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Research Article

Performance Evaluation of Fuzzy Controller Based IPFC with IDVR

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Abstract: This study discusses the operating principles and control characteristics of a Interline Power Flow Controller (IPFC) and Interline Dynamic Voltage Restorer (IDVR) for power quality improvement. The power quality disturbance includes voltage sag, swell, notch, spike and transients etc. are normally occur in both transmission and distribution lines. Both the IPFC and IDVR connected power system performance is presented in a strategic approach. The fuzzy logic controller added in the system improves the system performance and isolate the system sag and swell. The MATLAB/Simulink based model developed for IPFC and IDVR. The output response of the system is presented and an remarkable conclusion proposed.

Keywords: Injection transformer, interline dynamic voltage restorer, interline power flow controller, power quality, structure and control technique, test system, voltage source inverter

INTRODUCTION

Power quality improvement is one of the vital areas of research in recent years. In certain commercial and industrial electrical applications, it is critical that high quality and uninterrupted power be supplied; for fear that significant economic losses can be incurred. The reason for demanding high quality un-interruptible power during production process is mainly because of the modern manufacturing and process equipment that operate at high efficiency requires stable and defect free power supply for the successful operation of their machines. Machines, sensitive to power supply variations are to be designed more precisely (Fitzer *et al*., 2004).

Interline Power Flow Controller (IPFC) is an advanced voltage sourced Converter based FACTS controller (Dash *et al*., 2000) which employs a number of dc to ac converters each providing a series compensation for a different lines. VSC-based FACTS controllers include the Static Synchronous Compensator (STATCOM) for shunt reactive power compensation, the Static Synchronous Series Compensator (SSSC) for series reactive power compensation, the Unified Power Flow Controller (UPFC) with the unique capability of independently controlling both the active and reactive power flow in the line. Generally speaking, the IPFC employs a number of VSCs linked at the same DC terminal, each of which can provide series compensation for its own line. It can also be regarded as several SSSCs sharing a common DC link. In this way, the power optimization of the overall system can be realized in the form of appropriate power transfer through the common DC link from over-loaded lines to under-loaded lines (Chen *et al*., 2002).

Dynamic Voltage Restorer (DVR) has become very popular in recent years for compensation of voltage sag and swell. The voltage sag and swell is a very severe problem of Power quality for an industrial customer which needs urgent attention for its compensation (Nielsen *et al*., 2004). There are various methods for the compensation of voltage sag and swell. One of the most popular methods of sag and swell compensation is Dynamic Voltage Restorer (DVR), which is used in both low voltage and medium voltage applications (Nielsen and Blaabjerg, 2005; Ajaei *et al*., 2011). In this study, our main focus is on the DVR. DVR compensates the voltage sag by injecting voltage as well as power into the system. The compensation capability DVR mainly influenced by the various load conditions and voltage dip to be compensated. Efficient control technique (Park's Transformations) is used for mitigation of voltage sag through which optimized performance of DVR is obtained (Li *et al*., 2007). The performance of DVR is analyzed on various conditions of active and reactive power of load at a particular level of dc energy storage. Parameters of load are varied and the results are analyzed on the basis of output voltages (Araujo *et al*., 2007; Roncero-Sanchez *et al*., 2009).

MATERIALS AND METHODS

Interline Power Flow Controller (IPFC): The IPFC is a combination of the series connected VSC which can inject a voltage with controllable magnitude and phase

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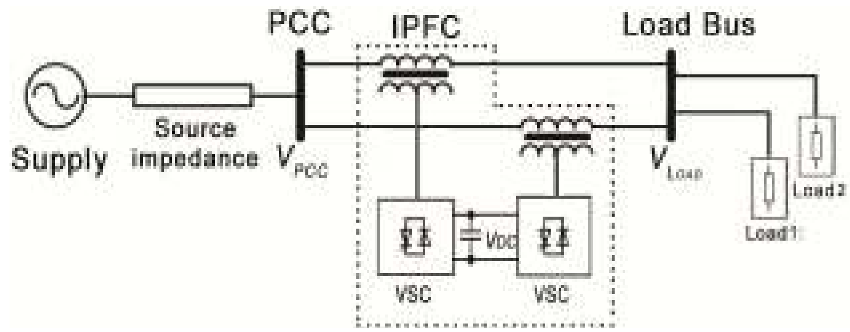

Fig. 1: Representation for fuzzy based IPFC

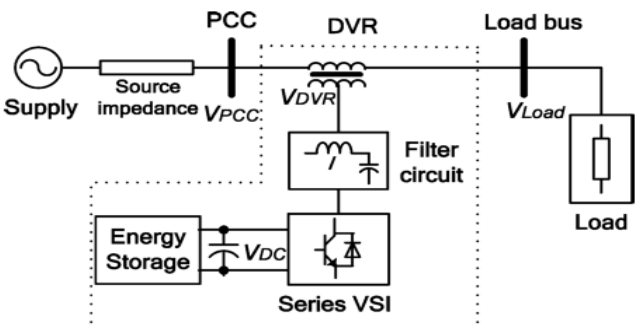

Fig. 2: Representation for LC filter added Fuzzy based DVR

angle at the fundamental frequency while DC link voltage can be maintained at a desired level. It act as a power flow controller with two or more in parallel controllable static synchronous series compensators which are solid state series voltage source converters injecting an almost sinusoidal voltage at variable magnitude and are linked via a common DC capacitor. Active power can be exchanged through these series converters via the common DC link in IPFC. The reactive voltage injected by individual VSCs can be maintained constant or controlled to regulate active power flow in the respective line. While one VSC regulates the dc voltage, the others control the reactive power flows in the lines by injecting series active voltage (Gyugyi *et al*., 1999).

