Voltages sag and swell mitigation using DPFC for Multibus system

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ABSTRACT*: Due to increasing in demand of electricity and nonlinear loads increases, power quality problems will be occurs in the interconnected power system network. Power quality problems are voltage sag and swell can be eliminated by using distributed power flow controller then power quality can be improved. The switching level model is constructed using three phase six pulse shunt converter and single phase four pulse series converters. Both the converters are modelled as back to back voltage source inverters connected without the D.C link are controlled by pulse width modulation scheme. This model is implemented in single-machine infinite bus power system including two parallel transmission linesystems. The detailed DPFC simulation in switching level model is performed in Matlab/Simulink environment.

I. INTRODUCTION

In recent years, power quality disturbances become most issue which makes many researchers interested to find the best solutions to solve it. Power quality in the power system is the important issue for industrial, commercial and residential applications today. The voltage problem is mainly considered from under-voltage (voltage sag) condition over current caused by short circuit or fault somewhere in the system. In customer opinion a power problem is deviation in voltage, current and frequency that results in failure.

To overcome the voltage sag and swell problems fast acting power electronics based FACTS (flexible A.C transmission system) devices are introduced. The flexible ac-transmission system (FACTS) that is defined by IEEE as "a power-electronic based system and other static equipment that provide control of one or more ac-transmission system parameters to enhance controllability and increase power-transfer capability" and can be Utilized for power-flow control. Currently, the distributed power-flow controller (DPFC) shown in Fig. 1

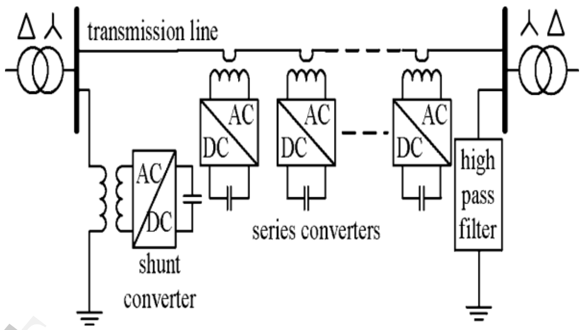


Fig.1. DPFC configuration

This paper introduces a new concept, called distributed power-flow controller (DPFC) that is derived from the UPFC. The same as the UPFC, the DPFC is able to control all system parameters. The DPFC eliminates the common dc link between the shunt and series converters. The active power exchange between the shunt and the series converter is through the transmission line at the third-harmonic frequency. The series converter of the DPFC employs the distributed FACTS (D-FACTS) concept.

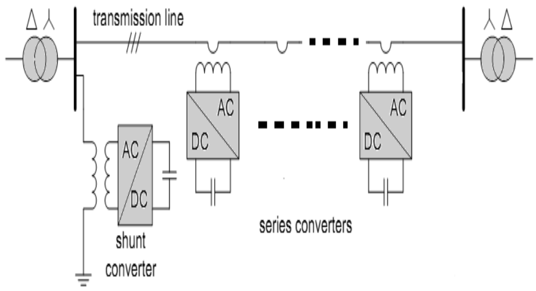


Fig. 2. The DPFC Structure

Comparing with the UPFC, the DPFC have two major advantages: 1) low cost because of the low-voltage isolation and the low component rating of the series converter and 2) high reliability because of the redundancy of the series converters. This paper begins with presenting the principle of the DPFC, followed by its steady-state analysis. After a short introduction of the DPFC control, the paper ends with the experimental results of the DPFC.

In this paper, a distributed power flow controller, introduced as a new FACTS device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC structure is derived from the UPFC structure that is included one shunt converter and several small independent series converters, as shown in Fig. 2. The DPFC has capability to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude.

II. PROPOSED MODEL OF DPFC

An infinite bus is a source of constant frequency and voltage either in magnitude or angle. Single Machine Infinite Bus System (SMIB) equipped with a DPFC is connected to the remote system through a transformer and a parallel
Transmission line having "2" section models as shown in Fig.3. A DPFC is placed in the transmission line at point m (between middle of two line sections m-n) to improve the dynamic behaviour of the system. The DPFC consists of shunt and series converters controlled by pulse width modulation (PWM) controller.

