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Voltage Ride Through Capability Improvement in Wind Farms Using Dynamic Voltage Restorer

Lekshmi Priya A.[1], T. Prabu[2] and D. Kavitha[3]

ABSTRACT

Contribution of wind electric generation to power grid has increased substantially over the last decade. Low voltage ride through capability during grid voltage disturbance is the major trouble assosciated with wind farms based on induction generator. Dynamic voltage restorer is one of the custom power devices which is an effective solution for grid voltage sag & swell mitigation. Improvement in low voltage ride through capability of wind turbine is ensured by dynamic voltage restorer through reactive power compensation. Control strategy is based on fuzzy logic controller which offers prevailing performance in contrast to conventional control techniques. The efficiency and performance of the proposed method are investigated with different simulation studies by MATLAB/Simulink software.

Keywords: Dynamic voltage restorer (DVR), voltage sag, fuzzy logic, Low voltage ride through capability(LVRT), Wind turbine generator(WTG)

1. INTRODUCTION

Wind power plants contribution to power grid has increased significantly over the last decade. Considering aspects like cost, environmental impact, availability and security of electric supply, wind energy based power generation is promising compared to conventional sources based power generation. Main problem with the wind generator is its behaviour during grid voltage disturbances [1]. Among various problems encountered excessive reactive power absorption form grid and low voltage ride through capability is of greater importance since it affects the overall power system stability [2].

The potentiality of wind generator to remain connected to grid in the event of grid voltage disturbances is termed as fault ride through capability. This accelerates rotor and the over speed detection circuit disconnects wind turbine from the grid. Excessive reactive absorption from grid during voltage dip prevents the voltage recovery even after fault. Since the penetration of wind turbines is more or less equivalent to conventional electric sources, the sudden tripping may create an unbalance between supply and demand in power system [3]. Hence the need for fault ride through capability improvement in wind turbines is of greater importance. Commonly used generators for wind turbine applications are Permanent magnet synchronous generators (PMSG), Doubly fed induction generators (DFIG), and Fixed speed induction generators (FSIG). Active and reactive power control is not flexible in FSIG wind turbines unlike DFIG and PMSG wind turbines due to the absence of power electronic interfaces. FSIG's stator is coupled to grid directly and during grid voltage perturbations voltage recovery and compensation of reactive power must be ensured [4]. Therefore induction generators require an external protection device for low voltage ride through capability improvement. A promising approach to tackle the fault derived problems with wind turbine generators is use of FACTs devices like STATCOM, SVC, DVR, TCSC etc. DVR is an adequate solution for mitigation of voltage dip and compensation of reactive power [5, 6]. DVR is a power electronic

[1,2,3] Dept. of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore Amrita Vishwa Vidyapeetham, Amrita University, India, *Emails: lekshmipriya19391@gmail.com, t_prabu@cb.amrita.edu, d_kavitha@cb.amrita.edu*

based series active power filter which injects/supressesa proper voltage to the grid during sag period and thus retains point of common coupling (PCC) voltage constant. In case of wind farms, a single DVR can be used for all wind turbines connected in same line which reduces the overall system complexity.

1.1. Dynamic Voltage Restorer

DVR consists of

- Energy storage and DC link: Used by VSI which provides properactive power for compensation during voltage sag.Eg. Capacitor banks, Batteries etc
- VSI: Power electronic based system which transforms dc voltage furnished by energy bank to ac voltage at required, magnitude, phase and frequency. It acts a source of supply during sag. Pulse width modulated voltage source inverters are generally used.
- Line filters: Used to reduce the harmonic voltage content in the inverter output. Low pass filters are used which converts the pulsed waveform in to sinusoidal waveform.
- Injection transformer: Specially designed transformer used for injecting voltageproduced by DVR to utility voltage. It also ensures the galvanic isolation of DVR from the utility and ensures protection. To prevent the saturation ofinjection transformer it is designed to operate at twice the normal flux requirement.

2. CONTROL STRATEGY FOR DVR

Voltage sag/ swell detection, compensating voltage calculation and triggering pulses generation for inverter are the main functions of control circuit during grid voltage fluctuations. Park's transformation or dq0 transformation is a popular method for voltage sag detection. It involves transformation from three phase coordinate system to dq0 coordinate system. An idea about voltage sag magnitude and phase shift can be obtained byanalysing d & q values. After transformation the three phase quantities (V_a, V_b, V_c) are converted in to two dc quantities (V_d, V_q) which can be easily controlled[7].

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = 2/3 \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

