VOLTAGE STABILITY IMPROVEMENT IN TRANSMISSION SYSTEMS USING DPFC

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ABSTRACT*:*

This project "Utilize Distributed Power Flow Controller (DPFC) to Compensate Unbalanced 3-phase Currents in Transmissions Systems" is composed of a Distributed Power Flow Controller is a new device within the family of FACTS. The DPFC has the same control capability as the UPFC, but with much lower cost and higher reliability. This project addresses one of the applications of the DPFC namely compensation of unbalanced currents in transmission systems. Since the series converters of the DPFC are single phase, the DPFC can compensate both active and reactive, zero and negative sequence unbalanced currents. To compensate the unbalance, two additional current controllers are supplemented to control the zero and negative sequence current respectively. The circuit will be simulated using MATLAB Simu-link. The circuit is implemented using embedded controller. Both Simulation results will be compared.

Keyword: 'Distributed Power Flow Controller (DPFC)', Basic Two Bus Radial System (BTBRS), Ten Bus Radial System (TBRS), Flexible AC transmission system(FACTS) Fuzzy Logic Controller, Proportional-Resonant Controller(PRC).

I. INTRODUCTION

THE voltage across the load decreases with the addition of extra load and the load voltage were restored back to normal value by using closed loop system. The ability of closed loop system to bring the voltage and reactive power back to the set value is represented in this thesis. The simulation studies for closed loop systems are also performed on a standard Basic Two Bus Radial System (BTBRS) and the results are presented. The results of comparative study are presented to show the improvement in dynamic response.

Distributed power flow controller (DPFC) can be used to improve receiving end voltage wherein case studies have been made on Ten Bus Radial System (TBRS) to regulate the receiving end voltage in TBRS. Modelling and tuning of TBRS with closed loop FL Controlled DPFC systems were carried out. Line impedance is obtained using the line parameters available in the hand book and investigation studies are performed. In a network unbalance in 'voltages and currents' are one of the major issues for both 'electric utilities' and 'end' users. Single-phase loads can 'cause extra losses' in the components in a network such as 'generators, motors' and transformers. The extra losses are 'created due to the unbalance' in voltages and currents. Unbalance can be partly compensated if the load side currents are corrected with the 'help' of 'active filters' and 'power factor' correctors, but they are 'focused on single load' there-by their 'contributions' to 'transmission systems' is not large. 'Unbalanced currents' and 'voltages' in 'transmission' systems are compensated by FACTS devices.

Series and 'shunt FACTS device' can only provide 'compensation' of 'unbalanced reactive currents' the most 'powerful device' – the U-P-F-C may partly provide unbalance compensation they cannot ‘compensate zero-sequence unbalance’ current, ‘because of the converter’ topology. UPFC can ‘enhance the power transfer capability’ and ‘utilized for power flow control’.

II.PRINCEPLE OF DPFC

The two converters get coupled through a ‘common DC link’ which is provided by a DC storage capacitor. The U-P-F-C is not ‘widely applied’ in ‘practice due’ to their ‘high cost’ and the ‘redundancy’ to failure. Since the ‘components’ of the ‘U-P-F-C handle’ the ‘voltages’ and ‘current’ with highrating, the total cost of the system is high. Due to the common ‘D-C link’ ‘interconnection’ a ‘failure’ that ‘happens’ at one ‘converter’ will ‘influence’ the ‘whole system’. ‘D-FACTS’ converters are ‘single-phase’ and ‘floating’ with ‘respect’ to the ‘ground’, there is no ‘high-voltage’ ‘isolation required’ b/w the ‘phases’.‘DPFC’ can compensate is active, reactive powers besides compensating ‘zero’ and ‘negative’ sequence ‘unbalanced’ currents.

In the ‘family’ of F-A-C-T-S devices recently ‘Distributed Power Flow Controller (DPFC)’ is usefull as a ‘powerful device’ at ‘lower cost’ and ‘higher reliability’ than the traditional FACTS devices. DPFC ‘derived from the UPFC’ has the capability of adjusting the ‘transmission line’ parameters simultaneously. Elimination of ‘D-C link b/w the shunt and series converters with the D-P-F-C is illustrated in the-flow-chart as portrayed in Fig. 1.1. Where STATCOM is used as shunt converter and multiple DVRs are used as series converters. Elimination of common DC line offers ‘greater flexibility’ to place the ‘series and shunt’ converters independently. The ‘concept’ of employing ‘multiple single-phase converters’ instead of ‘single’ threephase converter of large capacity reduces the ‘rating’ of the components besides providing high reliability due to redundancy. The ‘structure’ of a D-P-F-C in a ‘two-bus’ system is appeared in Fig. 1.2.