The IPFC functional and its schematic representation is shown in Fig. 1. With this arrangement, real power can be extracted fiom one line and injected to the other. The injected voltage does not have to be in quadrature with the line current. This implies that, both the voltage magnitude and the phase angle of the injected voltage can be controlled on one line. However, for proper operation of the device, the dc bus voltage must be held constant and the real power injected to one line by the VSC must be equal to the real power extracted from the other line. Hence, only one of the variables of the injected voltage of the other line can be independently controlled.

Interline Dynamic Voltage Restorer (IDVR): Dynamic voltage restorer is a series connected device is used for mitigating voltage disturbances in the distribution system. The DVRs can be used and are already in operation. DVR maintains the load voltage at a nominal magnitude and phase by compensating the voltage sag/swell, voltage unbalance and voltage harmonics presented at the point of common coupling. These systems are able to compensate voltage sags by increasing the appropriate voltages in series with the supply voltage and therefore avoid a loss of power. In Gyugyi (1994) (Patent No. 5329222) proposed an apparatus and a method for dynamic voltage restoration of utility distribution network. This method uses real power in order to inject the faulted supply voltages and is commonly known as the Dynamic Voltage Restorer (Gyugyi, 1994). The DVR should capable to react as fast as possible to inject the missing voltage to the system due to sensitive loads are very sensitive to voltage variations.

The DVR is a series conditioner based on a pulse width modulated voltage source inverter, which is generating or absorbing real or reactive power independently (Fig. 2). Voltage sags caused by unsymmetrical line-to-line, line to ground, double-line-to-ground and symmetrical three phase faults is affected to sensitive loads, the DVR injects the independent voltages to restore and maintained sensitive to its nominal value.

The capacitor-supported Dynamic Voltage Restorer (DVR) is a power electronic converter-based device that has been proposed to protect critical and