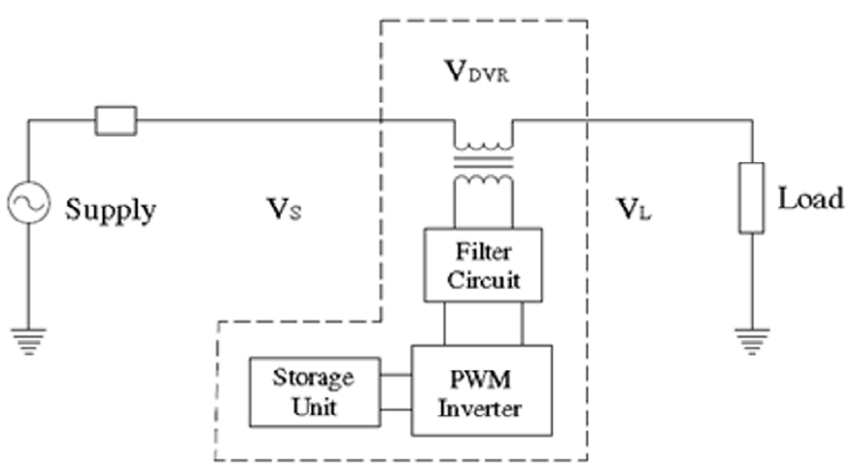


Figure 1: General configuration of dynamic voltage restorer

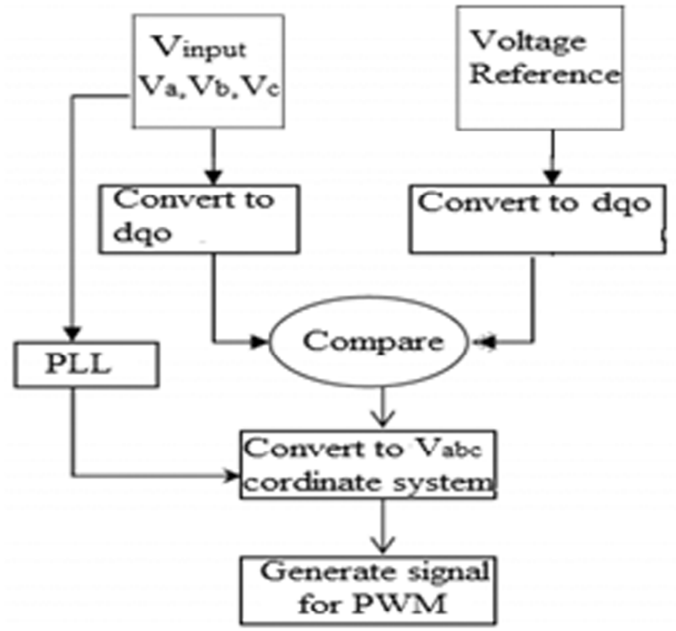


Figure 2: Flow chart of DVR control strategy

Conventional controllers like PI controllers have some disadvanatges. If operating condition is changed PI controller need to be retuned.ie linear controllers are sensitive to changes in operating point. This problem can be solved by using nonlinear controllers like fuzzy logic controllers [8].

3. FUZZY LOGIC CONTROLLER

Fuzzy logic is a language of imprecision. It uses the expert knowledge in controller design.Fuzzy logic controllers are insensitive to change in operational conditions unlike conventional controllers and this feature improves accuracy and efficiency of the system.

Fuzzy logic controller consists of four modules. Fuzzification which converts crisp inputs to linguistic variables, fuzzy inference engine which comprises of a data base with membership functions, rule base which comprises of set of rules and defuzzification which converts fuzzy outputs to crisp output [8, 9].

Two fuzzy logic controllers are used, one for signal d and other for signal q. Inputs to the fuzzy logic controller are error and error rate. These inputs are represented by the linguistic variables and LP (large

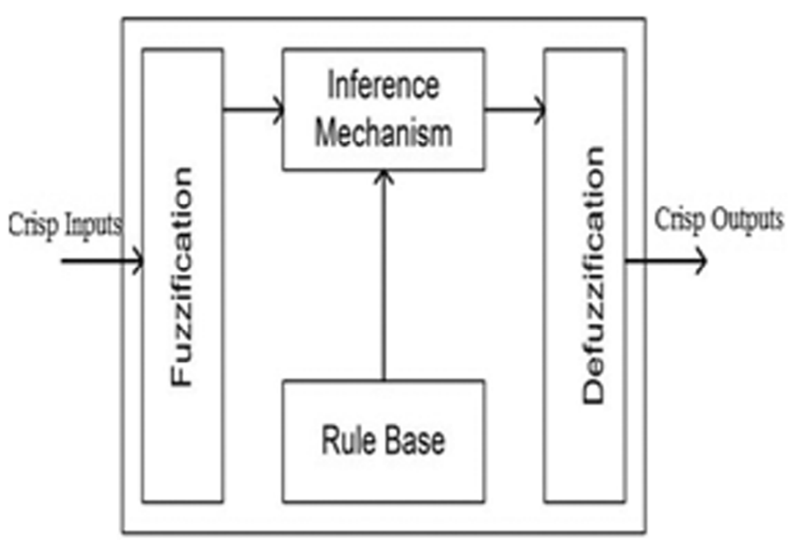


Figure 3: Block diagram of Fuzzy logic controller

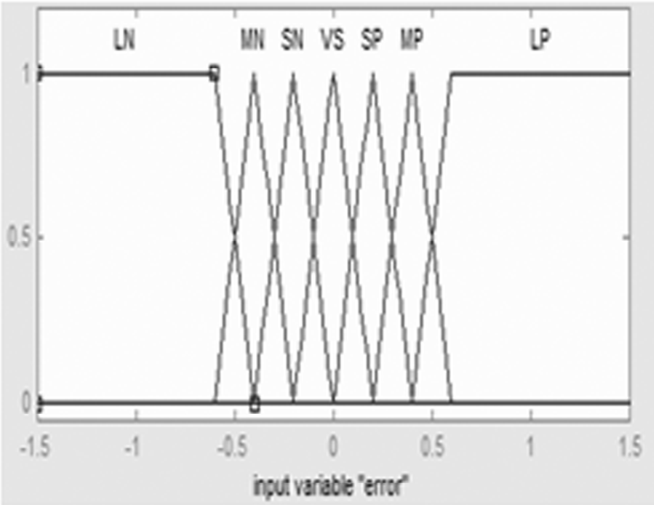


Figure 4: Membership functions- error

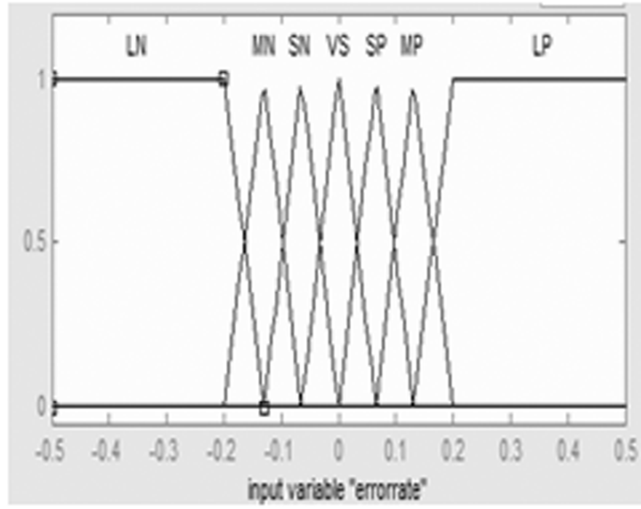


Figure 5: Membership functions- error rate

Table 1
Fuzzy decision table[10]

Error rate

error	LP	MP	SP	VS	SN	MN	LN
LP	PB	PB	PB	PM	PM	PS	Z
MP	PB	PB	PM	PM	PS	Z	NS
SP	PB	PM	PM	PS	Z	NS	NM
VS	PM	PM	PS	Z	NS	NM	NM
SN	PM	PS	Z	NS	NM	NM	NB
MN	PS	Z	NS	NM	NM	NB	NB
LN	Z	NS	NM	NM	NB	NB	NB

positive), MP(medium positive), SP(small positive), VS(very small), SN(small negative), MN (medium negative), LN (large negative) [10]

