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Experimental Verification and Matlab Simulation of UPFC for Power Quality Improvement

Prof.Kishor Porate[1] , N Santhosh Kumar[2]
[1]*(HOD, Department of Electrical Engineering,Priyadarshini College of engineering/Nagpur university, India)*
[2]*(ME (by research) scholar, G.H.Raisoni College of Engineering/Nagpur university, India)*

Abstract :*This paper aims in presenting the importance of presence of Unified Power Flow Controller(UPFC) for enhancement of power quality of existing transmission network.UPFC is used for controlling varioustransmission parameters such as series impedance, shunt impedance, line voltage, current, active and reactive power, oscillation damping etc. Experimental controlled reading of UPFC is obtained with the help of lab model for various parameters.Controlling is done with the help of IGBT based converters through DSP kit(for controlling firing angle of converters).This paper also presents the study of UPFC using MATLAB 7.9 and lab prototype is also setup. Effect of presence of UPFC on various parameters is obtained and is compared with parameters without UPFC for real system through simulation using MATLAB 7.9.*
Keywords:*Upfc, Vsc, Sssc, Statcom.*

I. Introduction

With the increase in load demand, we have to increase the generation & require proper channel to transfer electrical power from generating end to receiving end which is highly efficient in nature (i.e transmission line). But when we try to add one or more number of generator to the existing transmission network then system suffers from large number of problems such as reduction in power , voltage dip, interruption , over voltage etc which can cause ill effect to the power system quality. It is necessary to maintain or enhance the quality of the network in order to get efficient power flow. Adding large number of generating to the existing transmission makes it more and more complex. Hence designing of such system is really a hectic job or we have to redesign the whole system by selecting the proper filter rating, power system stabilizer etc. We can use the traditional controller also for controlling power flow of this lines but frequent tuning is again a problem. Hence to overcome from above mention problem, we can use the fast acting power electronics controllers called FACTS devices. In late 1980's ,Electric power research institute introduce the new technology called Flexible AC Transmission Technology and the controller used for controlling power flow is known as FACTS devices. Deregulated environment is again one of the major cause of making line network more and more bulky. The AC system cannot be preferable for long transmission of power because of high transmission losses but by using this technology we can able to transfer the AC power for long distance.

Unified Power Flow Controller

Gyugyi proposed the Unified Power Flow Controller (UPFC) concept in 1991. The UPFC was devised for the real time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the 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 (i.e., voltage, impedance and phase angle), and this unique capability is signified by the adjective "unified" in its name. Alternatively, it can independently control both the real and reactive power flows in the line. The UPFC not only performs the functions of STATCOM, TCSC and phase angle regulator but also provides additional flexibility by combining some of the functions of these controllers.

The Unified Power Flow Controller (UPFC) consists of two voltage sourced converters using power switches, which operates from a common DC circuit of a DC-storage capacitor. This arrangement functions as an ideal ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of the two converters and each converter can independently generate (or absorb) reactive power at its own ac output terminal.

The UPFC (Fig.1) is a combination of an STATCOM and an SSSC, sharing a common dc link. The UPFC can control both the active and reactive power flow in the line. It can also independently provide controllable shunt reactive compensation. In other words, the UPFC can provide simultaneous control of all the basic transmission line parameters.

The UPFC is a two-port circuit (in series with a transmission line and parallel with a busbar); it uses forced commutation; its switching frequency is high; it has capacitive energy storage; and it employs a dc port.Fig.1shows the structure of UPFC