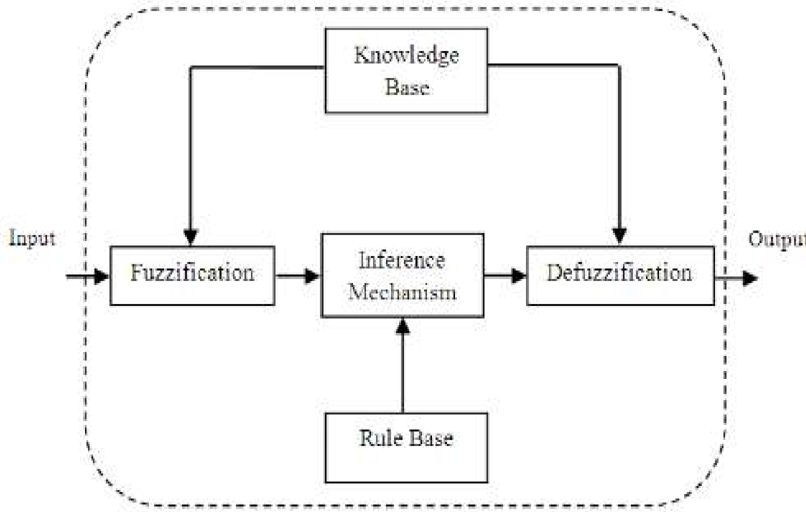

Fig. 3: Fuzzy controller design diagram

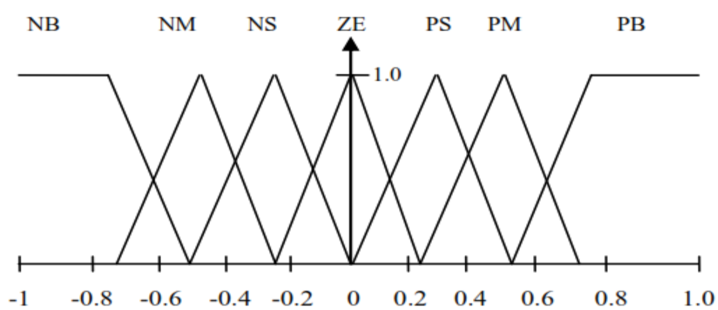

Fig. 4: Membership function for input variable error

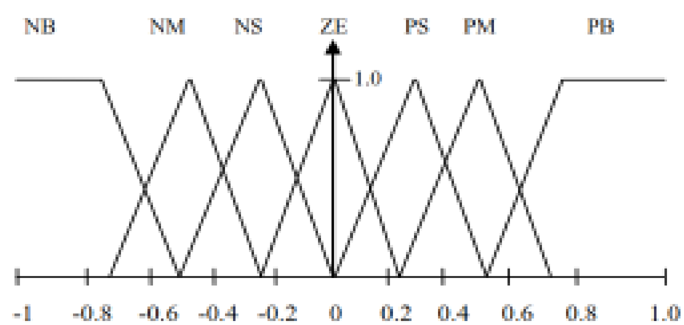

Fig. 5: Membership function for input variable change in error

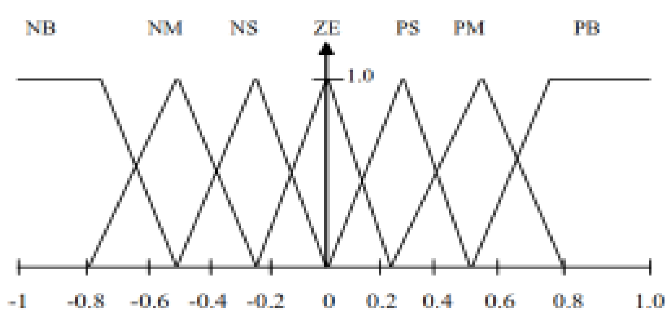

Fig. 6: Membership function for output variable change in control signal

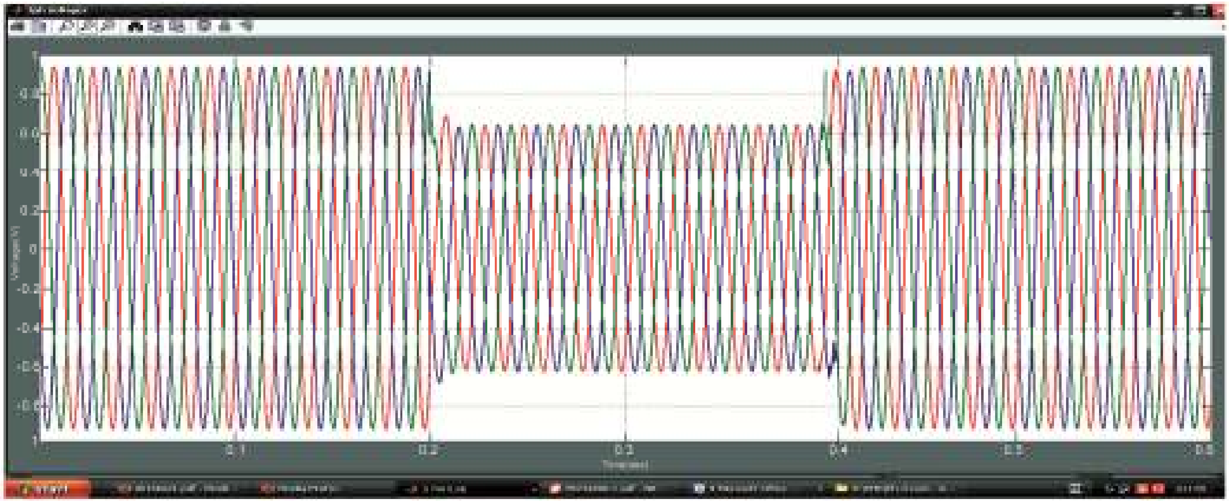

Fig. 7: Voltage profile when Fuzzy based IPFC is not activated

sensitive loads from supply side disturbances, except outages. It is connected in series with a distribution feeder and is capable of generating or absorbing reactive power at its AC terminals and interchange real power with the AC network under transient conditions.

The dynamic voltage restorer is used in the system to compensate voltage sags and swells and eliminating harmonics when sudden voltage faults happen in the grid. The DVR system is designed to protect the consumers especially the sensitive load. The DVR system is essentially composed of a series-connected transformer, a voltage source inverter, an inverter output filter and an energy storage device. The operation of the dynamic voltage restorer is injecting a proper series voltage with the supply through a transformer when sudden sags and swells happen and make the voltage level of the grid remains in the present status. In the experiments, the system is equal to the series connection of a voltage source and impedance. The use of inverter in the dynamic voltage restorer would introduce switching harmonics in the grid; therefore, L filter and LC filter are proposed to eliminate the high-frequency inverter switching noises and pass through the fundamental component. Compared with the traditional L filter, the LC filter could achieve the same performance of damping the switching harmonics using smaller inductance. The filter has the features of better attenuation for switching frequency harmonic and low cost; it is widely used for grid connected power electronic systems.

Fuzzy logic controller: Fuzzy logic control has achieved very much importance in recent years. Many successful applications have been reported and these applications of the fuzzy logic control have often produced advanced results to those of conventional control (Pratumsuwan *et al*., 2010). This greater reputation of the fuzzy logic control can be recognized to the reality that fuzzy logic systems provide a controlling tool to incorporate human reasoning in the control algorithm. The fuzzy logic system design is not based on the mathematical model of process (Samuel, 2010). Fuzzy logic theory is considered as a mathematical approach combining multi-valued logic, probability theory and artificial intelligence to replicate the human approach in reaching the solution of a specific problem by using approximate reasoning to relate different data sets and to make decisions (Raviraj and Sen, 1997).