4. SIMULATION AND RESULTS

The limiting factors which affects compensation in DVR are power rating and sag magnitude. In -phase compensation method , in-phase advanced compensation method and pre sag compensation method are the main compensation strategies used in DVR .In this paper in-phase compensation method is employed. Major benefit of this technique is that the injected voltage is minimum compared to other methods of compensation [11]. Despite pre-fault voltage and current value injected voltage is always in phase with the generator voltage

The proposed system is modeled in MATLAB/SIMULINK to verify the effectiveness of designed DVR. The system configuration comprises of a 415V, 50Hz three phase voltage source connected to a wind turbine model which contains a squirrel cage induction generator of rating 200kW. A voltage sag is introduced between 1 sec to 2 sec. DVR is connected in series with grid voltage so that sag is mitigated before being fed by wind turbine of rating 200 kW. System parameters are shown in Table 2

Table 2
System parameters

Parameters	*Value*
Supply voltage	415V(rms) at 50Hz
Transition times	1 sec- 2sec
DC link voltage	400 V
Filter inductance	1mH
Filtercapacitance	2μF

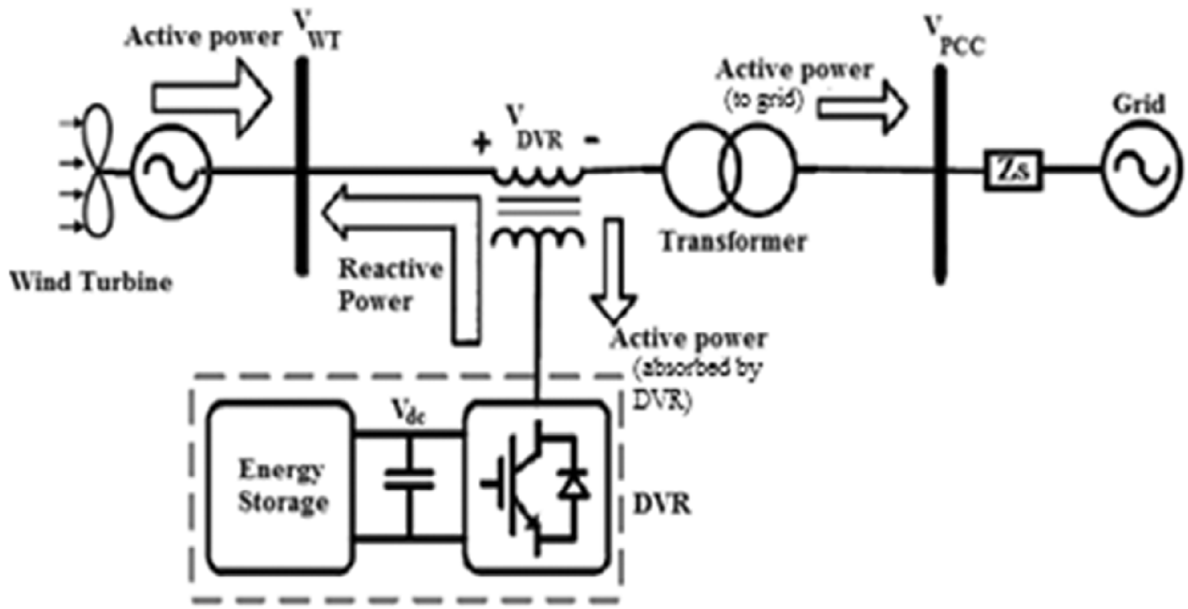
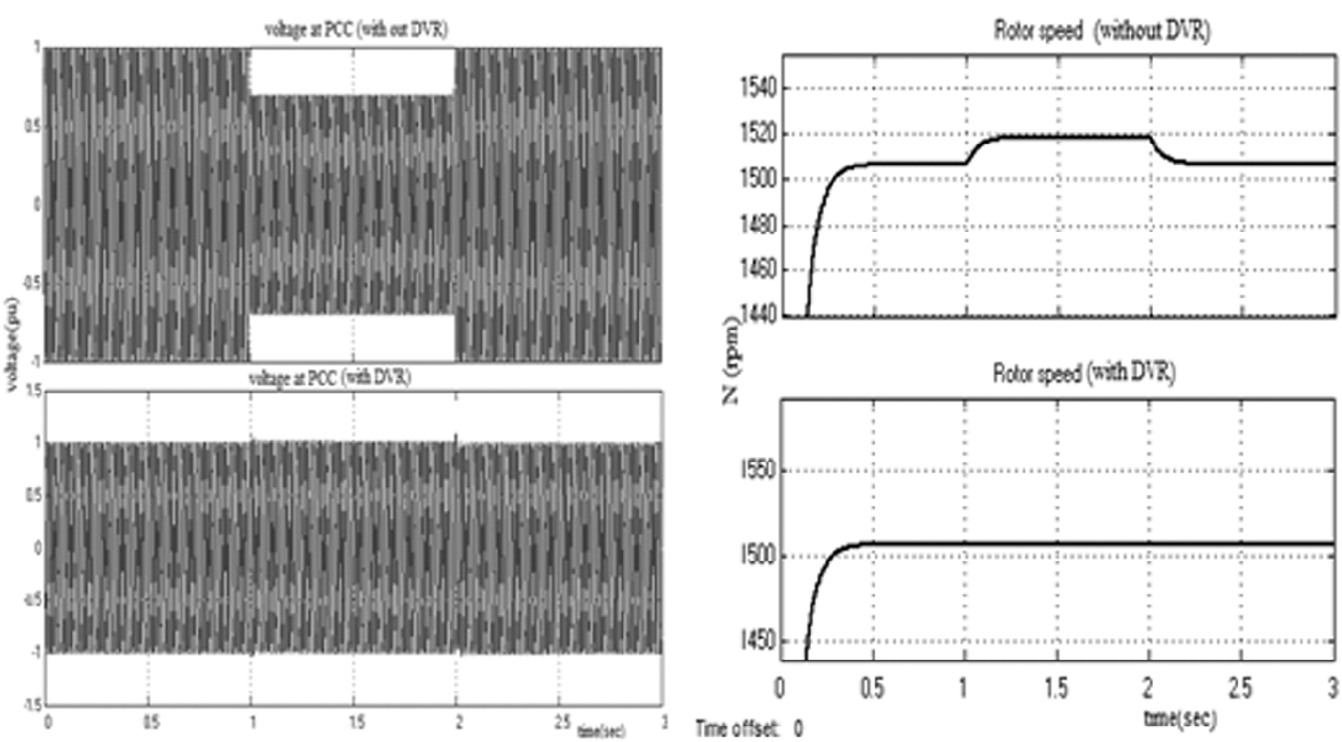
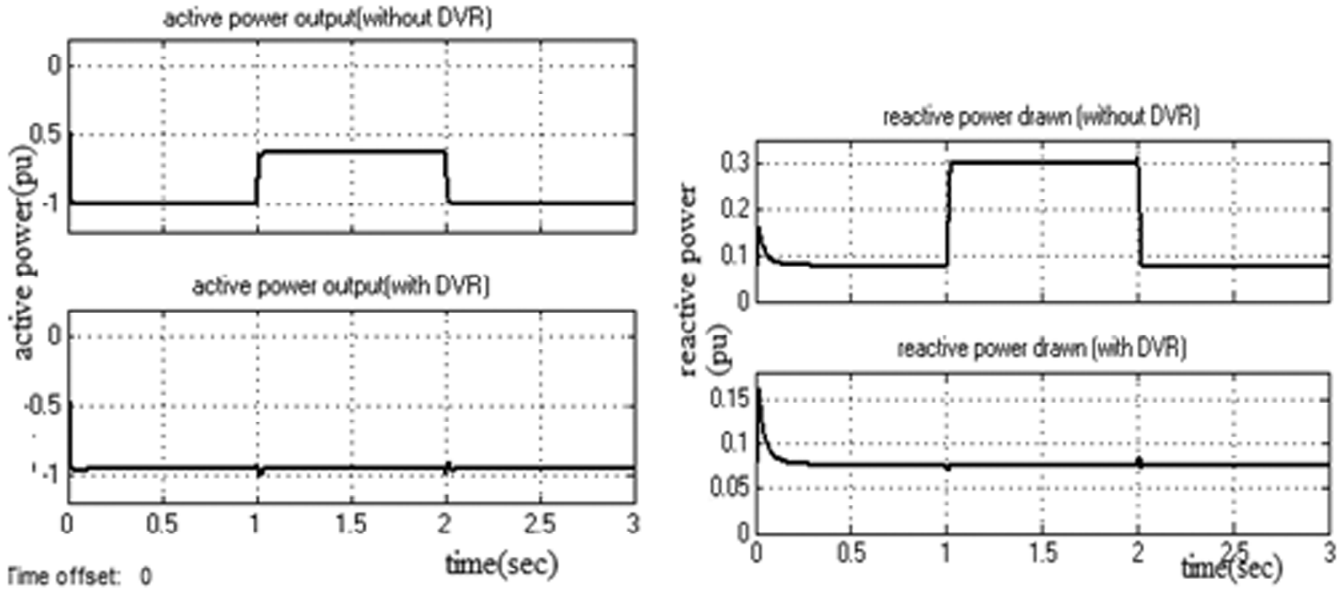