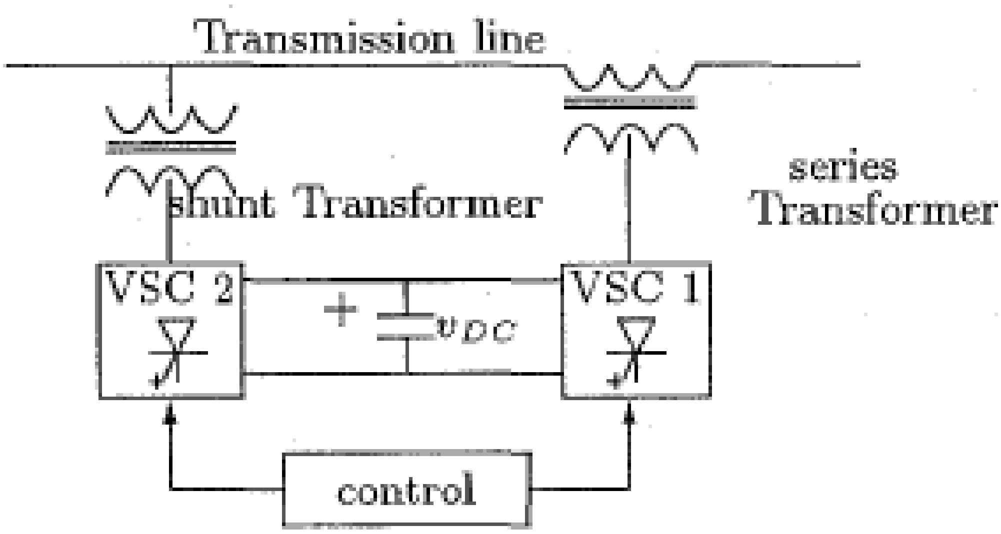


Fig.1. Structure of UPFC

Operation OfUpfc

Inverter 2 provides the main function of UPFC by injecting an ac voltage V_{pq} with controllable magnitude V_{pq} ($0 \leq V_{pq} \leq V_{pqmax}$) and phase angle ($0 \leq \dot{\rho} \leq 360$), at power frequency, in series with the line via an insertion transformer. The injected voltage is considered essentially as a synchronous voltage source. The transmission line current flows through this voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal (i.e at the terminal of insertion transformer) is converted by the inverter into dc power that appears at the dc link as positive or negative real power demanded. The reactive power exchanged at the ac terminal is generated internally by the inverter. Fig 2 shows UPFC as two port device.

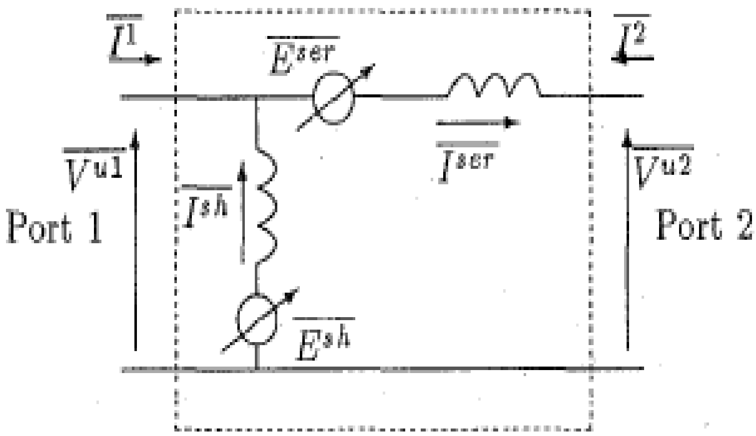


Fig.2 UPFC as 2-port Device

The basic function of Inverter 1 is to supply or absorb the real power demanded by Inverter 2 at the common dc link. This dc link power is converted back to ac and coupled to the transmission line via a shunt connected transformer. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and there by it can provide independent shunt reactive compensation for the line. It is important to note thatif there is a closed “direct” path for the real powernegotiated by the action of series voltage injection through Inverters 1 and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by inverter 2 and therefore it does not flow through the line. Thus, inverter 1 can be operated at unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by Inverter 2. This means there is no continuous reactive power flow through UPFC.