The performance of Fuzzy Logic Controllers is well documented in the field of control theory since it provides robustness to dynamic system parameter variations as well as improved transient and steady state performances. In this study, a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed IPFC and IDVR. Fuzzy logic controller is preferred over the conventional PI and PID controller because of its robustness to system parameter variations during operation and its simplicity of implementation.

The proposed FLC scheme exploits the simplicity of the Mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

The fuzzy logic based control scheme can be divided into five main functional blocks namely Fuzzification, Knowledge base, Rule base, Inference mechanism and Defuzzification as shown in Fig. 3. The knowledge base is composed of data base and rule base. Data base consists of input and output membership functions and provides information for appropriate fuzzification and defuzzification operations. The rule-base consists of a set of linguistic rules relating the fuzzified input variables to the desired control actions. Fuzzification converts a crisp input signal, error (e) and change in error (ce) into fuzzified signals that can be identified by the level of memberships in the fuzzy sets as shown in Table 1.

Table 1: Rule base for fuzzy logic controller

‘e’/ ‘ce’	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The inference mechanism uses the collection of linguistic rules to convert the input conditions to fuzzified output. Finally, the defuzzification converts the fuzzified outputs to crisp control signals using the output membership function, which in the system acts as the changes in the control input (u). The typical input membership functions for error and change in error are shown in Fig. 4 and 5 respectively, whereas the output membership function to change in control input is shown in Fig. 6. The output generated by fuzzy logic controller as shown in Fig. 7 must be crisp which is used to control the PWM generation unit and thus accomplished by the defuzzification block. The defuzzification technique used here is based upon Centroid method.

RESULTS AND DISCUSSION

The simulation involves that both the controller part of the IPFC and IDVR which incorporates the Fuzzy Logic Controller as shown in the Fig. 8. The modeling and simulation of the proposed Fuzzy Logic Controller using Matlab/Simulink have been presented. Detection and quantization of sags are done using the classical Fourier Transform (FT) technique. Calculation of the compensating voltage was one with reference to voltage only, since induction motors are not sensitive to changes in phase angle. A controller based on feed-forward technique is used which utilizes the error signal i.e., difference between the reference voltage and actual measured voltage The proposed controller utilizes energy drawn from the supply line source during normal operation and stored in capacitors and which is converted to an adjustable three phase AC voltage suitable for mitigation of voltage sags.

To investigate the effect of IPFC in power system and study its effect of power flow the simplest power system of 600 kV/300 kV Transmission System is taken into consideration. For better understanding the effect of IPFC on power system the results of power flow including voltage magnitude and active, reactive power flow is investigated. The Matlab/Simulink model for the proposed IPFC system is as shown in Fig. 9. The voltage instability created in the load side is analyzed by connecting the Fuzzy based IPFC. The transition time for the circuit breaker of the second load is given as 0.2-0.5 sec. Similarly the transition time of the circuit breaker in the transmission line is given as 0.4-0.5 sec. The voltage from the source is 1 pu. The voltage instability is created by connecting the second load. When the circuit breaker connected to the second load is closed the voltage is decreased from 0.98 p.u to 0.65 p.u. After a delay of 0.2 sec, the load voltage changes from 0.65 p.u. to 0.98p.u. is clearly shown in Fig. 7. After compensating with the Fuzzy based IPFC, there is a compensated stable flow of voltage magnitude exists and the voltage waveform across the load terminal is shown in the Fig. 10. It is seen that there is considerable improvement in the active and reactive power flows as well as the receiving end voltage. For a capacitor value of 350 μf, the active and reactive powers obtained are 0.286 MW and 0.5725 MVAR, respectively through the line is regulated as shown in the Fig. 11.

Dynamic Voltage Restorer is simulated using MATLAB/SIMULINK and the results are analyzed on the basis of output voltage. Various cases of different active power of load at different DC energy storage are considered to study the impact on sag waveform and compensated waveform as shown in Fig. 11 to 14. A three-phase fault is created via a fault resistance of 0.55 Ω, load 1 is 5 KW, 100 VAR and load 2 is 10 KW, 100 VAR which results in a voltage sag of 10.07%.