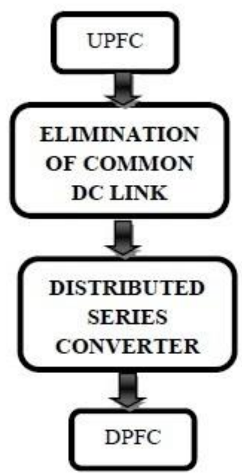

Fig 1.1 Flow chart for converting UPFC to DPFC

Independent control of “current” in each phase is possible in DPFC as the ‘series converters are single-phase’ which can result in both ‘negative and zero sequence compensation of unbalance’ in currents, monitoring of ‘negative and zero sequences currents’ from the transmission network and making them zero is possible with the addition of controllers ‘with the existing’ DPFC.

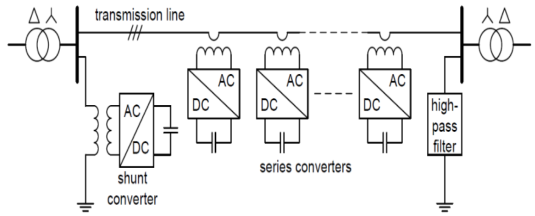

Fig 1.2 Structure of D-P-F-C

III.INTRODUCTION OF THE D-P-F-C

'Co-ordination of multiple' individual converters which compose the 'D-P-F-C is appeared in Fig.1.2. 'Series converters' in transmission lines 'inject' a 'controllable voltage at the fundamental frequency' thereby they subsequently 'control the power flow through the line'. Compensation of the reactive power, supplying 'active power required' by the 'series converter' is possible with the 'shunt converter' which is connected between the line and the ground. D-C link that connects the 'series converter' with the 'shunt converter' in a normal 'UPFC' provides the activepower exchanged by 'harmonics' and through the 'AC' network. The time average active power canbe expressed in term of mathematical equation, which is appeared in equation 2.1. Where the 'integrals' of all crossproduct of terms with different frequencies is zero.

$$P = \sum_{n=1}^{\infty} V_n I_n Cos\Phi_n \qquad \text{………………..(1)}$$

In equation 1 'n' represents the order of the 'harmonic' frequency, the angle between the 'current' and 'voltage' of the n^{th} harmonics is denoted by ϕ_n. Isolation of activepowers at different frequencies from eachother is made without the 'influence' of either 'voltage' or 'current' in one frequency component with the others. Since Y-Δ transformers easily filter third harmonics they are chosen for exchange of active power.

IV.CIRCUIT SCHEMATIC OF D-P-F-C

The circuit schematic of proposed D-P-F-C system is appeared in Figure 1.3. This system consists of single STATCOM that is provided at the sendingend and two DVRs to inject the 'voltage' in 'series' with the line. The DVRs are capable of injecting the voltage in 'phase' with system voltage to compensate line impedance drop. The voltage sag can be created by adding an extra load in 'parallel' with the existingload.

The proposed work deals with the 'closedloop' control of voltage using DPFC. The results of closedloop system with P-I, P-I-D and FLC are compared. DPFC is proposed for TBRS and TTBRS to improve the powerquality.

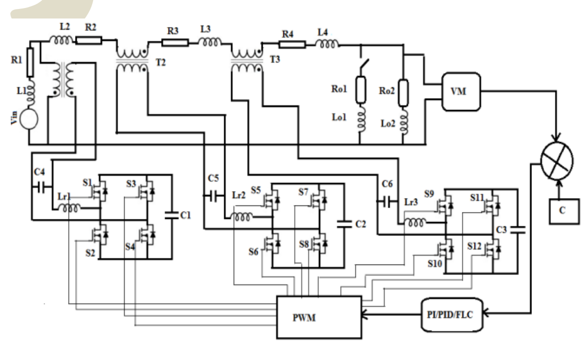

Fig 1.3 Circuit Schematic of DPFC

IV.CONTROL PRINCIPLE OF DPFC

The ‘DPFC’ system consistsof twotypes of converters, and each type of converter requires a different control scheme. The blockdiagram of the DPFC’ and its control is appeared in Fig.1.4 and the simple schematic diagram is depicted in Fig. 1.5.