Lab Prototype

1. Lab Prototype Specification

Vsc Based Facts Controller Trainer

Model: Vfct-100

The main parts of experimental panel are:

1. Transmission line simulator module
2. Voltage Source Converter (VSC)
3. Transformer with LC Filter
4. Digital Meters and Load Setup

1**.**Transmission Line Simulator Module

- L=24mh/ph
- R=8 ohm/phase
- Input Voltage=3phase,110V
- Input Current=1A per phase
- Length=200km

Fig 3 shows transmitter line simulator module.

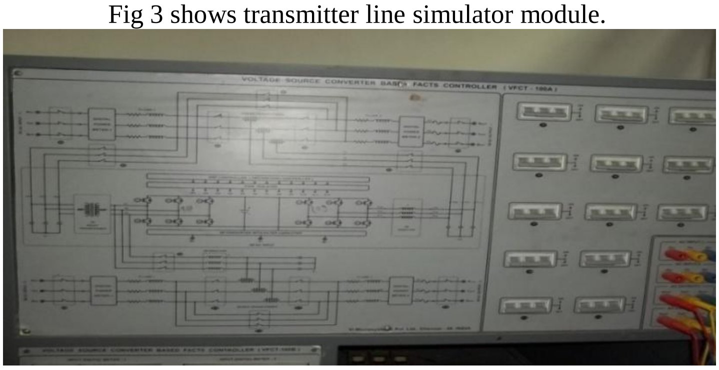


Fig.3 Transmission line simulator module

2. Voltage Source Converter (VSC)

It consists of two nos of IGBT base converter along with 1 no of DSP kit for controlling firing angle of signals. It consists of following:

1. IGBT based Power Module - 02 Nos
2. TMS320F2407 based DSP Controller - 01 No.

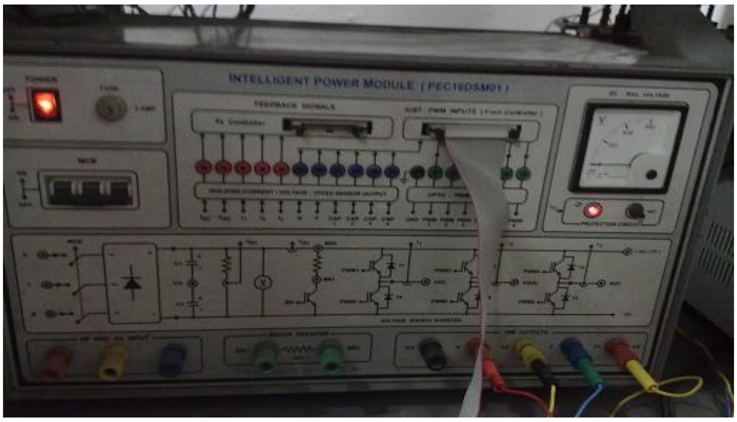


Fig.4 Intelligent Power Module

- 600V,20A 3phase IGBT based inverter bridge for both the VSC.
- 1200V,25A Uncontrolled rectifier with capacitor of 440 micro farad for both the VSC.
- Input Voltage: 1 Phase,230V.
- Outputs of IGBTs in DIPM terminated at banana sockets,
- Hall sensors provided to sense dc links voltage, dc link current & the DIPM output currents,6 high side and 6 low side high speed optos to isolate gating signals to DIPM.
- Independent onboard power supplies to all channels.

- Optically isolated fault output DIPM.
- Build in control power supply.
- Test point on the front panel to monitor/measure the voltage and current as well as control power supply.
- DC voltmeter to measure the dc link voltage.
- Protection for short circuit, over current, earth fault, over voltage, under voltage and over temperature provided.
- Output AC: variable frequency and voltage
- FRC connector provided to interfaceTMS320F2407A DSP trainer with DIPM.
- 1 no. of 1KVA auto transformer for VSC input voltage.

Here we are using two VSC's back to back operation via common dc link. The capacitor terminals of VSC 1 and 2 are available on left side of module. If we want to form the UPFC then we have to short these two VSC capacitor terminals.