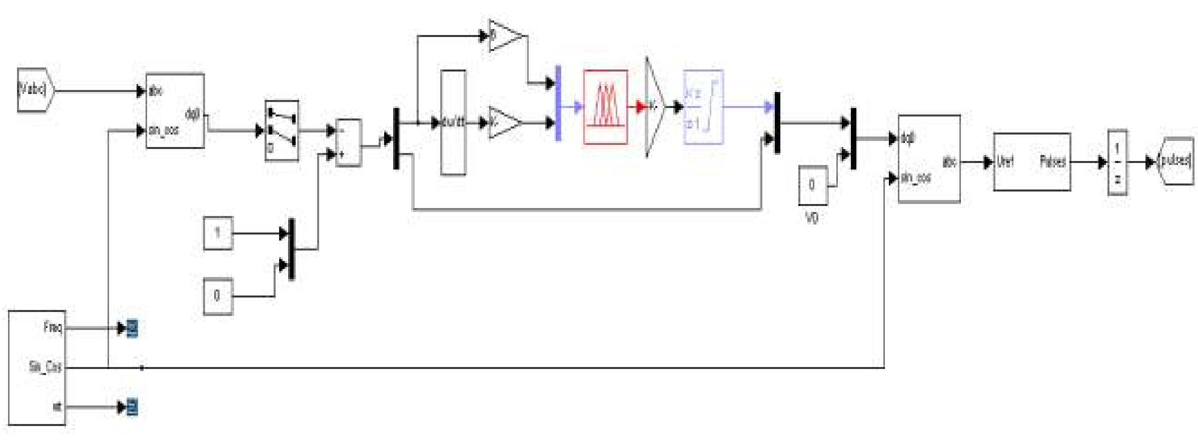

Fig. 8: Fuzzy logic controller

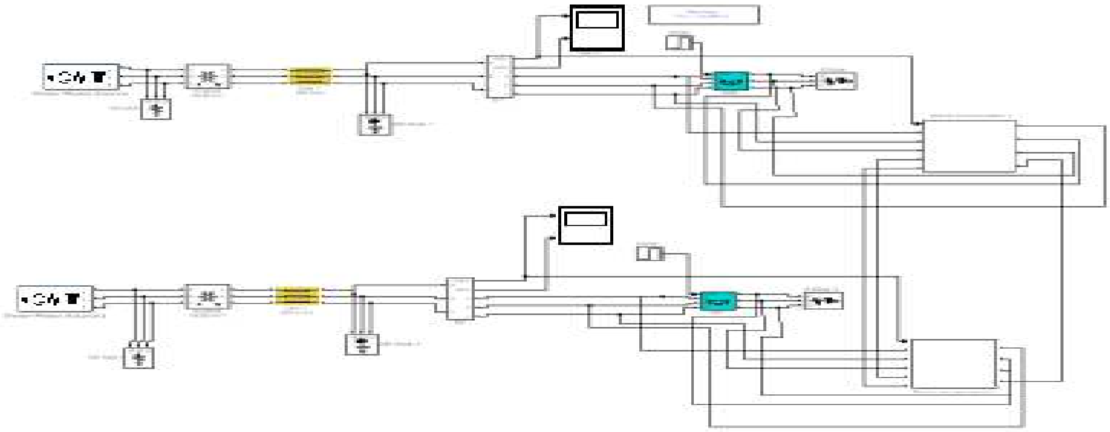

Fig. 9: Matlab/Simulink model for proposed IPFC system

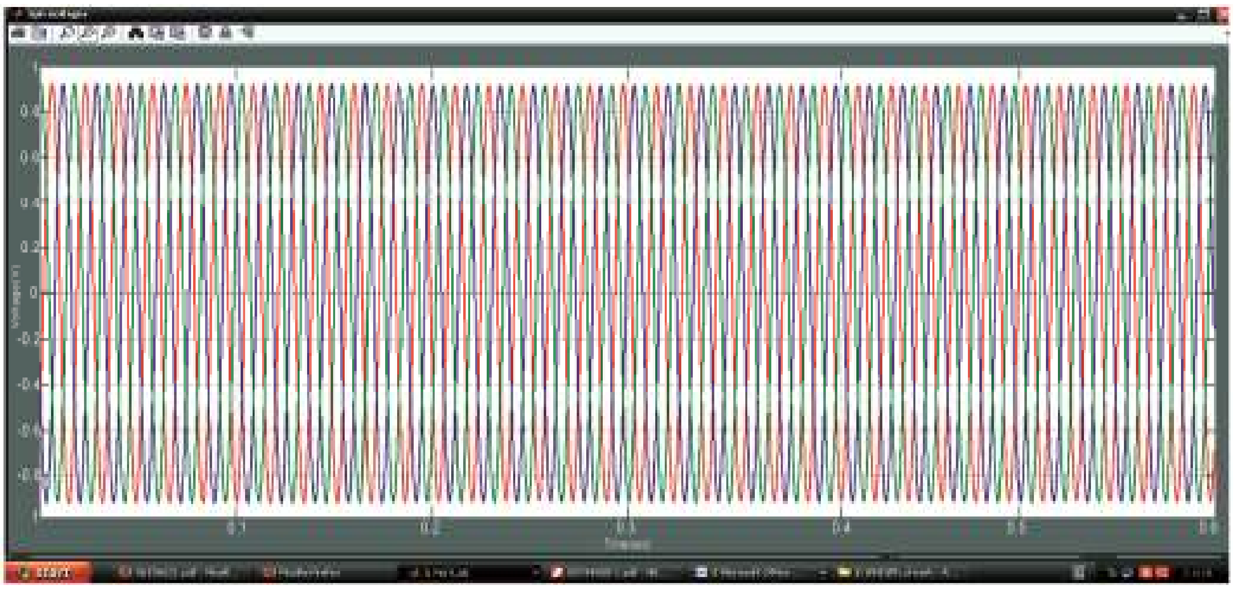

Fig. 10: Voltage profile when fuzzy based IPFC is activated

