control algorigthm for UPFC

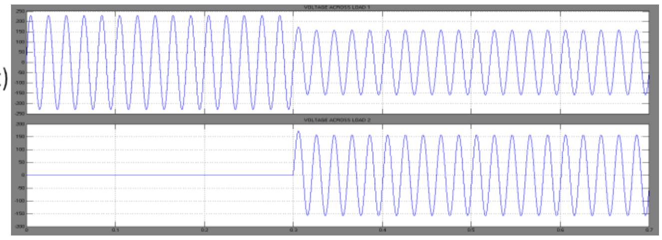

Fig 3.7a Volage across load 1 and load 2

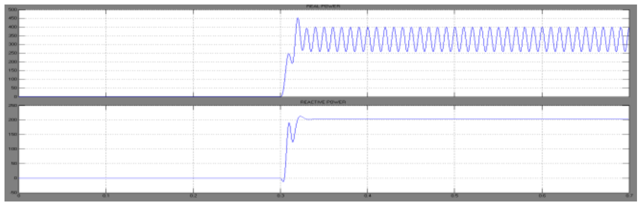

Fig 3.7b Real and reactive power

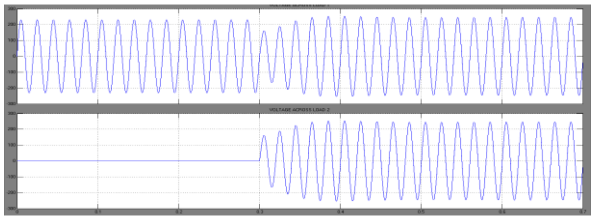

Fig 3.7c Volage across load 1 and load 2

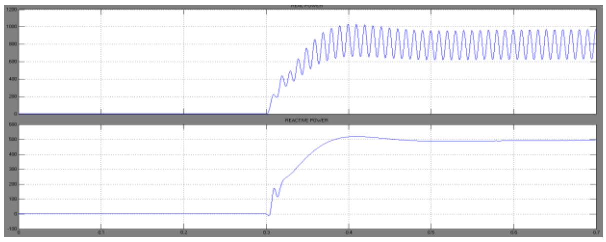

Fig 3.7d Real and reactive power

From the Fig. 3.2a we can observe that load1 is initially in ON condition, at time t=0.3 sec Load 2 is switched ON and at this instant the voltage drops across the load.

In Fig 3.7 (c) UPFC is connected and we can observe that as soon as the voltage drops UPFC comes into action automatically and the voltage drop is overcome by series voltage injection through the series inverter. Also the real and reactive power as shown in Fig 3.7 (d) is more, when UPFC is connected, than the Real and Reactive Power when UPFC is not connected as shown in Fig. 3.7 (b). Comparison of inverter output voltage and THD values are shown in figures 3.8 and 3.8a when we are employing IGBT and MOSFET in the inverter circuit.

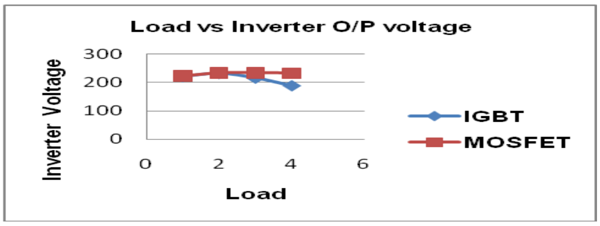

Fig 3.8 Comparison of inverter voltage

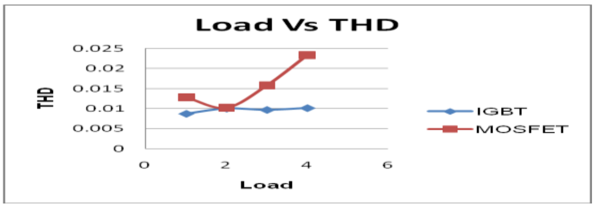

Fig 3.8a Comparison of THD

VI. HARDWARE SETUP

Laboratory model of UPFC was designed and fabricated. It is tested in the laboratory to obtain the experimental results. Experimental set ups are shown in figures 4.1, 4.1a & 4.1c. From the hardware setups, Fig 4.1c Shows the inverter output voltage to be injected in series when the firing angle is 0^0 when the IGBT is employing as switching devices. Driving pulses for the inverter circuit is shown in Fig 4.1d. Theortical and pratical values of the inverter volatges are compared are shown in figures 4.1e and 4.1f