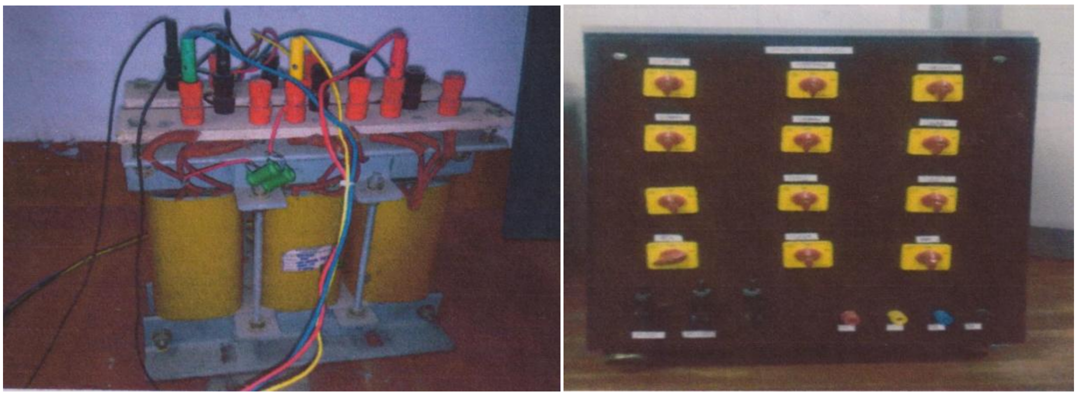
TMS320F2407A Based DSP Trainer(MICRO-2407A)

Fig. 5. DSP Trainer TMS320F2407

- In this DSP controller the program has been fixed. The PWM output are given to two VSC's. We can vary the pulse by using increment and decrement keys provide in that unit. We have separate pulses for each unit. The processor is running at 25ns instruction cycle time.
- Input:230V AC
- Output:5V/3.0A,12V/150Ma

3. TRANSFORMER WITH LC FILTERS

- 1 No. of 3 phase 1 KVA transformer act as shunt transformer with capacitor filter provided for STATCOM applications.
- 03 No. of 3 phase 1 KVA transformer act as series transformer with capacitor filter provided for SSSC applications.



(a) (b)