Fig. 11: Compensated active and reactive power with fuzzy based IPFC

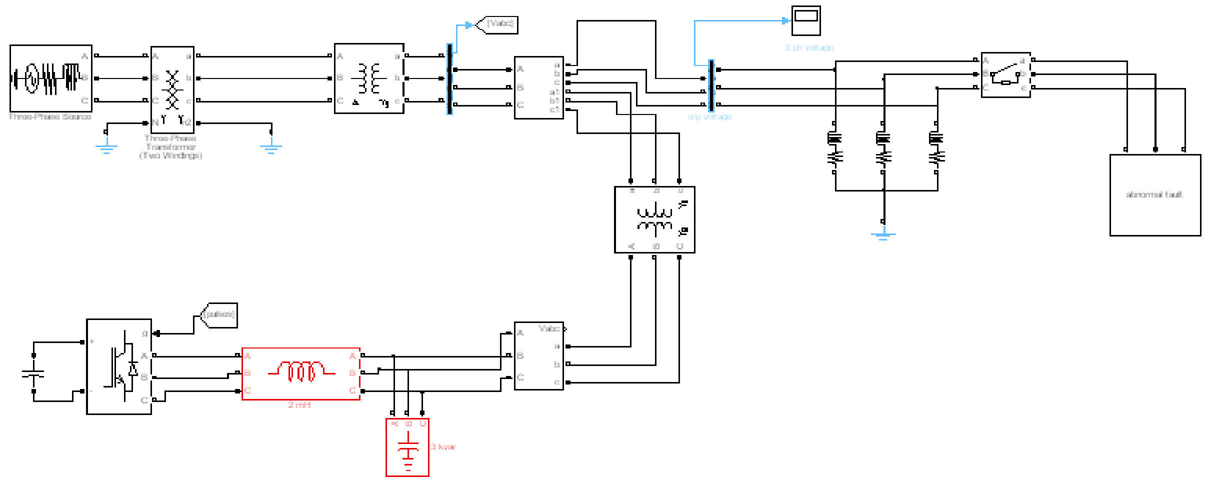

Fig. 12: Matlab/Simulink model for proposed IDVR system

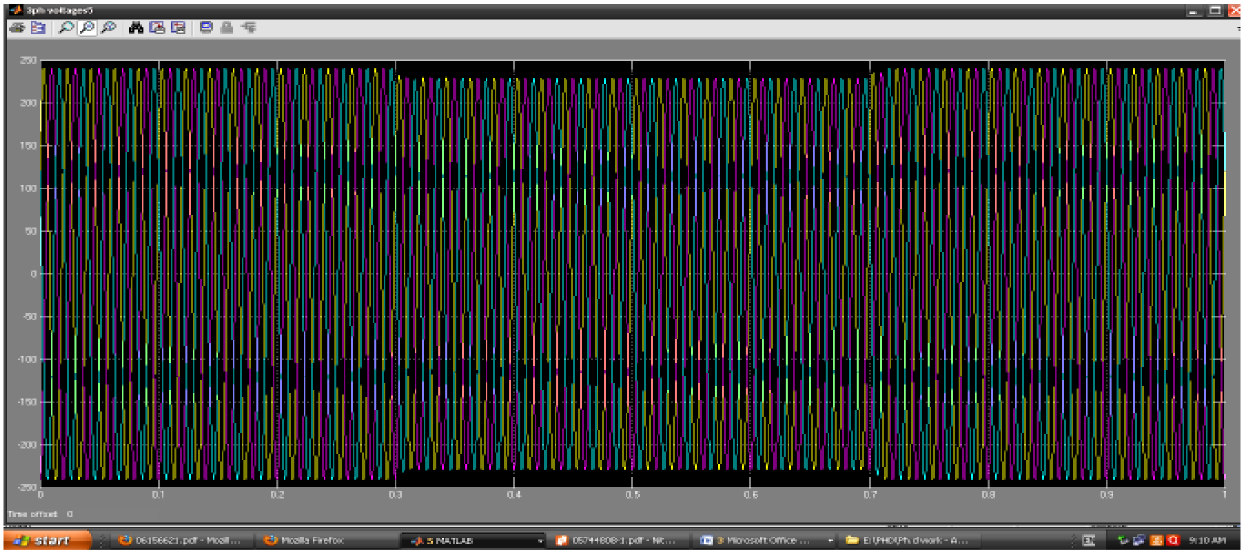

Fig. 13: Voltage profile with sag occurrence when fuzzy based DVR is not activated