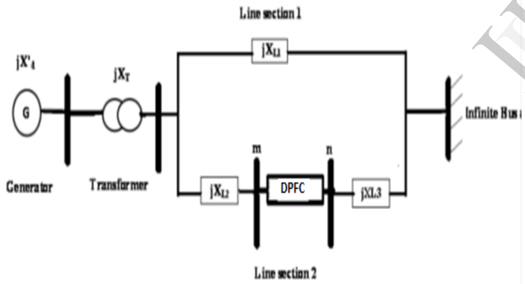


Fig.3.Single line diagram of UPFC with parallel transmission lines

Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively, all the parameter affecting power flow in the transmission line (i.e., voltage, impendence, and phase angle). Alternatively, it can independently control both the real and reactive power flow in the line.

The DPFC Advantages

(A)High Control Capability

The DPFC can simultaneously control all the parameters of the power system: the line impedance, the transmission angle, and the bus voltage. The elimination of the common dc link enables separated installation of the DPFC converters. The shunt and series converters can be placed at the most effectively location. Due to the high control capability, the DPFC can also be used to improve the power quality and system stability, such as low-frequency power oscillation damping, voltage sag restoration.

(B)High Reliability

The redundancy of the series converter gives an improved reliability. In addition, the shunt and series converters are independent, and the failure at one place will not influence the other converters. When a failure occurs in the series converter, the converter will be short-circuited by bypass protection, thereby having little influence to the network. In the case of the shunt converter failure, the shunt converter will trip and the series converter will stop providing active compensation and will act as the D-FACTS controller.

(C)Low Cost

The single-phase series converters rating are lower than one three-phase converter. Furthermore, the series converters do not need any high voltage isolation in transmission line connecting; single-turn transformers can be used to hang the series converters.

(D)Eliminate DC Link

Within the DPFC, there is a common connection between the ac terminals of the shunt and the series converters, which is the transmission line. Therefore, it is possible to exchange the active power through the ac terminals of the converters. The method is based on the power theory of non-sinusoidal components. According to the Fourier analysis, a non-sinusoidal voltage and current can be expressed by the sum of sinusoidal functions in different frequencies with different amplitudes.

(i)Control Scheme of Shunt Converter

The objective of the shunt control is to inject a constant third harmonic current into the line to provide active power for the series converters. The third-harmonic current is locked with the bus voltage at the fundamental frequency.

A PLL is used to capture the bus-voltage frequency, and the output phase signal of the PLL is multiplied by three to create a virtual rotation reference frame for the third-harmonic component.

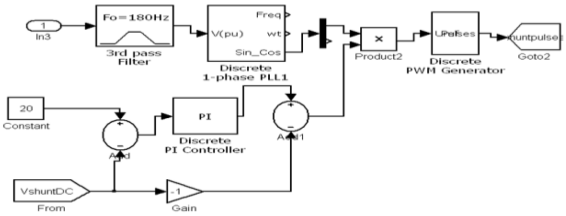


Fig.4.Control Scheme of Shunt Converter

The shunt converter's fundamental frequency control aims to inject a controllable reactive current to grid and to keep the capacitor dc voltage at a constant level. The control for the fundamental frequency components consists of two cascaded controllers. The current control is the inner control loop, which is to modulate the shunt current at the fundamental frequency. The *q*-component of the reference signal of the shunt converter is obtained from the central controller, and *d*-component is generated by the dc control.

(ii)Control scheme for series converter

Each single-phase converter has its own series control through the line. The controller inputs are series capacitor voltages, line current, and series voltage reference in the dq frame. The third-harmonic frequency control is the major control loop with the DPFC series converter control. The principle of the

Fig.5. Control scheme for series converter

vector control is used here for the dc-voltage control. The third-harmonic current through the line is selected as the rotation reference frame for the single-phase park transformation, because it is easy to be captured by the phase-locked loop(PLL) in the series converter.

(iii)CentralControlScheme

The central control generates the reference signals for both the shunt and series converters of the DPFC. It is focused on the DPFC tasks at the power-system level, such as power-flow control, low-frequency power oscillation damping, and balancing of asymmetrical components.