Figure 6: Power flow in a grid connected wind turbine employing DVR (during voltage sag)



a) Voltage at PCC without & with DVR **b) Rotor speed without & with DVR**

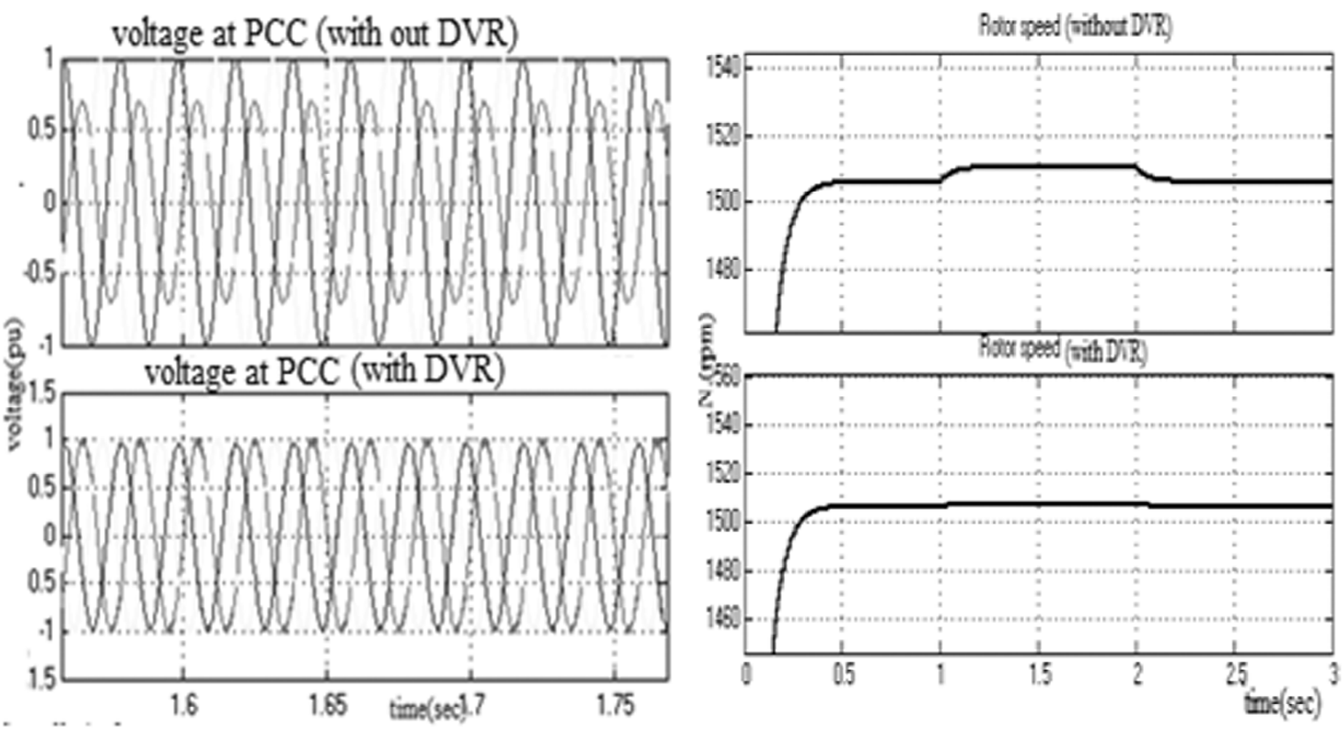


c) Active power output of WTG without & with DVR **d) Reactive power drawn by WTG without & with DVR**