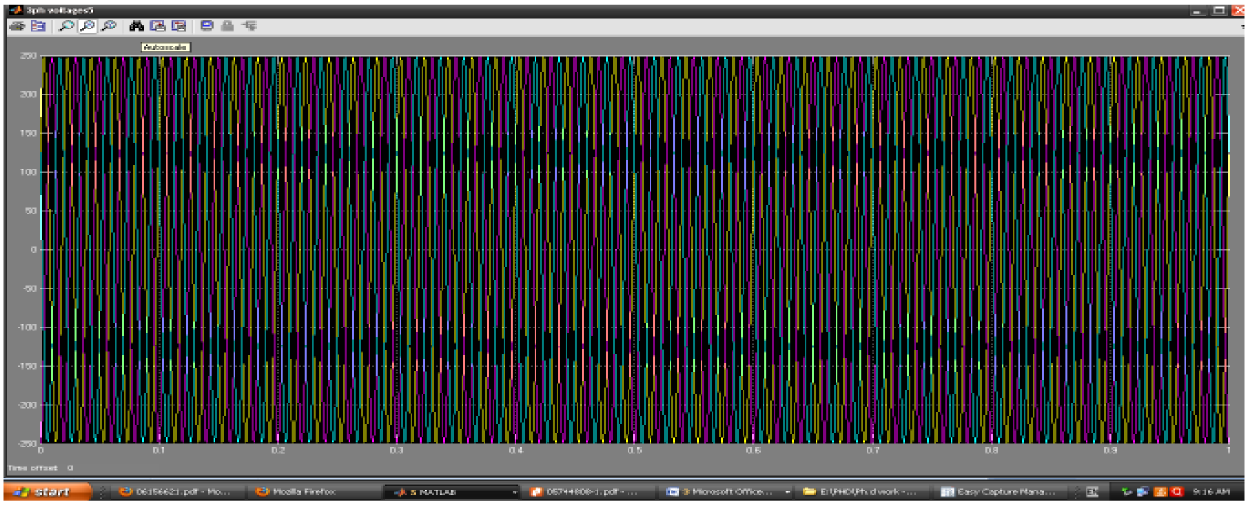

Fig. 14: Voltage profile with sag elimination when fuzzy based DVR is activated

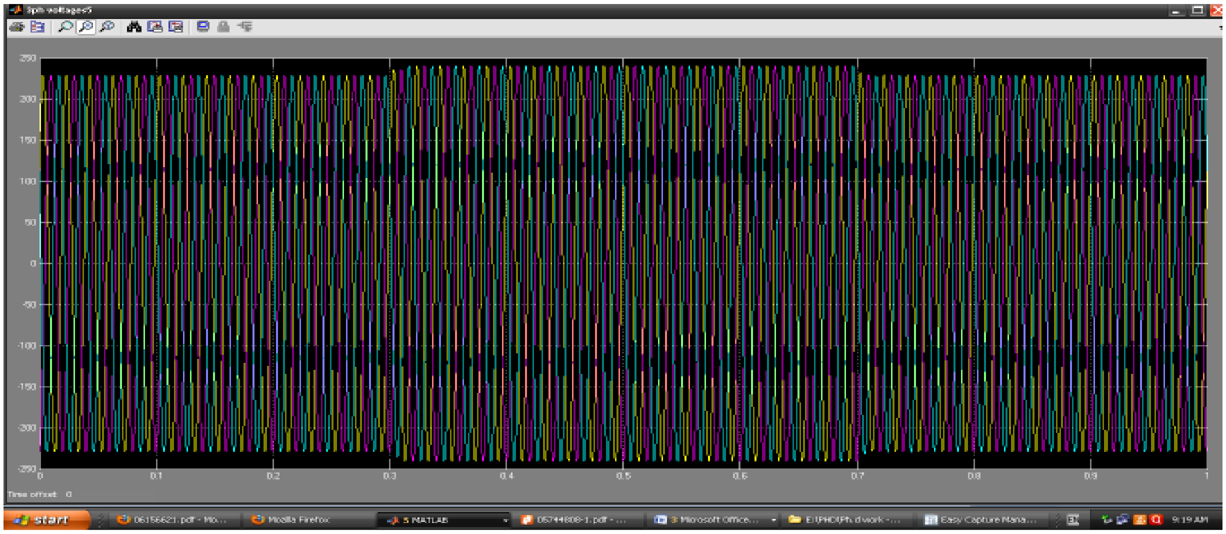

Fig. 15: Voltage profile with swell occurrence when fuzzy based DVR is not activated