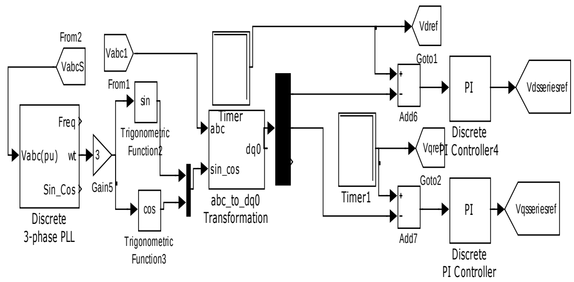


Fig.6. Central Control Scheme

According to the system requirement, the central control gives corresponding voltage-reference signals for the series converters and reactive current signal for the shunt converter. All the reference signals generated by the central control are at the fundamental frequency.

III. MODELING OF DPFC

This modelling is done with Simulink block set and simulationis carried out in MATLAB environment as shown in Fig.7. The system is modelled with a three phase source connected to a load. The source is connected to load through parallel transmission lines. The transmission line consists of transmission line I, transmission line II .These two transmission lines are connected in parallel. Each parallel transmission line has equal length.

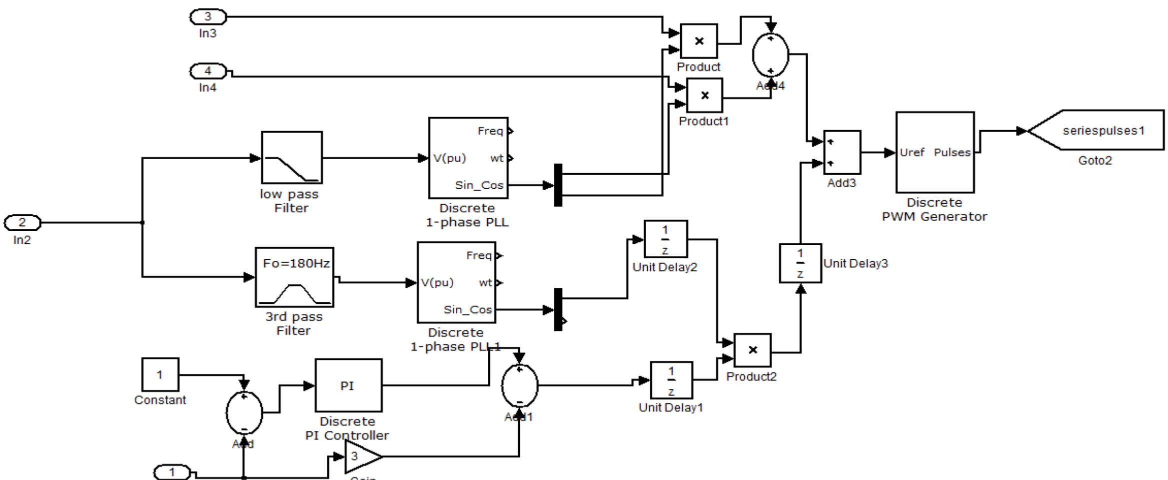


Fig.5. Control scheme for series converter

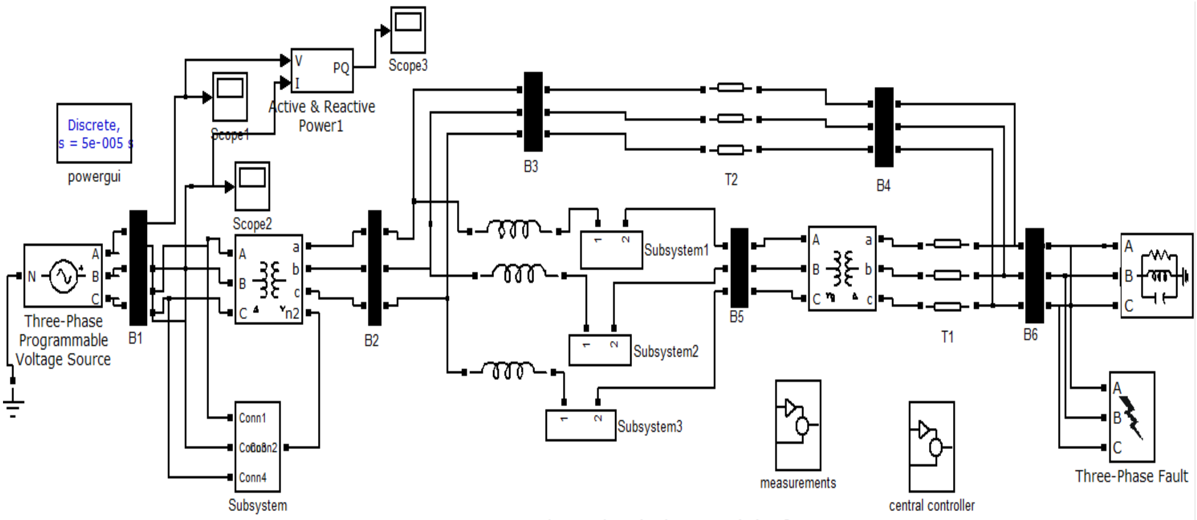


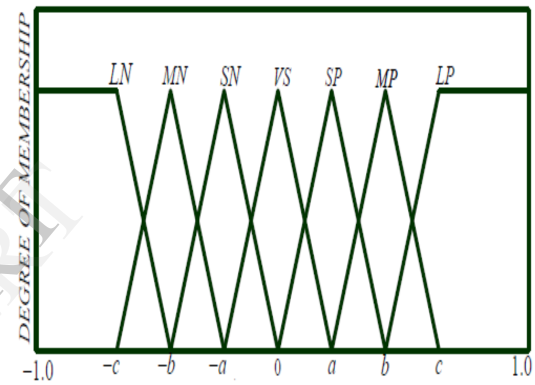
Fig.7.Simulation model of DPFC

The DPFC is incorporated between transmission line I & II. The inductive and capacitive loads are connected for dynamic performance analysis. To obtain the transient analysis the fault can be connected near the load. The system circuit parameters are given in appendix. The simulation model of DPFC is modelled with a three phase voltage source inverter connectedto different

loads. Each transmission line has the busmeasurement block to measure the real power, reactive power, voltage and the current. The shunt and series device of DPFC consists of three phase IGBT converter with PWM controller. The shunt converter is connected to the transmission line in parallel through a three phase transformer. The series converter is connected to the transmission line in series through three independent single phase transformers. The IGBT firing pulses are generated for shunt & series converters as described earlier in section (2).Three leg, six pulse bridges are used for the model of converters.

IV. IMPLEMENTATION OF FLC IN DPFC