To ‘supply’ activepower for series converters, the shunt converters is controlled for injection of a constant ‘third harmonic’ current. Extraction of some activepower from the ‘grid’ by the shuntconverter is necessary to ‘maintain its D-C voltage’. DC voltage is by means of ‘d’component of the ‘current’ at fundamental frequency, whereas the ‘*q’* component is used for compensation of reactive power. Generation of voltage using the ‘third harmonic’ frequency for ‘absorbing activepower’ to maintain a constant DC voltage value is ‘achieved’ by series control. Realization of the power flow control is possible by an outer controlloop and the ‘powerflow control block’. Through ‘wireless or P-L-C communication’ method, the powerflow block sends remotely the ‘reference signals’ and the ‘control signals’ for ‘D-P-F-C series’ converters. The function of eachcontrol block shown in Fig.2.5 can be described as:

- **Power flow control:**

Generating the voltagereference signals for series converter of the ‘DPFC’ is possible by means of powerflow control and the ‘control function’ is ‘dependent’ on the specifications of the ‘DPFC’ used for particular application.

- **Series converter control:**

Generation of switching signals ‘according’ to the received data with stabilized DC voltage is ‘achieved’ by using third ‘harmonic frequency components’ as each seriesconverter has its ‘own series’ control.

- **AC voltage control:**

For compensation of reactivepower at the fundamentalfrequency, AC voltage control fixes the set points to shunt converter and generates the ‘reference signals’ for the shuntconverter of the DPFC. DPFC application specifications determine the ‘control function’ of A-C voltage control and its control function provides the ‘reference signals' for reactivecurrent signal for the shuntconverter at the powersystem level for ‘low frequency’ power ‘oscillation damping’ and ‘balancing’ of ‘asymmetrical’ components.

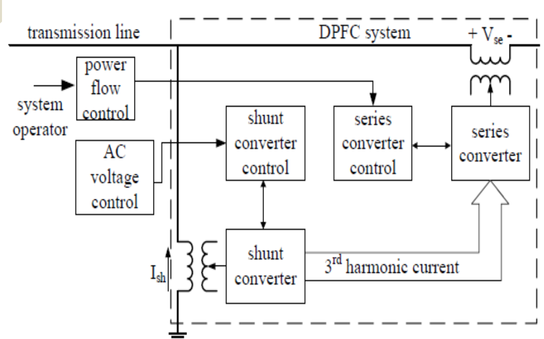

Fig 1.4 Block diagram representation of the control scheme of a DPFC

V. PROBLEM FORMULATION

Line data and Load data of TBS are specified. It is required to model and simulate TBS using the blocks of Simulink. The 'following equations' were used to 'calculate the real and reactive' powers.

$$P_{ik} = \frac{V_i V_k}{Z_{ik}} Sin(\partial_i - \partial_k) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$Q_{ik} = \frac{V_k}{Z_{ik}} (V_i - V_k) Cos(\partial_i - \partial_k) \ldots\ldots\ldots\ldots(3)$$

It is required to 'improve the voltage profile' of the buses. To 'improve' the voltage, DPFC is included in TBS.

A. Shunt converter control

Injection of third 'harmoniccurrent' constantly to supply the 'activepower' for the 'series converters' is done by shunt converter control. By stabilizing the D-C 'voltage' and injecting the reactivecurrent at the 'fundamental frequency', maintenance of 'capacitor D-C voltage' of the shuntconverter at a constant 'value' by absorption of activepower is achieved.

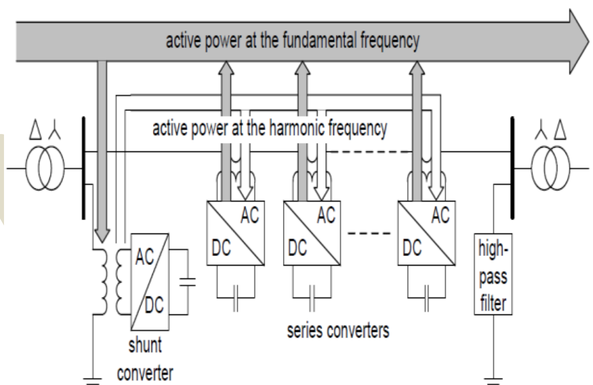

Fig 1.5 Simple circuit schematic of DPFC

Application of KVL to series converter primary is as appeared below

$$Vi = iR + L\frac{di}{dt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$V_o = IZ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The real and reactive powers are calculated by the following equations.

$$P = V_s V_R \frac{Sin\partial}{X} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$Q = V_R \frac{(V_S - V_R)}{X} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