Fig.6(a) Digital Meters (b) 3 phase RLC Load

Block Diagram Of Prototype

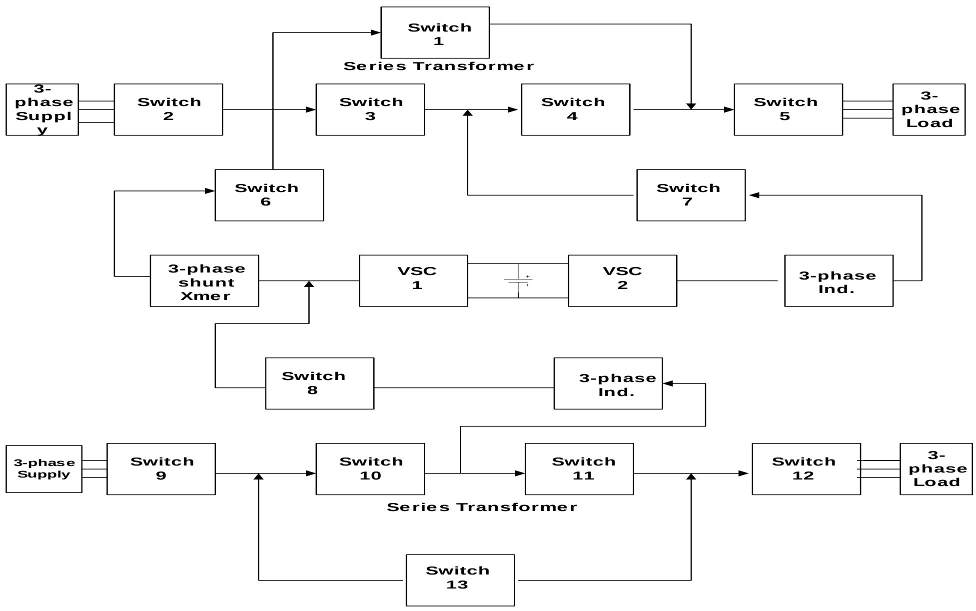


Fig.7 Block Diagram

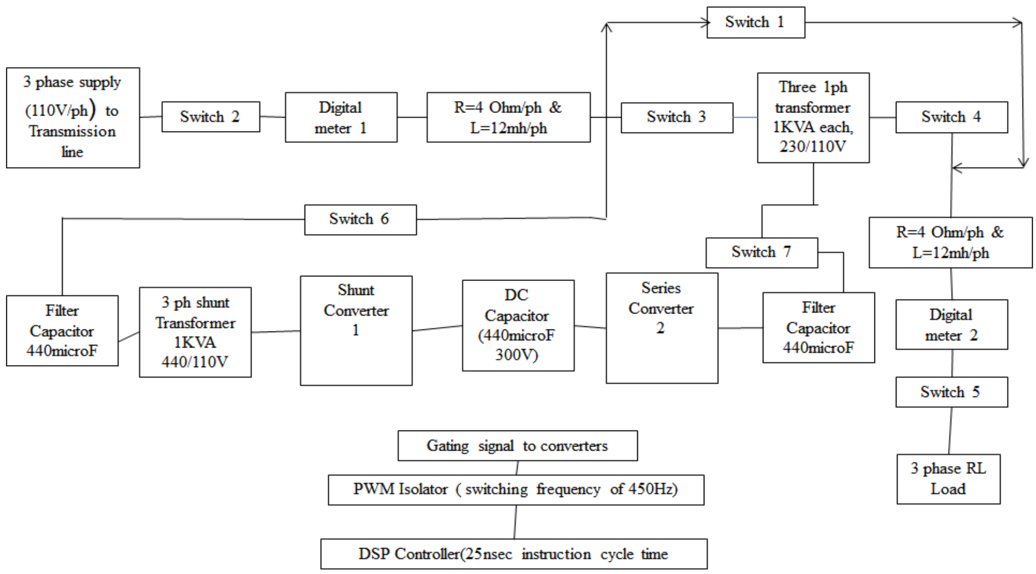


Fig.8 Block Diagram with Specification for UPFC

II. Working Of Prototype As Upfc

This panel consists of various elements such as voltage source converter, Transmission line, DSP kit, Shunt Transformer, Series Transformer, Switches, Filters etc. There are 13 switches as shown in above fig. 7 for forming different devices. As this paper is based on UPFC, hence form this converter for analyses. Switch on the three phase supply for auto transformer and single phase supply for VFCT 100.Now vary the auto transformer voltage gradually to 230V. After setting that, switch on MCB 2.The input digital meters shows the input voltages and currents(R,Y,B) resp. Add some load and switch on 3,4 . The input/output meters shows the sending end voltage (V_S), receiving end voltage (V_r) and currents. The receiving end voltage is lower than sending end voltage because of line losses.Reset and then switch on VSC 1 and 2 through 6 and 7 switches . Now switch on the DSP kit 2407 and vary the voltage to90% using increment and decrement key by putting toggle switch of DSP in voltage mode. Hence we can give the controlled output pulse to VSC. Same through DSP we can vary thetai.e the controlled phase angle between current and voltage waveform. Hence give modulated pulse. When we want to take readings for system without UPFC switch on supply, Switch 2,Switch 1,Switch 5 and load and take the reading for various parameter like sending & receiving end voltage, sending & receiving end current, dc voltage, firing angle etc. When want reading with UPFC Switch on S4, S5, S6& S7 and switch off S1 and take reading.