FLC are formed by simple rule based on “If x and y then z”. These rules are defined by taking help from person’s experience and knowledge about the system behaviour. The performance of the system is improved by the correct combinations of these rules. Each of the rules defines one membership which is the function of FLC. More sensitivity is provided in the control mechanism of FLC by increasing the numbers of membership functions. In this study, the inputs of the fuzzy system are assigned by using 7 membership functions and the fuzzy system to be formed in 49 rules. Hence, the sensitivity in the control mechanism is increased.



The basic if-then rule is defined as “If (error is very small and error rate is very small) then output”. The signals errorand error rate are described as linguistic variables in the FLCsuch as large negative (LN), medium negative (MN), small negative (SN), very small (VS), small positive (SP), mediumpositive (MP) and large positive (LP). These are shown in Fig.5. In the same way, the input values of the fuzzy controller areconnected to the output values by the if-then rules. The relationship between the input and the output values can be achieved easily by using Takagi-Sugeno type inference method. The output values are characterized by memberships and named as linguistic variables such as negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive big(PB). The membership functions of output variables and the decision tables for FLC rules are seen in Table I

.

FUZZY DECISION TABLE							
Error rate\error	**LP**	**MP**	**SP**	**VS**	**SN**	**MN**	**LN**
LP	PB [1]	PB[2]	PB [3]	PM[4]	PM[5]	PM[6]	Z[7]
MP	PB [8]	PB [9]	PM [10]	PM [11]	PS [12]	Z [13]	NS [14]
SP	PB [15]	PM [16]	PM [17]	PS [18]	Z [19]	NS [20]	NM [21]
VS	PM [22]	PM [23]	PS [24]	Z [24]	NS [26]	NM [27]	NM [28]
SN	PM [29]	PS [30]	Z [31]	NS [32]	NM [33]	NM [34]	NB [35]
MN	PS [36]	Z [37]	NS [38]	NM [39]	NM [40]	NB [41]	NM [42]
LN	Z [43]	NS [44]	NS [45]	NM [46]	NB [47]	NB [48]	NB [49]

TABLE.I.
Fig.8.Error and error rate of fuzzy membership functions

V. RESULT ANALYSI

Case (i)
In this case the impact of sag can be analysed by creating the three phase fault on the network system as shown in Fig.9. The time duration for fault is 0.05s (0.05-0.1 s).The length between the feeders will determine the severity of dropped voltage. In this case, the SMIB is connected with capacitive load. The DPFC can compensate 100% of drop voltage in theSystem as shown in Fig.10& fig.11.