This equation gives how reactive power and voltage balance is archived

$$I_R = \frac{V_S \cos\delta + jV_S \sin\delta - V_R}{jX} \qquad \ldots\ldots\ldots\ldots(8)$$

$$I_R^* = \frac{V_S \sin\delta}{X} + j\frac{(V_S \cos\delta - V_R)}{X} \qquad \ldots\ldots\ldots\ldots(9)$$

$$S^R = \frac{V_S R_S}{X}\sin\delta + j\frac{V_S V_R \cos\delta - V_R^2}{X}\ldots\ldots(10)$$

$$Q_R = \frac{V_R}{X}(V_S - V_R)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

Now by this we can say that if V_S is 'greater than' the V_R then the reactivepower flows from sending end to receiving end

Mathematical modeling for transformer

$$V_i = R_i + L\frac{di}{dt} + E_i\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

$$V_i - E_i - R_i = L\frac{di}{dt}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

$$\frac{di}{dt} = \frac{1}{L}(V_i - E_i - R_i)\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

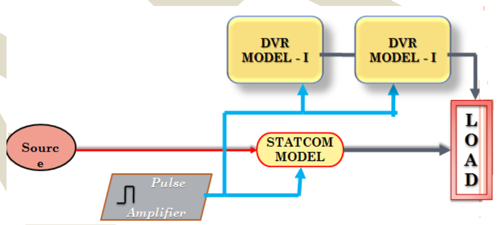

Fig 1.6 Simulation Block Diagram

The Simulation Block Diagram of statcom is load data are appeared in Fig 1.6. The Modified DPFC in 33 bus system is shown in Fig 1.7. On sensing the 'output voltage' and its comparison with the reference voltage, error signal is generated which is applied to a 'Fuzzy Logic Controller' (FLC) whose output is given to a pulse generator for updating the pulse width.

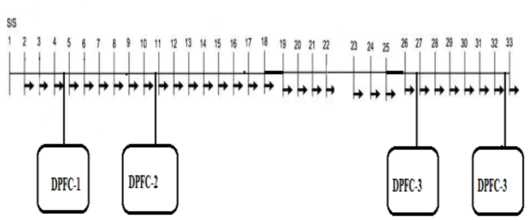

Fig 1.7 Modified DPFC in 33 bus system

VI. SIMULATION RESULTS

Transmission Systems Using without DPFC model 33-bus is appeared in Fig 2.1. Input generating voltage with DPFC is appeared in Fig 2.2 and its value is 6600V. Voltage at Bus -5 with DPFC is appeared in Fig 2.3 and its value is 5000V.