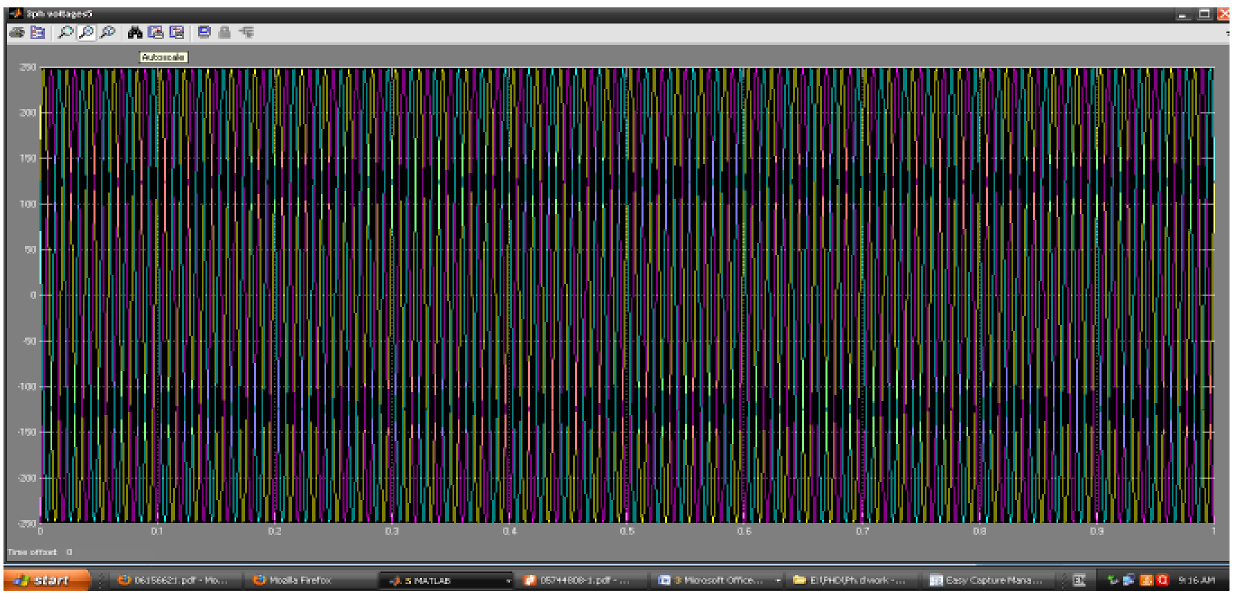

Fig. 16: Voltage profile with swell elimination when fuzzy based DVR is activated

Transition time for the fault is considered from 0.1 to 0.14 sec. The simulation results and DVR performance in the presence of DC energy storage reveals that 99.43% of sag is compensated and deviation of 0.57% is attained from three phase source voltage with 600 V of DC energy storage.

When the abnormal fault is effected the system; the sag takes place in the power line. Figure 11 represents the sag conditions in between 0.3 to 0.7 sec. When swell condition appeared in the line there will be a bulk amount of voltage will go to appear at that particular instant as shown in Fig. 13 in about 0.3-0.7 sec. When the proposed system is activated the sag and swell occurred can be cleared as shown in the Fig. 15 and 16 shows the stable voltage profile.

CONCLUSION

This study analysis and design the output profile with fuzzy based IPFC and IDVR. The fuzzy control system used has shown in dynamic system response improvement. The response for different conditions like sag and swell occur in the voltage magnitude and the active, reactive profile has presented and proved as proposed system can eliminate the problem occurring in power system. It is seen from the simulation result shows that the performance of both the devices is satisfactory. The main advantages of the proposed IPFC and IDVR are simple control, fast response and low cost. Future work will include a comparison with a laboratory experiments on a low voltage IPFC and

IDVR in order to compare simulation and experimental results.

REFERENCES

Ajaei, F.B., S. Afsharnia, A. Kahrobaeian and S. Farhangi, 2011. A fast and effective control scheme for the dynamic voltage restorer. IEEE T. Power Deliver., 26(4): 2398-2406.

Araujo, S.V., A. Engler, B. Sahan and F. Antunes, 2007. LCL Filter design for grid-connected NPC inverters in offshore wind turbines. Proceeding of the 7th International Conference in Power Electronics (ICPE'07). Daegu, pp: 1133-1138.

Chen, J., T.T. Lie and D.M. Vilathgamuwa, 2002. Basic control of interline power flow controller. IEEE Power Eng. Soc., 1: 521-525.

Dash, P.K., S. Mishra and G. Panda, 2000. Damping multimodal power system oscillation using a hybrid fuzzy controller for series connected FACTS devices. IEEE T. Power Syst., 15(4): 1360-1366.

Fitzer, C., M. Barnes and P. Green, 2004. Voltage sag detection technique for a dynamic voltage restorer. IEEE T. Ind. Appl., 40(1): 203-212.

Gyugyi, L., 1994. Dynamic compensation of AC transmission lines by solid-state synchronous voltage sources. IEEE T. Power Deliver., 9(2): 904-911.

Gyugyi, L., K.K. Sen and C.D. Schauder, 1999. The interline power flow controller concept: A new approach to power flow management in transmission systems. IEEE T. Power Deliver., 14(3): 1115-1123.

Li, Y.W., D.M. Vilathgamuwa, F. Blaabjerg and P.C. Loh, 2007. A robust control scheme for medium-voltage-level DVR implementation. IEEE T. Ind. Electron., 54(4): 2249-2261.

Nielsen, J.G., M. Newman, H. Nielsen and F. Blaabjerg, 2004. Control and testing of a dynamic voltage restorer (DVR) at medium voltage level. IEEE T. Power Electr., 19(3): 806-813.

Nielsen, J.G. and F. Blaabjerg, 2005. Detailed comparison of system topologies for dynamic voltage restorers. IEEE T. Ind. Appl., 41(5): 1272-1280.

Pratumsuwan, P., S. Thongchai and S. Tansriwong, 2010. A hybrid of fuzzy and proportional-integral-derivative controller for electro-hydraulic position servo system. Energ. Res. J., 1: 62-67.

Raviraj, V.S.C. and P.C. Sen, 1997. Comparative study of proportional-integral, sliding mode, and fuzzy logic controllers for power converters. IEEE T. Ind. Appl., 33(2): 518 -524.

Roncero-Sanchez, P., E. Acha, J.E. Ortega-Calderon, V. Feliu and A. Garcia-Cerrada, 2009. A versatile control scheme for a dynamic voltage restorer for power-quality improvement. IEEE T. Power Deliver., 24(1): 277-284.

Samuel, N.N., 2010. An intelligent fuzzy logic controller applied to multi-area load frequency control. Am. J. Sci. Ind. Res., 1: 220-226.