Case (ii)
In this case, the impact of swell can be analysed by effect of line current due to three phase fault on the network system as shown in Fig.12.The time duration of the fault is 0.05 seconds.
In this simulation study after implementation of DPFC the magnitude of line current is comparatively reduced. The mitigation of swell for this simulation can be observed from the Fig.13& fig.14.

case(iii)
due to the effect three phase fault on the network system the real and reactive power magnitude will be distorted in the time duration of 0.05s to 0.1s as shown in fig.15. In this simulation study after implementation of DPFC the magnitude of real and reactive power is comparatively increased as shown in fig.16 & fig.17

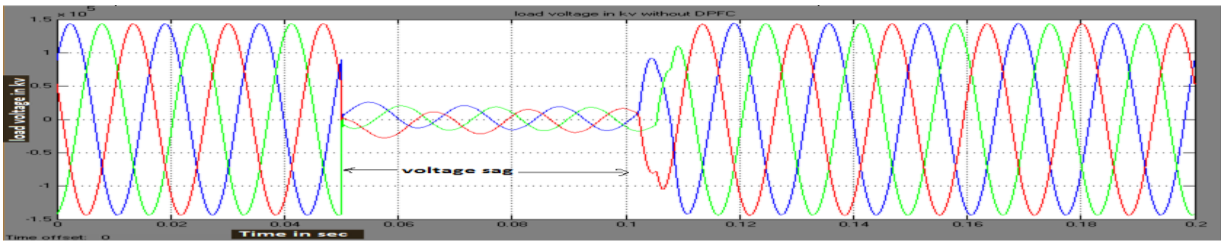


Fig.9.Without DPFC Load voltage sag wave form

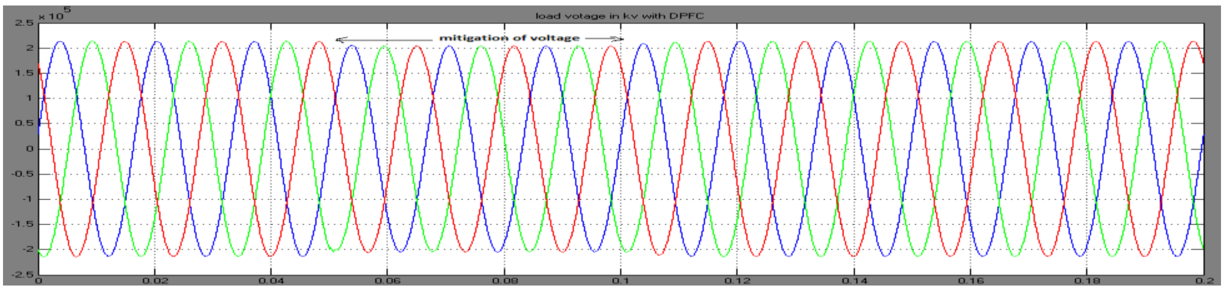


Fig.10.Mitigation of load voltage sag with DPFC(PI)

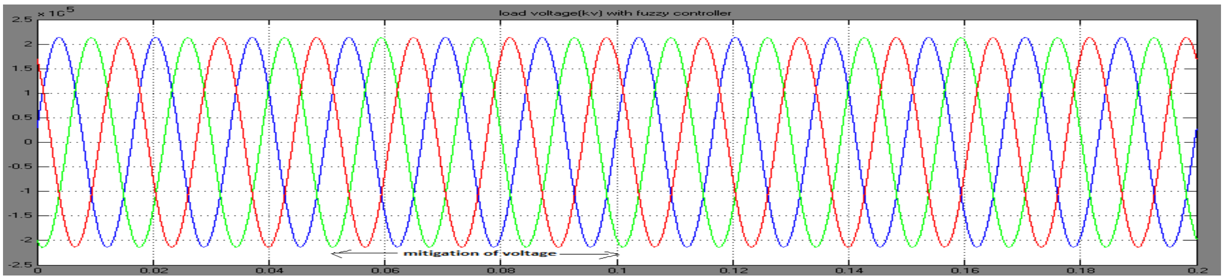


Fig.11.Mitigation of load voltage sag with DPFC (Fuzzy)