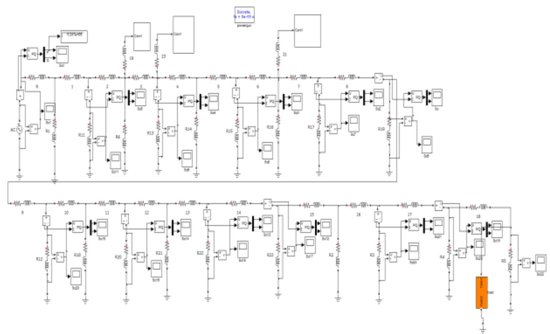

Fig 2.1 Without DPFC model 33-bus system

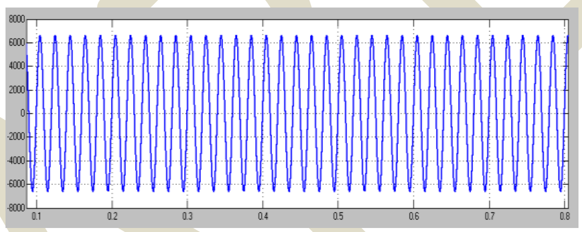

Fig 2.2 Input generating voltage

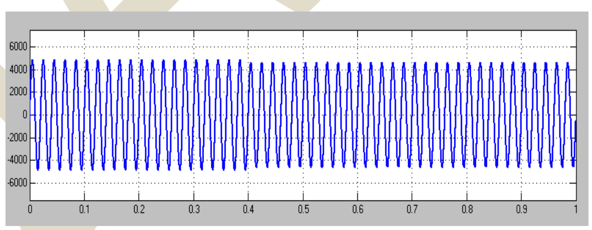

Fig 2.3 voltage at Bus -5 with DPFC

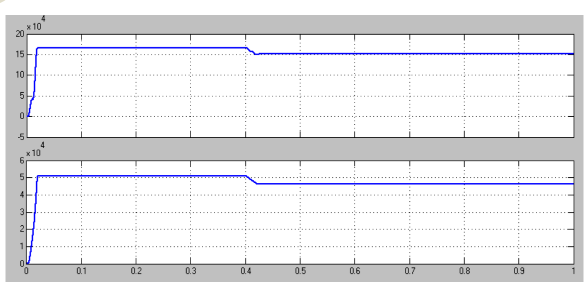

Fig 2.4 Real & reactive power at Bus-5 with DPFC

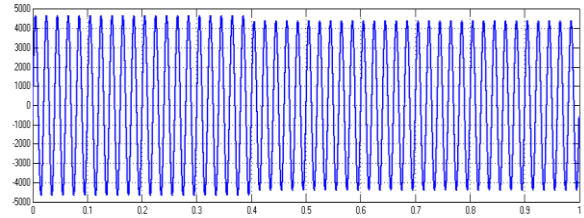

Fig 2.5 voltage at Bus-11 with DPFC

Real and reactive power at Bus-5 with DPFC are appeared in Fig 2.4 and its value is $15*10^4$ MVAR and $4.8*10^4$ MWatts. Voltage at Bus-11 with DPFC is appeared in Fig 2.5 and its value is 4500V. Real and reactive powers at Bus-11 with DPFC are appeared in Fig 2.6 and its value is $13*10^4$ MVAR and $3.9*10^4$ MWatts. Voltage at Bus-17 with DPFC is appeared in Fig 2.7 and its value is 4000V. Real and reactive powers at Bus-17 with DPFC are appeared in Fig 2.8 and its value is $10*10^4$ MVAR and $3*10^4$ MWatts.

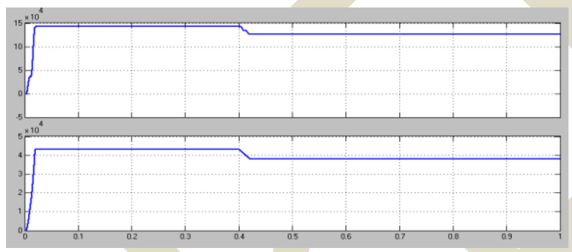

Fig 2.6 real & reactive power at Bus-11 with DPFC

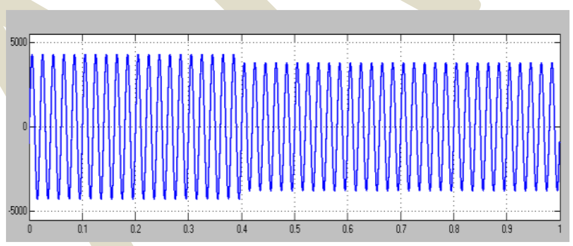

Fig 2.7 voltage at Bus-17 with DPFC

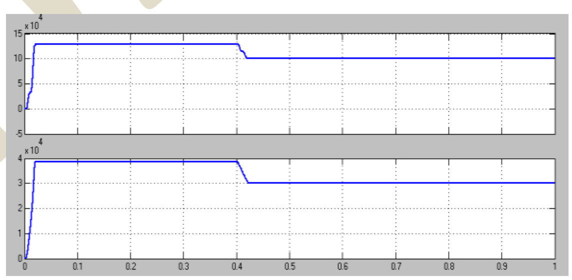

Fig 2.8 Real & reactive power at Bus-17 with DPFC

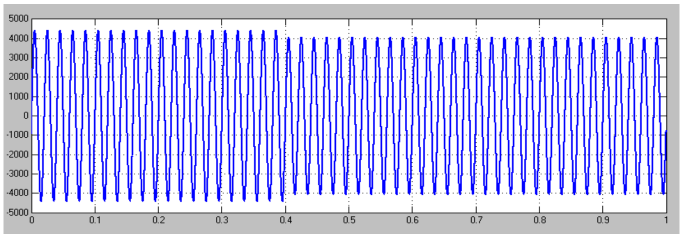

Fig 2.9 voltage at Bus-27 with DPFC

Voltage at Bus-27 with DPFC is appeared in Fig 2.8. The voltage at Bus-27 with DPFC is appeared in Fig 2.9 and its value is 4500V. Real & reactive power at Bus-27 with DPFC is appeared in Fig 2.10 and its value is $13*10^4$ MVAR and $3.9*10^4$ MWatts.