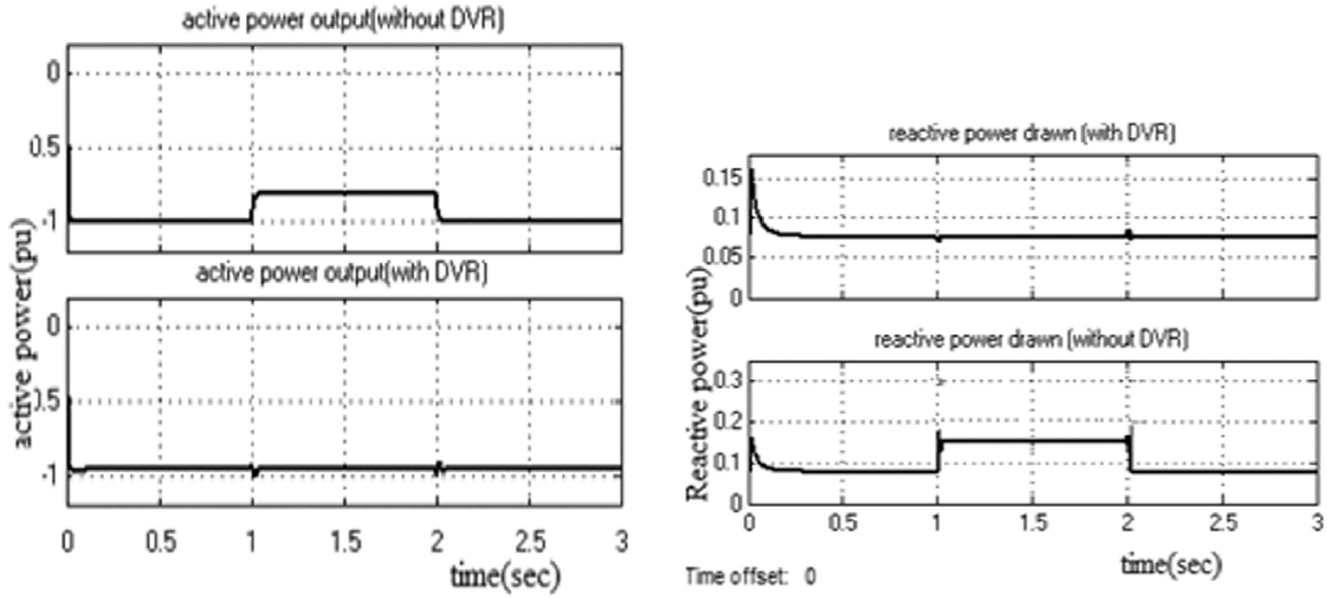
Figure 7: Case1: 30% voltage sag due to symmetrical fault

Voltage at PCC, active power output by wind turbine generator, reactive power drawn from grid and rotor speed without and with DVR for a balanced voltage sag of 30% are shown in Fig. 7. It is clear from figure that during sag period wind turbine generator's active power output lowers and reactive power drawn from the grid increases. Rated speed of rotor is 1503 rpm. During sag period rotor accelerates and rotor speed becomes 1520 rpm. With the use of DVR voltage at PCC, active power output, reactive power drawn and rotor speed remains constant.

Voltage at PCC, active power output by wind turbine generator, reactive power drawn from grid and rotor speed without and with DVR for an unbalanced voltage sag of 30% are shown in Fig. 8. Unsymmetrical



a) Voltage at PCC without & with DVR **b) Rotor speed without & with DVR**

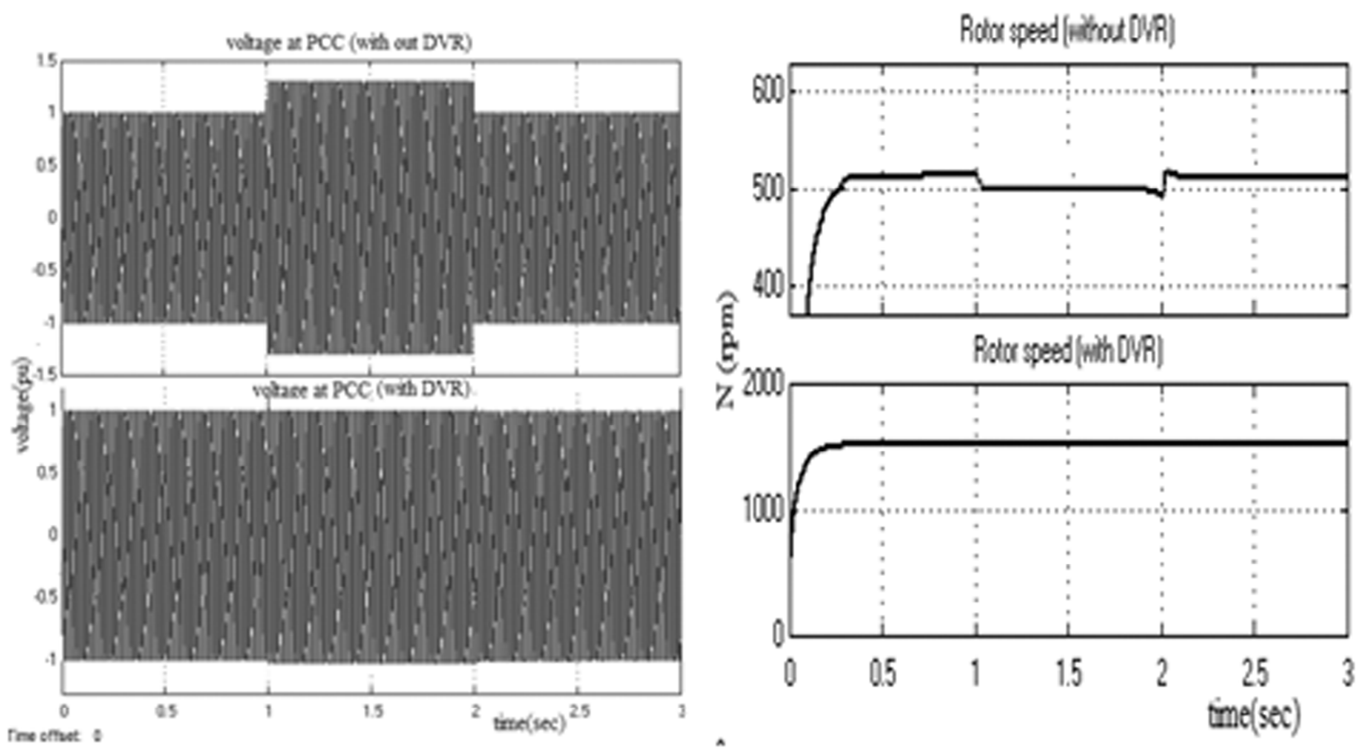


c) Active power output of WTG without & with DVR **d) Reactive power drawn by WTG without & with DVR**