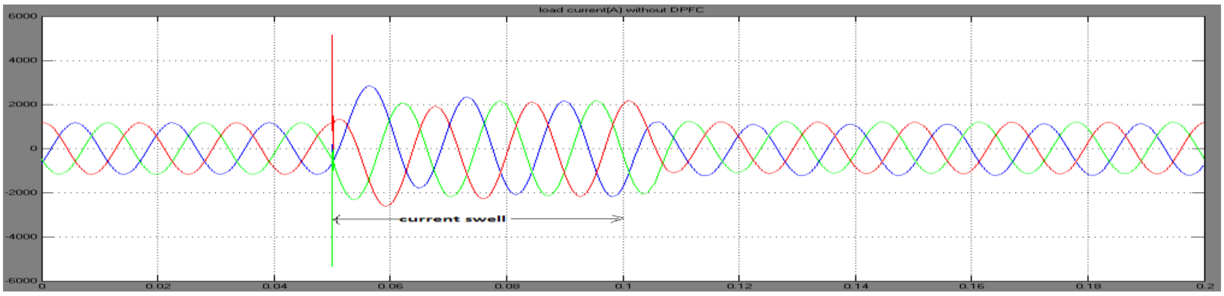


Fig.12.Without DPFC swell wave form of load current

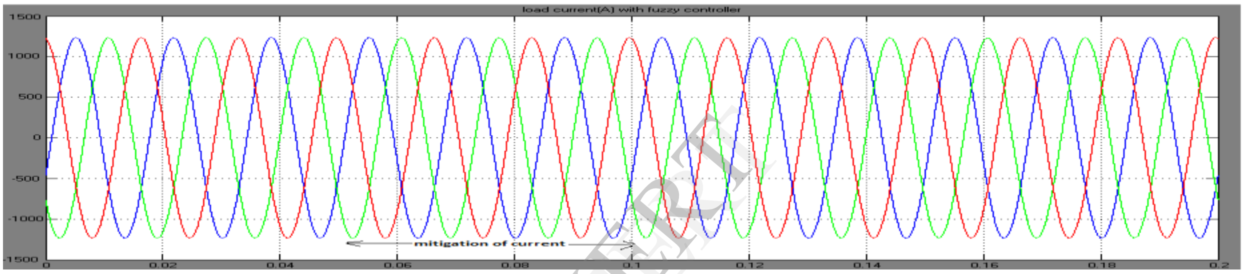


Fig.13.mitigation of load current with DPFC(PI)

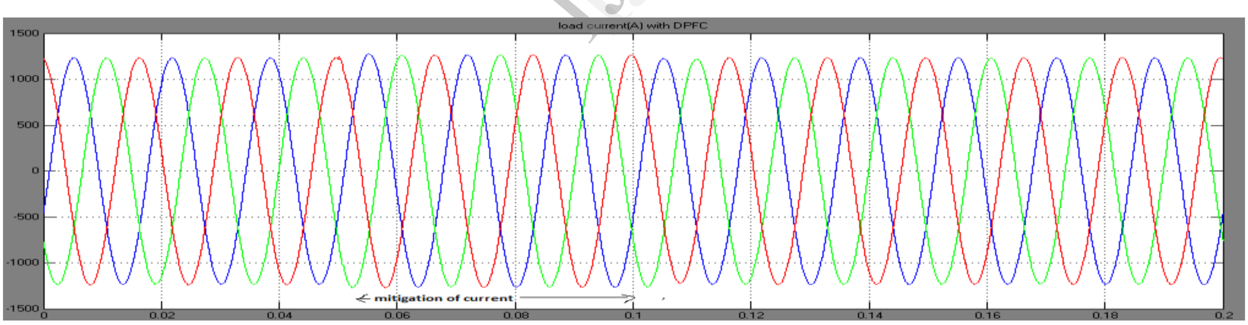


Fig.14.mitigation of load current with DPFC(fuzzy)