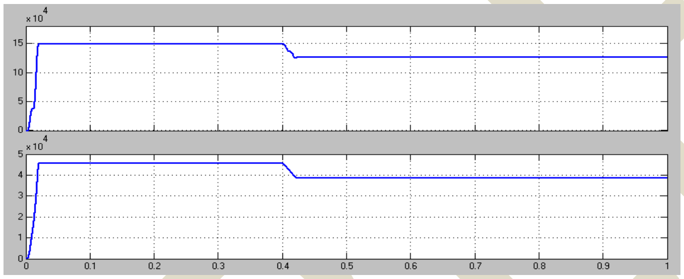

Fig 2.10 real & reactive power at Bus-27 with DPFC

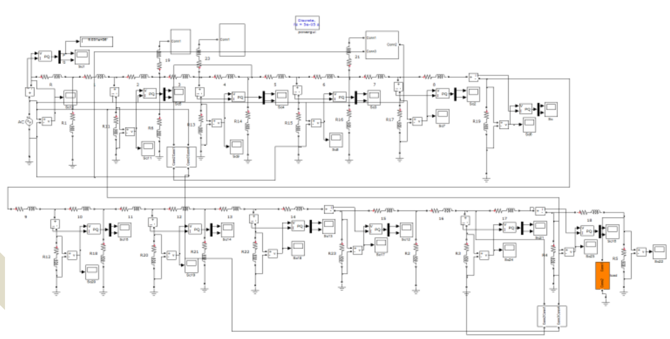

Fig 2.11 With DPFC model 33-bus system

Transmission Systems Using with DPFC model 33-bus is appeared in Fig 2.11. STATCOM Circuit diagram is appeared in Fig 2.12. Input generating voltage with DPFC is appeared in Fig 2.13 and its value is 6900V. Voltage at Bus -5 with DPFC is appeared in Fig 2.14 and its value is 5000V.

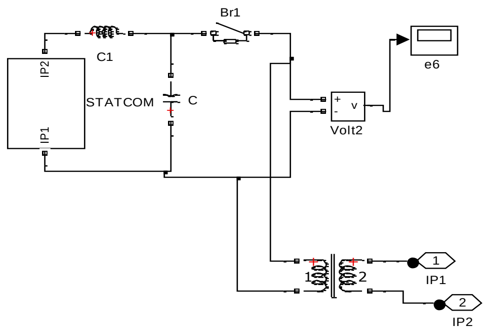

Fig 2.12 STATCOM Circuit diagram

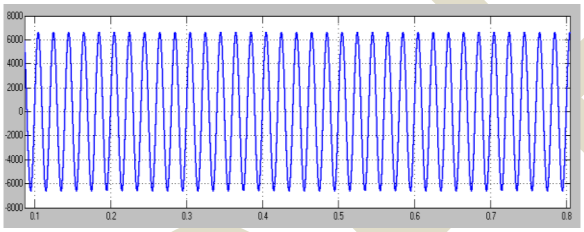

Fig 2.13 Input generating voltage with DPFC

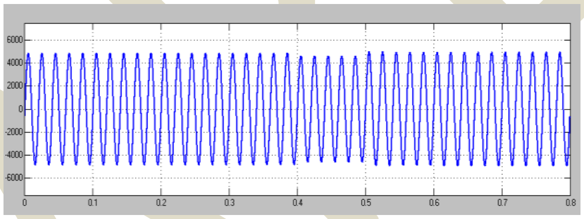

Fig 2.14 voltage at Bus -5 with DPFC

Real and reactive power at Bus-5 with DPFC are appeared in Fig 2.15 and its value is $17.5*10^4$ MVAR and $5.4*10^4$ MW. Voltage at Bus-11 with DPFC is appeared in Fig 2.16 and its value is 4500V. Real and reactive powers at Bus-11 with DPFC are appeared in Fig 2.17 and its value is $15*10^4$ MVAR and $4.5*10^4$ MW.