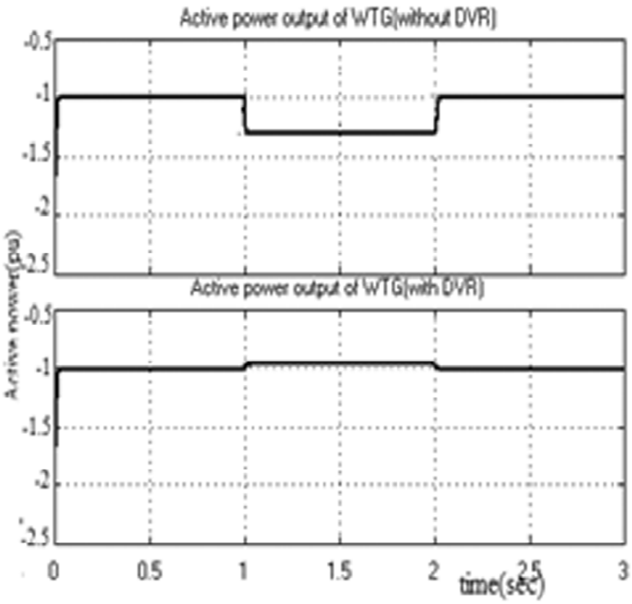
Figure 8: Case 2: 30% voltage sag due to unsymmetrical fault

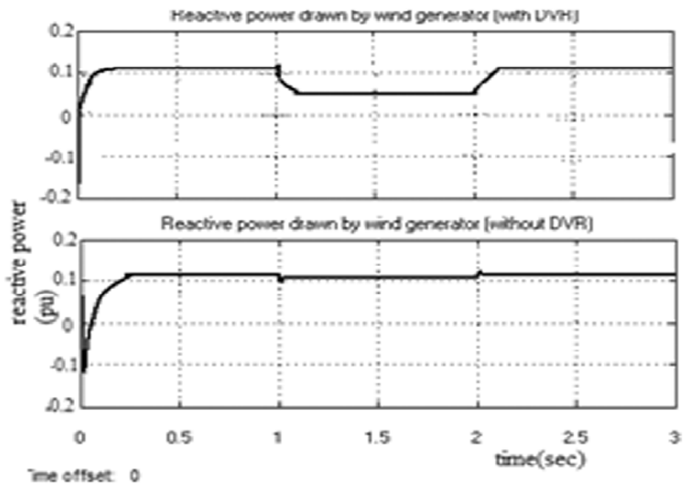
fault is the most common fault occurring in power system. Results are similar as in the case of balanced voltage sag. Increase in rotor speed and reactive power drawn has a less value compared to balanced voltage sag during sag period. By using DVR voltage at PCC is maintained at 1pu, rotor speed, active power output and reactive power drawn are maintained constant

During voltage swellwind turbine generators active power output rises, reactive power drawn from the grid decrease and rotor decccelerates. With the use of DVR volt ageat PCC, active power output, reactive power drawn and rotor speed are maintained constant.



a) Voltage at PCC without& with DVR **b) Rotor speed without & with DVR**





c) Active power output of WTG without & with DVR

d) Reactive power drawn by WTG without & with DVR

Figure 9: Case 3: 30% balanced voltage swell

Wind farm is modelled and a single DVR is designed for the wind farm so that all wind turbines connected is able to withstand grid voltage disturbances. Wind farm comprises of four wind turbines of different rating and various wind speeds. Wind farm details and DVR specifications are given in Table2 and Table3

Table 2
System parameters

Parameters	*Value*
Supply voltage	415V(rms) at 50Hz
Transition times	1 sec- 2sec
DC link voltage	1000 V
Filter inductance	12mH
Filtercapacitance	18μF

Wind farm details are given in Table 3

Table 3
Wind farm details

Wind turbine generator rating	*Wind speed*
200kW	14m/s
500kW	10m/s
200kW	10m/s
200kW	9m/s(0.5-1sec), 9-14m/s(1-2 sec), 14-10m/s(2-3sec)

Wind turbine generator subjected to varying wind speed is shown in Fig. 11. During increased wind speed reactive power drawn from grid reduces and active power output of generator increases. Voltage sag is in between 1 sec to 2 sec. DVR absorbs active power and gives reactive power to generatorand thus low voltage ride through capability is enhanced