DSP is used as a controller and had been used to generate a PWM output for VSC. In actual power system of very high MVA rating PWM technique is not prevalent due to high switching losses. Fig 9 shows the PWM output of DSP.

Fig.9 PWM pulse from DSP

III. Prototype Result

3.1 UPFC

Sr no.	Vs	Vr	Line current	Theta 1 (SSSC)	Theta 2 (STATCOM)	Vdc
1	43	26	0.4	0	0	0
2	42	30	0.52	90LD	50LD	30.5
3	41	31	0.55	90LD	100LD	24.5
4	41	33	0.57	90LD	150LD	17.7
5	41	38	0.59	90LD	180LD	15.2
6	43	23	0.32	90LD	20LG	24.2
7	42	24	0.35	90LD	50LG	19.6
8	41	26	0.42	90LD	100LG	14.9
9	41	29	0.45	90LD	150LG	14
10	41	31	0.59	90LD	180LG	13.2
11	43	18	0.3	90LG	20LG	20.9
12	43	23	0.4	90LG	100LG	17.3
13	42	26	0.52	90LG	150LG	11.4
14	42	27	0.55	90LG	180LG	7.8
15	43	25	0.3	90LG	50LD	26.5
16	43	27	0.42	90LG	100LD	17.5
17	43	27	0.45	90LG	150LD	09.4
18	42	27	0.6	20LG	90LD	13.6
19	43	28	0.52	100LG	90LD	23.2
20	43	29	0.57	150LG	90LD	23.6
21	43	29	0.58	180LG	90LD	24.3
22	42	30	0.4	21LD	90LD	23
23	43	32	0.52	50LD	90LD	27.6
24	44	34	0.57	100LD	90LD	30
25	42	23	0.55	20LD	90LG	10.8
26	42	25	0.59	50LD	90LG	15.2
27	43	26	0.43	100LD	90LG	17.5
28	42	23	0.5	20LG	90LG	108
29	43	22	0.4	100LG	90LG	13.8
30	43	21	0.3	180LG	90LG	22.5

Table 1. Reading for UPFC

Here UPFC is connected at the mid point of transmission line in lab prototype and after performing, observe above mention readings for various parameter of UPFC. When UPFC is not connected, there we have low receiving end voltage and current but as UPFC is connected we found there is increase in receiving end voltage. Now fire SSSC at constant firing angle and fire STATCOM at variable angle and find its effect on other parameter. Again in same manner, make constant to firing angle of STATCOM and vary firing angle of SSSC and process for the same. By observing above result we can say that when we fire SSSC at 90LD and STATCOM at 180LD we are getting best performance value i.e most efficient reading (when receiving end voltage is close to sending end).

(a) (b)

Fig.10 Waveform Observed (a) Without UPFC (b) With UPFC At Sending End For Injected Voltage And Current

IV. Simulation And Results

1. UPFC Prototype With Lab Specification

In this, we can make UPFC model with same specification as on prototype and it gives same results as output of both converters are 600V, dc voltage is 300V, AC current is 20A which is proved through simulation as follows:

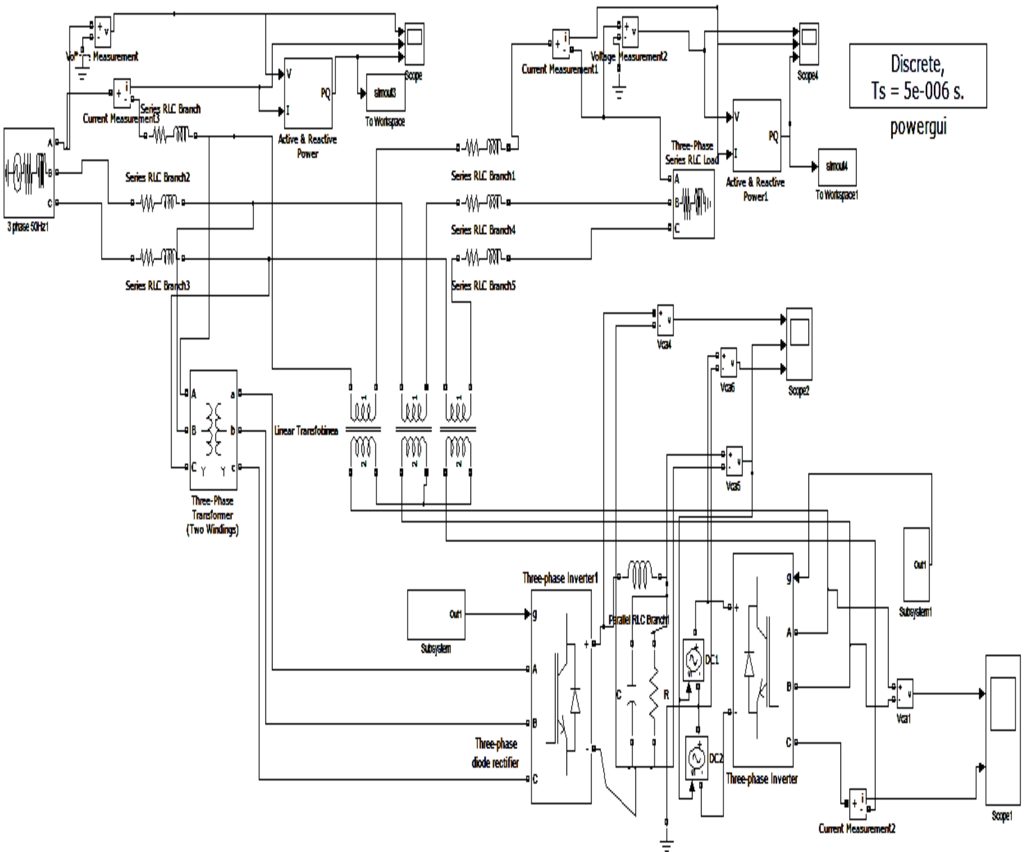


Fig.11.Prototype System

Here we make same transmission system as on prototype and then UPFC model is connected & is run for best performance result.