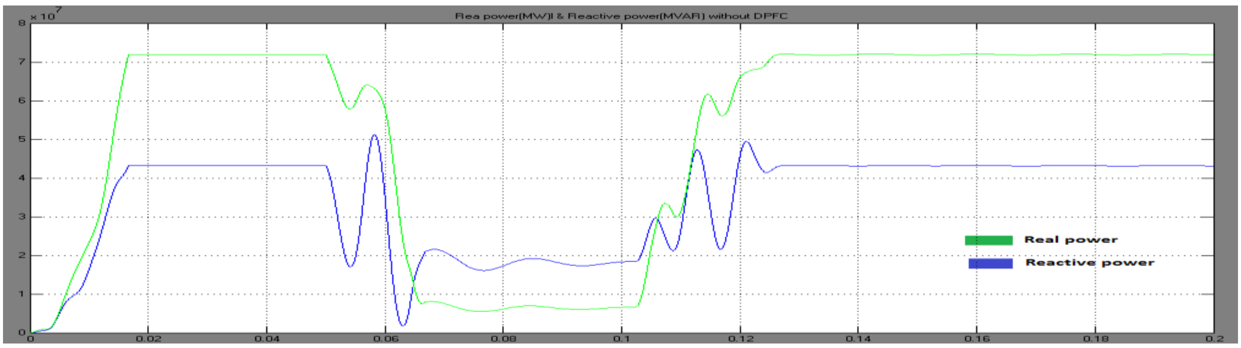


Fig.15.without DPFC real and reactive power wave form

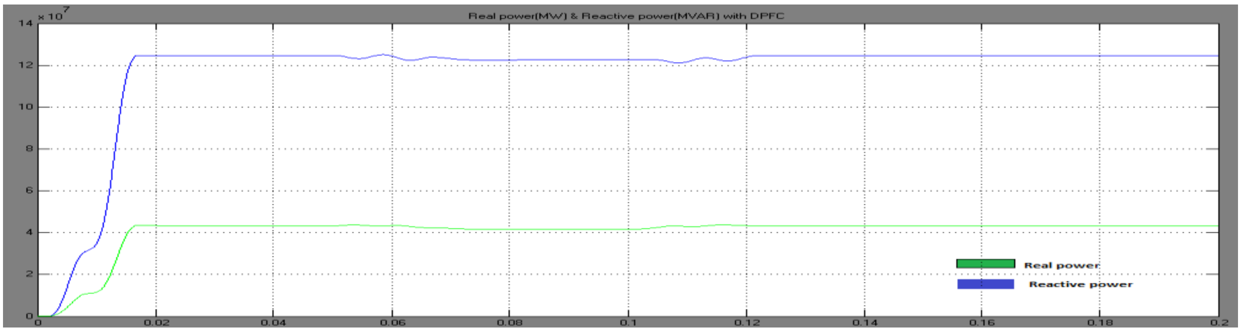


Fig.16.with DPFC real and reactive power wave form(PI)

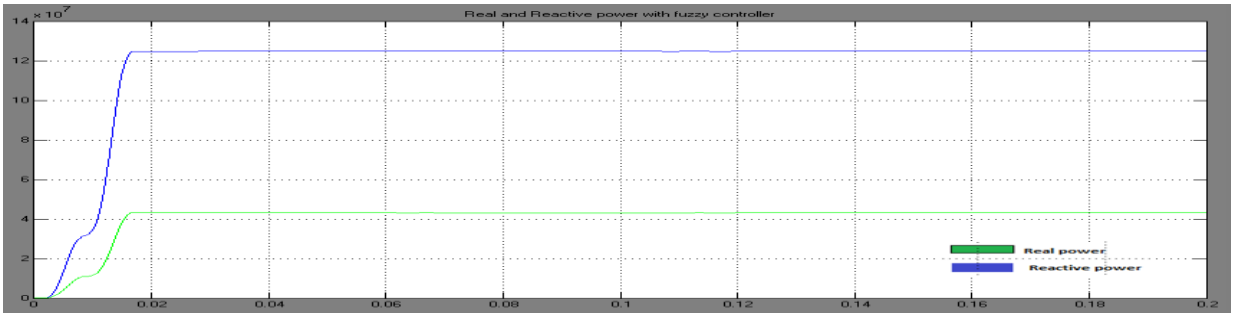


Fig.17.with DPFC real and reactive power wave form(Fuzzy)