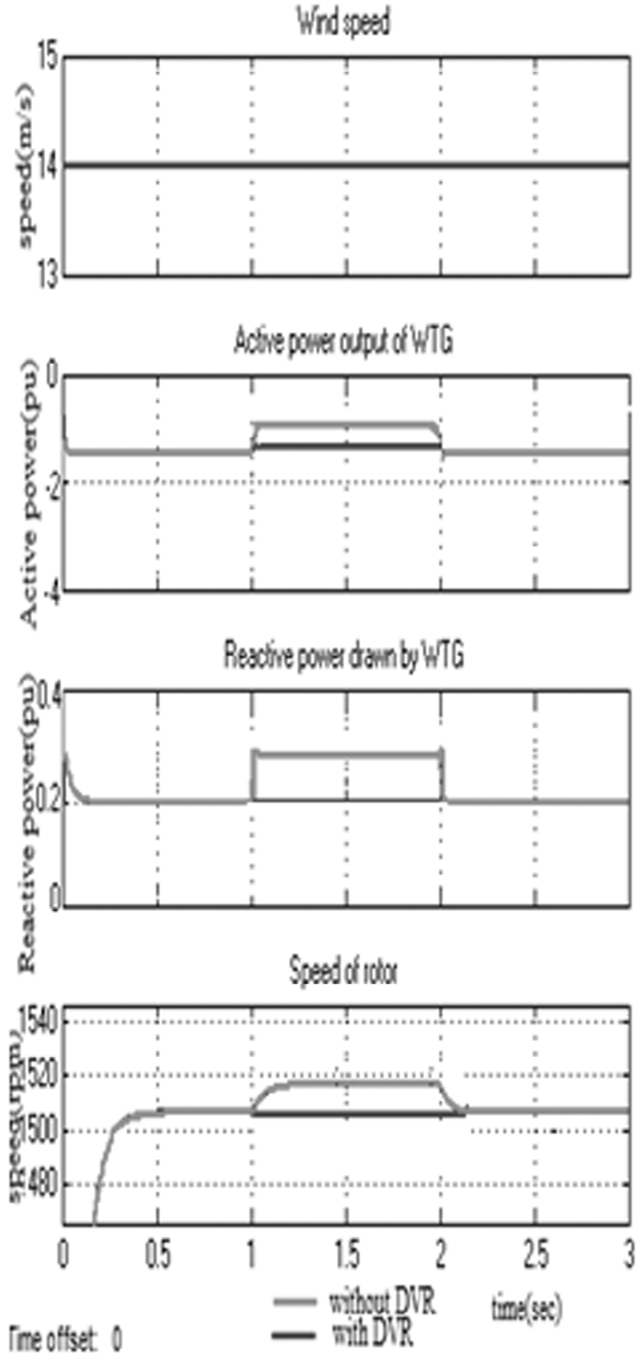


Figure 10: Wind speed, active power output reactive power drawn & rotor speed (WTG1)without & with DVR for 30% balanced voltage sag

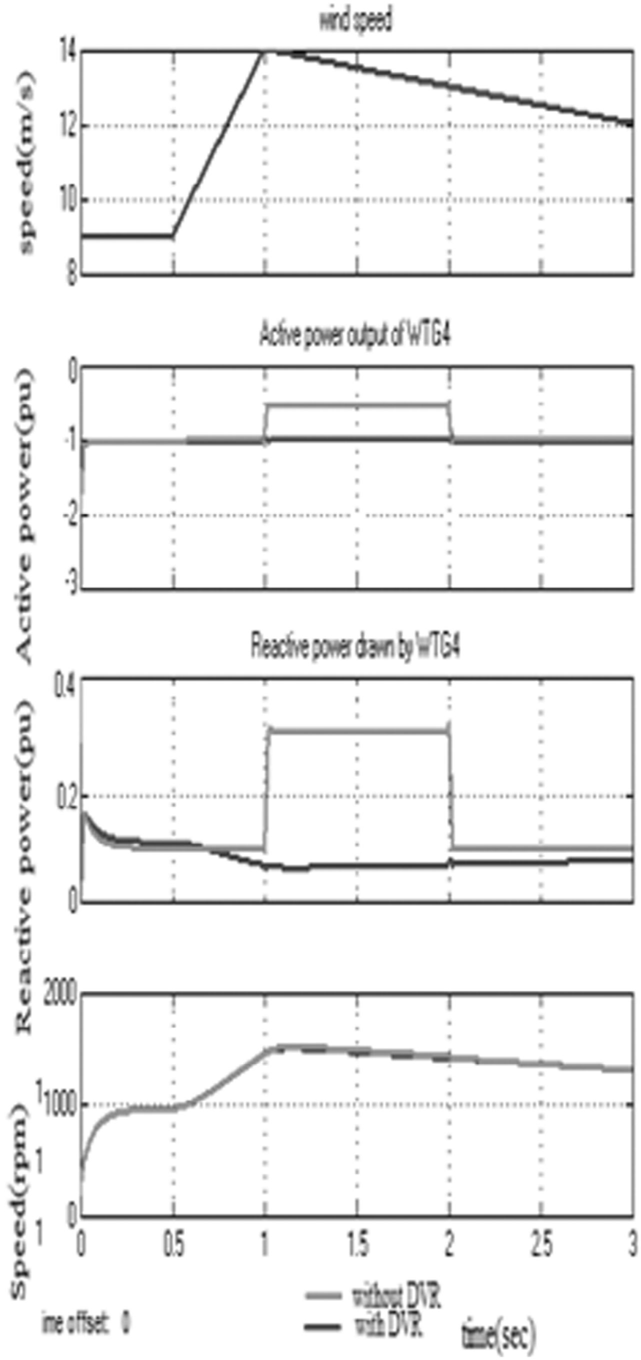


Figure 11: Wind speed, active power output reactive power drawn & rotor speed (WTG4) without & with DVR for 30% balanced voltage sag

FFT analysis of PCC voltage without and with DVR are shown in Fig.12 and Fig.13 respectively. With the use of DVR, (THD) total harmonic distortion in PCC voltage is reduced and becomes less than 5% which is within the acceptable limits.

The results shows that all the wind turbines connected in wind farm has improved voltage ride through capability under conditions of unbalanced and balanced voltage sag and swell in the grid side. Control part of DVR remains same irrespective of wind turbine rating only DVR power circuit is changed. Even though cost of DVR is increased by using a single DVR for the wind farm the overall system complexity is reduced. So in large scale it may become economical too. It also ensures improved reactive power compensation and overall power system stability.