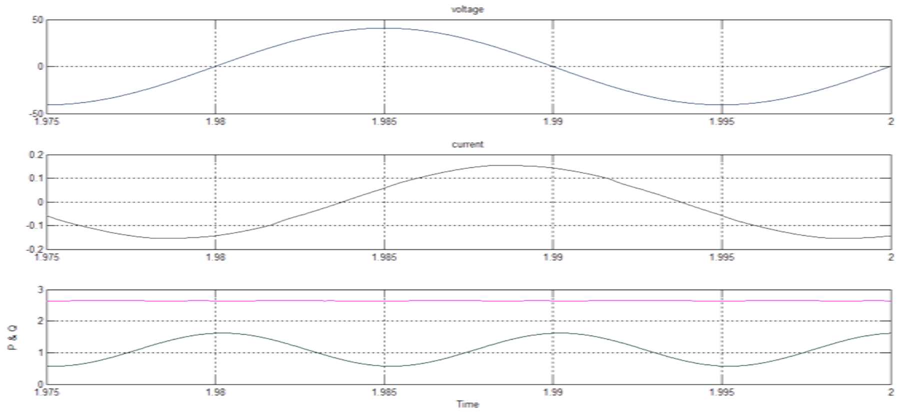


Fig. 12 Sending End Parameters

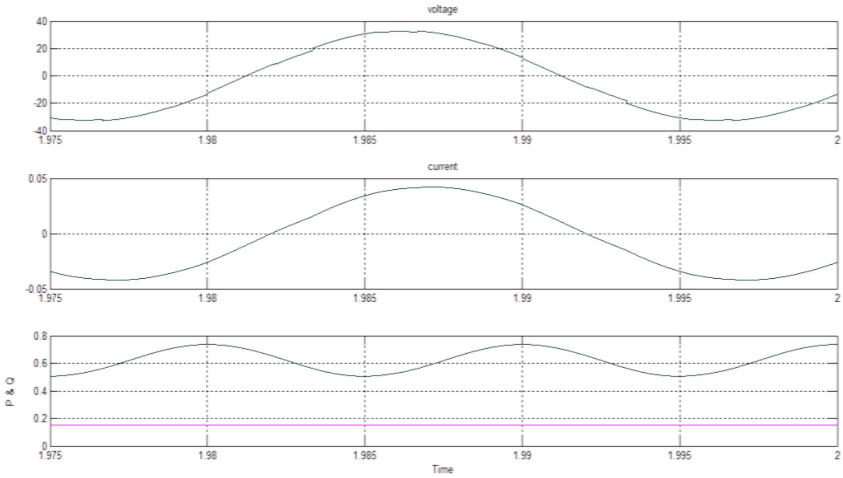


Fig.13. Receiving End Parameters

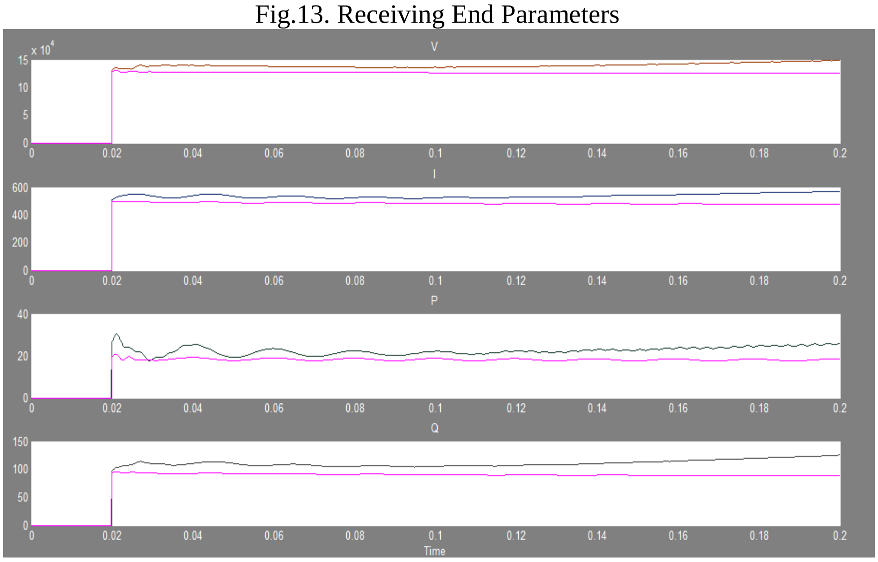


Fig.14 Comparison of result with UPFC And Without UPFC

V. Results And Discussion

The main aim of this paper is to study UPFC theoretically & practically with the help of lab prototype & MATLAB 7.9 software. With the help of prototype model we can analyze the circuit operation of the controller. Here we can take two cases (a) operation without UPFC (b) Operation with UPFC.

Sr no.	Vs	Vr	Line current	Theta 1 (SSSC)	Theta 2 (STATCOM)	Vdc
1	43	26	0.4	0	0	0
2	42	30	0.52	90LD	50LD	30.5
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28	42	23	0.5	20LG	90LG	108
29	43	22	0.4	100LG	90LG	13.8
30	43	21	0.3	180LG	90LG	22.5

Table 2. Observation reading for UPFC

V. Conclusion

In the presence of UPFC, there is better power transfer for the existing system. This paper presents the hardware (prototype) through which circuit operation of device is understood. When we connect UPFC in the system, it increases the receiving end voltage concluding that it gives efficient operation with low transmission losses by controlling firing angle of IGBT based converter through DSP kit.

Same network is formed with the help of MATLAB 7.9 software with lab specification & on firing the converters with same angle that was considered for prototype, it shows that the same receiving end result as that of hardware and hence proving the software work is authenticated.

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