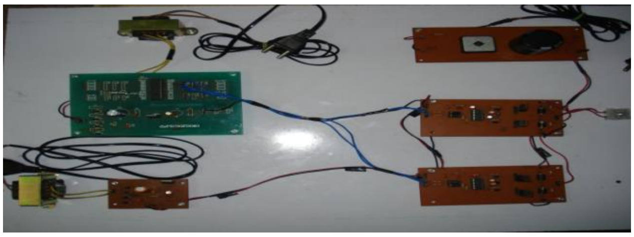

Fig 4.1 Converter Circuit

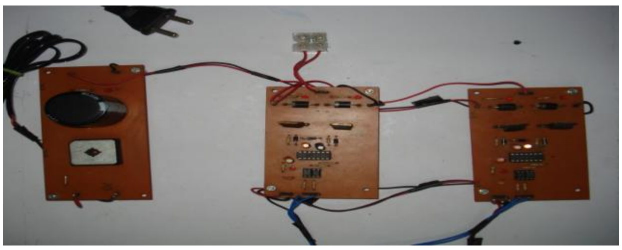

Fig 4.1a Inverter Circuit

Fig 4.1b Controller Circuit

Fig 4.1c Inverter output voltage

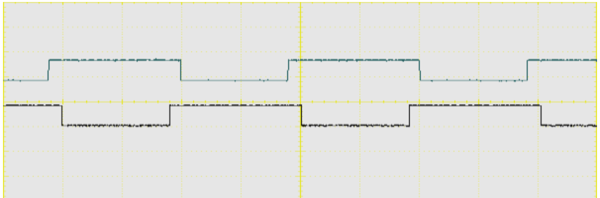

Fig 4.1d Driving pulse for inverter circuit

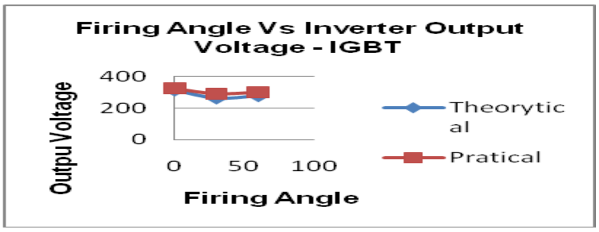

Fig 4.1e Comparison of Inverter output voltage – IGBT

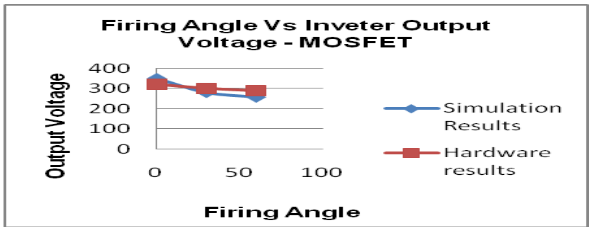

Fig.4.1f Comparison of Inveter output voltage - MOSFET

VII. CONCLUSION

In the simulation study, matlab simulink enviroment is used to simulate the model of open loop and closed based UPFC. This paper presents the control & performance of the UPFC used for power quality improvement. Simulation results show the effectiveness of UPFC to control the real and reactive powers. It is found that there is an improvement in the real and reactive powers through the transmission line when UPFC is introduced. From the voltage THD values that we have observed from simulation using IGBT and MOSFET as the switching device for the inverter circuit, it is clear that IGBT gives better results when compared to MOSFETs. From the hardware developed it is clear that when dsPIC is used for generating firing pulses,

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it gives better control when compared to other conventional controllers The UPFC system has the advantages like reduced hormonics and ability to control real and reactive powers. The heating in the transformer is reduced by using multilevel output. This is due to the reduction in the harmonics. The simulation results are inline with the predictions and hardwar results.

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AUTHORS PROFILE

S.Muthhukrishnan, has obtained his B.E. degree from Bharathiar University and M.Tech. degree from National Institute of Technology, Trichy in the years 1996 and 2004 respectively. He has 14 years of teaching experience. He is presently a research scholar in Anna University. His research area is power quality improvement using UPFC. His research area includes power quality and FACTS devices.

Dr. A. Nirmalkumar has obtained his B.E. degree from Calicut University and M.E. degree from Kerela University in the years 1972 and 1976 respectively. He has completed his Ph.D in the area of Power Electronics from Bharathiar University in the year 1989. He has secured a gold metal from Institution of Engineers in the year 1989. He has 30 years of teaching experience. He is presently working as professor and Head of EEE dept, Info Institute of Engineering , Coimbatores. His research area includes power quality and FACTS devices.