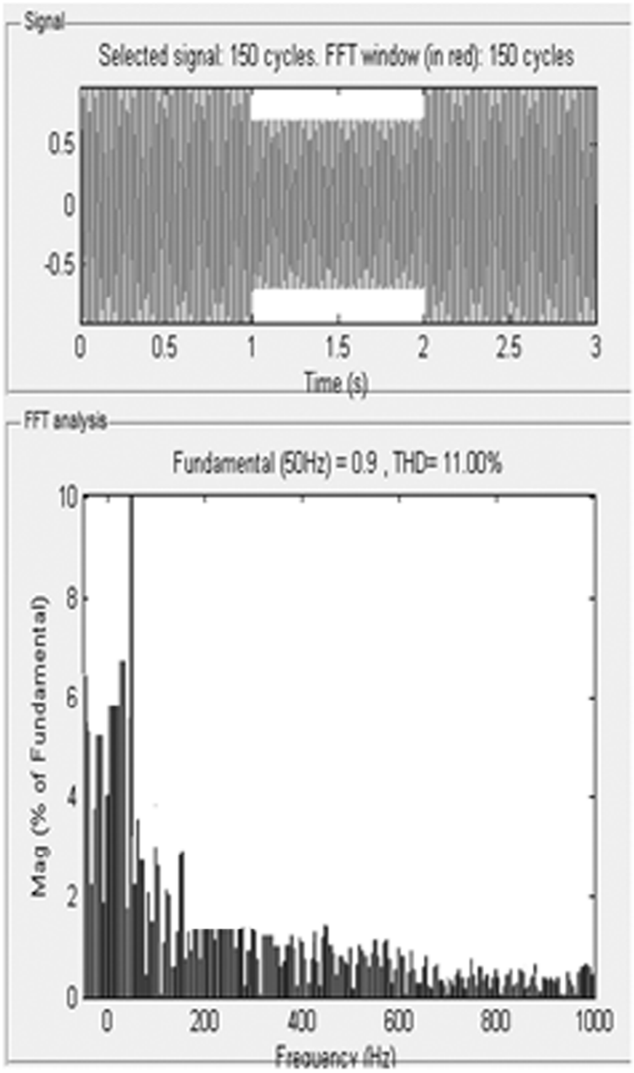


Figure 12: FFT analysis of voltage at PCC without DVR

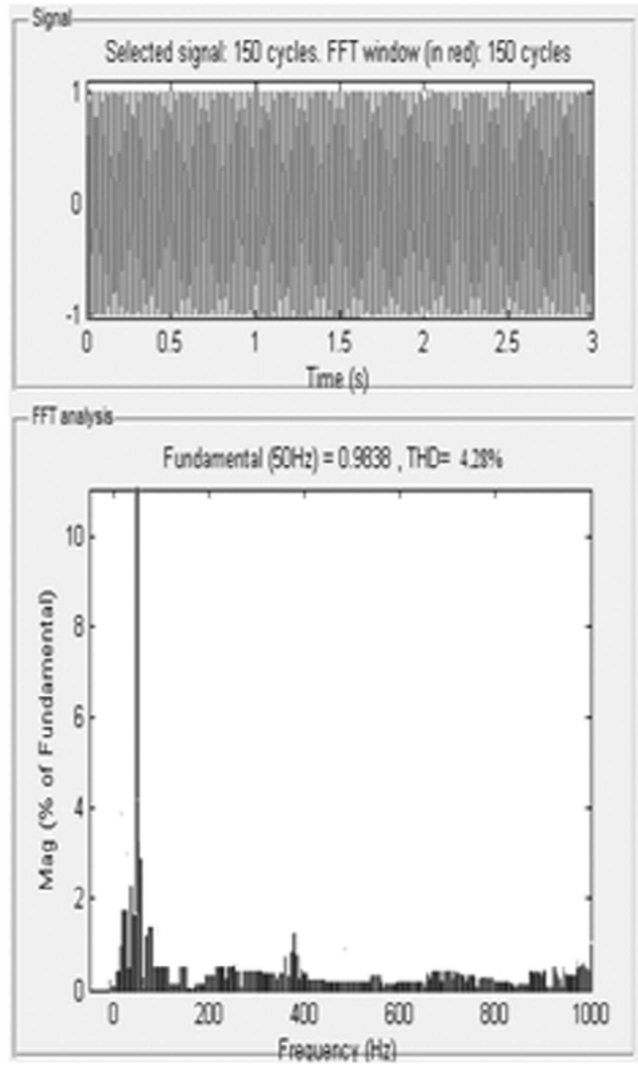


Figure 13: FFT analysis of voltage at PCC with DVR

5. CONCLUSION

In this paper a DVR is proposed for fault ride through capability improvement in a wind farm based on asynchronous squirrel cage wind generator. DVR is able to transfer reactive and real power demanded by the wind generators in wind farm under conditions of balanced and unbalanced voltage swell and sag in grid. Modelling of wind farm is done in MATLAB/SIMULINK and a control strategy based on fuzzy logic controller is considered which offers superior performance compared to conventional control techniques. THD in wind turbine generator side voltage is reduced with in the acceptable limits by the use of DVR. Using a single DVR for wind farm is beneficial considering aspects like complexity, reactive power and harmonic compensation. It is found that the chance of disconnection of wind turbine during grid voltage disturbances is minimised using DVR

REFERENCES

[1] Ramirez, D., Martinez, S., Platero, C. A., Blazquez, F., & De Castro, R. M. (2011). Low-voltage ride-through capability for wind generators based on dynamic voltage restorers. *Energy Conversion, IEEE Transactions on*, *26*(1), 195-203.

[2] Leon, A. E., Farias, M. F., Battaiotto, P. E., Solsona, J. A., & Valla, M. I. (2011). Control strategy of a DVR to improve stability in wind farms using squirrel-cage induction generators. *Power Systems, IEEE Transactions on*,*26*(3), 1609-1617.

[3] Chompoo-Inwai, C., Yingvivatanapong, C., Methaprayoon, K., & Lee, W. J. (2005). Reactive compensation techniques

to improve the ride-through capability of wind turbine during disturbance. *Industry Applications, IEEE Transactions on*, *41*(3), 666-672.

[4] Vanitha, V., &Devarajan, N. (2012). Transient Stability Improvement of a squirrel cage induction generator in wind farm using STATCOM with Supercapacitor. *Wind engineering*, *36*(2), 197-218

[5] Ramasamy, A. K., Iyer, R. K., Ramachandaramuthy, V. K., &Mukerjee, R. N. (2005, November). Dynamic Voltage Restorer for voltage sag compensation. In *Power Electronics and Drives Systems, 2005. PEDS 2005. International Conference on* (Vol. 2, pp. 1289-1294). IEEE.

[6] Nielsen, J. G., &Blaabjerg, F. (2005). A detailed comparison of system topologies for dynamic voltage restorers. *Industry Applications, IEEE Transactions on*, *41*(5), 1272-1280..

[7] Jowder, F. A. L. (2009). Design and analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation. *Generation, Transmission & Distribution, IET*, *3*(6), 547-560.

[8] Jurado, F., Valverde, M., &Carpio, J. (2003, May). Voltage sag correction by dynamic voltage restorer based on fuzzy logic control. In *Electrical and Computer Engineering, 2003. IEEE CCECE 2003. Canadian Conference on*(Vol. 1, pp. 421-424)..

[9] Ashari, M., Hiyama, T., Pujiantara, M., Suryoatmojo, H., &Purnomo, M. H. (2007, September). A Novel Dynamic Voltage Restorer with Outage Handling Capability Using Fuzzy Logic Controler. In *Innovative Computing, Information and Control, 2007. ICICIC'07. Second International Conference on* (pp. 51-51). IEEE.

[10] BAYINDIR, K. Ç.,Teke, A., & TÜMAY, M. (2007, September). A robust control of dynamic voltage restorer using fuzzy logic. In *Electrical Machines and Power Electronics, 2007. ACEMP'07. International Aegean Conference on* (pp. 55-60). IEEE.

[11] Singh, B., Chandra, A., & Al-Haddad, K. (2014). *Power quality: problems and mitigation techniques*. John Wiley & Sons.