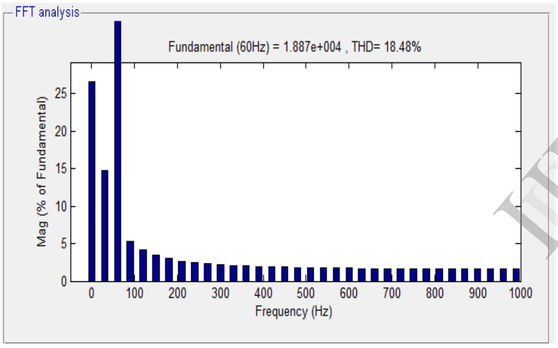


Fig.18.without DPFC THD

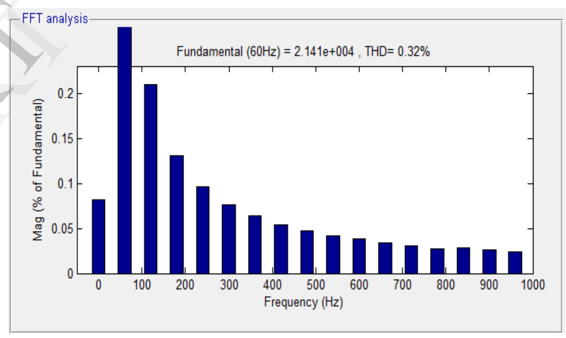


Fig.20.with DPFC THD (fuzzy)

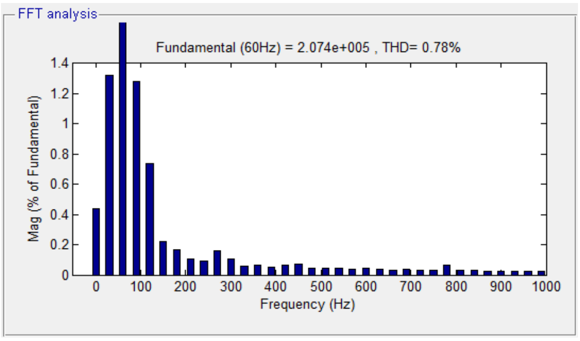


Fig.19.with DPFC THD (pi)

The load voltage harmonic analysis without presence of DPFC is illustrated in Fig.18. It can be seen, after DPFC implementation in system, the even harmonics is eliminated, the odd harmonicsare reduced within acceptable limits, and total harmonic distortion (THD) of load voltage is minimized from 18.48 to 0.32percentage (Fig.19 & 20).

VI.CONCLUSION

To improve power quality in the power transmission system, there are some effective methods. In this paper, the voltage sag and swell mitigation, using a new FACTS device called distributed power flow controller (DPFC) is presented. The DPFC has a control capability to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude. However, the DPFC offers some advantages, such as high control capability, high reliability, and low cost. The DPFC is modelled and three control loops, i.e., central controller, series control, and shunt control are designed. The system under study is a single machine infinite-bus system, with and without DPFC. To simulate the dynamic performance, a three-phase fault is considered near the load. It is shown that the DPFC gives an acceptable performance in power quality mitigation and power flow control and simulation results values are shown in table II.

	Rated voltage (kv)	***Load voltage(kv)***	***Load current(A)***	***Real power(MW)***	***Reactive power(MVAR)***	***Apparent power(MVA)***	***THD %***
Without DPFC	230	190	1200	75	45	88	18.48
With DPFC using PI controller	230	210	1300	48	125	134	0.78
With DPFC using Fuzzy controller	230	210	1300	48	125	134	0.32

Table.II. Simulation results

APPENDIX

TABLE III. Simulation System Parameters

Parameters	**values**
Three phase source	
Rated voltage	230 kV
Rated power/Frequency	100MW/60 HZ
X/R	3
Short circuit capacity	11000MW
Transmission line	
Resistance	0.012 pu/km
Inductance/ Capacitance reactance	0.12/0.12pu/km
Length of transmission line	100 km
Shunt Converter 3-phase	
Nominal power	60 MVAR
DC link capacitor	600 µF
Continue of Table I :	
Coupling transformer (shunt)	
Nominal power	100 MVA
Rated voltage	230/15 kV
Series Converters	
Rated voltage	6 kV
Nominal power	6 MVAR
Three-phase fault	
Type	ABC-G
Ground resistance	0.01ohm

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