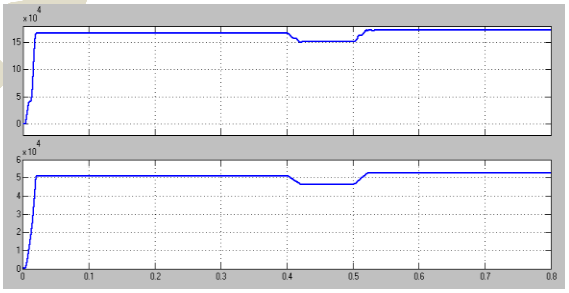

Fig 2.15 Real & reactive power at Bus 5 with DPFC

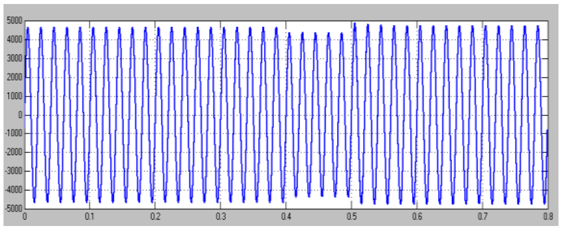

Fig 2.16 voltage at Bus-11 with DPFC

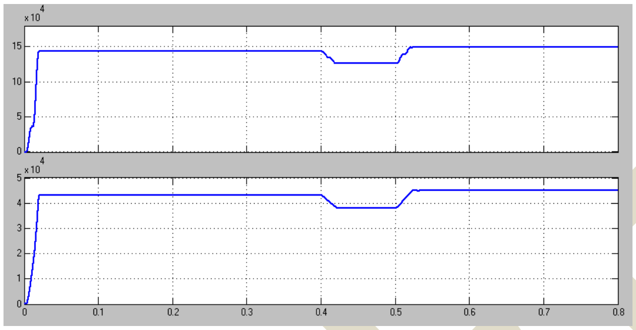

Fig 2.17 real & reactive power at Bus-11 with DPFC

DVR Circuit Diagram is appeared in Fig 2.18. Voltage at Bus-17 with DPFC is appeared in Fig 2.19 and its value is 4500V. Real and reactive powers at Bus-17 with DPFC are appeared in Fig 2.20 and its value is 14.5*10^4 MVAR and 4.05*10^4 MWatts. Voltage at Bus-27 with DPFC is appeared in Fig 2.21. The voltage at Bus-27 with DPFC is appeared in Fig 2.22. The voltage at Bus-33 is appeared in Fig 2.23. The real & reactive powers at Bus-33 with DPFC are appeared in Fig 2.24. Comparison of 33 Bus System is given in Table-1.

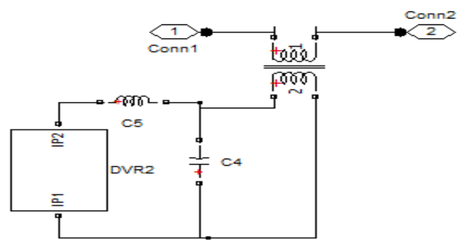

Fig 2.18 DVR Circuit Diagram

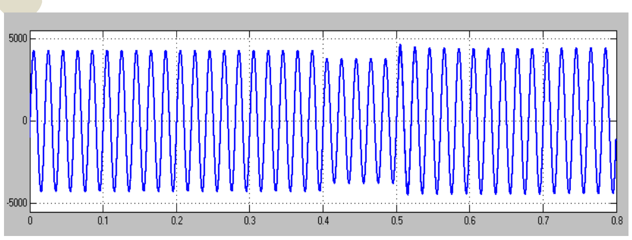

Fig 2.19 voltage at Bus-17 with DPFC

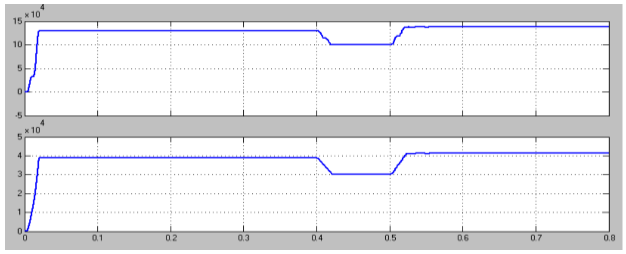

Fig 2.20 real & reactive power at Bus-17 with DPFC

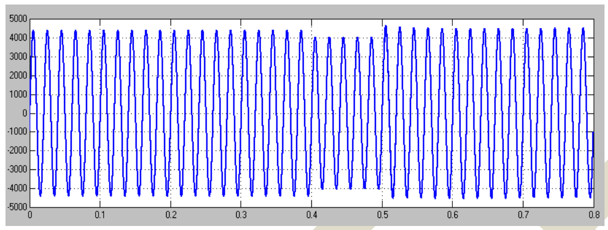

Fig 2.21 voltage at Bus-27

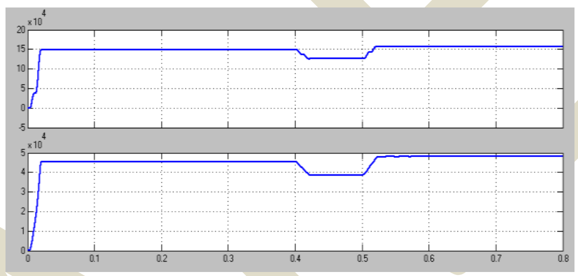

Fig 2.22 real & reactive power at Bus-27 with DPFC

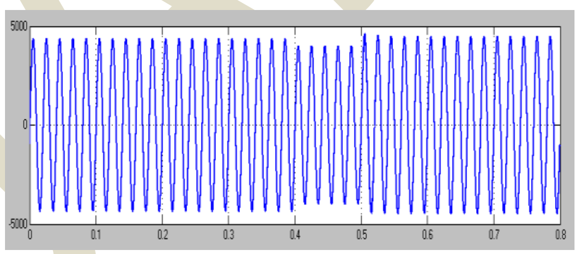

Fig 2.23 voltage at Bus-33

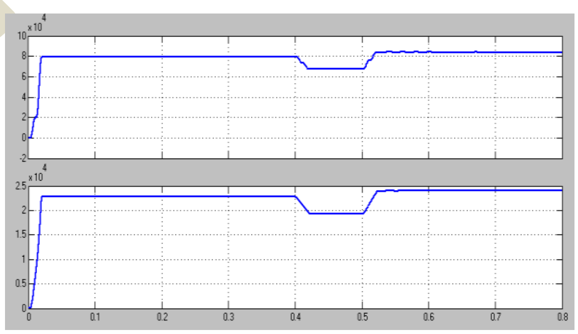

Fig 2.24 real & reactive power at Bus-33 with DPFC

Table-1 Comparison of 33 Bus System

BUS NO	Real power (MW) Without dpfc	Real power (MW) With dpfc	Reactive power(MVAR) Without dpfc	Reactive power(MVAR With dpfc
BUS-1	0.421	0.478	0.448	0.464
BUS-2	0.337	0.361	0.324	0.337
BUS-3	0.475	0.491	0.234	0.272
BUS-4	0.321	0.334	0.249	0.299
BUS-5	**0.299**	**0.331**	**0.228**	**0.397**
BUS-6	0.258	0.289	0.324	0.368
BUS-7	0.264	0.325	0.277	0.382
BUS-8	0.289	0.302	0.313	0.421
BUS-9	0.273	0.335	0.351	0.478
BUS-10	0.253	0.317	0.321	0.468
BUS-11	**0.421**	**0.478**	**0.448**	**0.464**
BUS-12	0.331	0.361	0.324	0.337
BUS-13	0.475	0.495	0.231	0.271
BUS-14	0.384	0.394	0.244	0.291
BUS-15	0.293	0.335	0.224	0.399
BUS-16	0.258	0.287	0.327	0.361
BUS-17	**0.264**	**0.321**	**0.273**	**0.380**
BUS-18	0.289	0.302	0.313	0.421
BUS-19	**0.278**	**0.336**	**0.351**	**0.471**
BUS-20	0.254	0.317	0.325	0.466
BUS-21	0.423	0.479	0.441	0.469
BUS-22	0.332	0.369	0.328	0.336
BUS-23	0.471	0.494	0.232	0.278
BUS-24	0.325	0.339	0.241	0.291
BUS-25	0.293	0.335	0.226	0.398
BUS-26	0.257	0.291	0.323	0.361
BUS-27	**0.261**	**0.333**	**0.268**	**0.398**
BUS-28	0.289	0.312	0.319	0.408
BUS-29	**0.273**	**0.328**	**0.331**	**0.458**
BUS-30	0.253	0.308	0.319	0.460
BUS-29	0.269	0.328	0.312	0.481

BUS-30	0.278	0.351	0.329	0.438
BUS-31	0.264	0.337	0.269	0.358
BUS-32	0.281	0.316	0.328	0.438
BUS-33	0.291	0.321	0.324	0.484

VII. CONCLUSION

DPFC systems controlled by PI and FOPID Controllers were designed, modeled and simulated using Matlab Simulink is future work. The simulation results of open loop and closed loop systems were presented. The proposed reactive power loop was successfully employed to maintain constant reactive power. The response of FOPID Controller controlled system was found to be superior to the PI controlled system. This was due to reduction in the peak time, the peak overshoot and the steady state error. The advantages of DPFC are improved voltage and reactive power profiles. The disadvantage of DPFC is the requirement of about six inverters, six driver circuits and injection transformers.

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