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Dynamic Voltage Restorer for Voltage Compensation and Fault Current Limiting Functions

Nikhy P C, MTech Scholar and Anil Antony P,
Asst. Prof. EEE, Thejus Engineering College,
Erumappetty, Thrissur, Kerala 680584.

***Abstract*—Power quality has become the major area of concern at present due to the increase in modern and sophisticated loads connected to the distribution system.DVR is one of the series compensating type custom power devices. In this paper the application of dynamic voltage restorers (DVR) on power distribution systems for both fault current limiting and voltage compensation. The new topology uses a bidirectional thyristor switch across the output terminals of a conventional back-to-back DVR.When a short circuit occurs, the DVR controller will deactivate the faulty phase of the DVR and activate its thyristor to insert the DVR filter reactor into the grid to limit the fault current. The fault condition is identified by sensing the load current and its rate of change. Both modeling and experimental results confirm the effectiveness of the new fault current limiting dynamic voltage restorer concept for performing both voltage compensation and fault current limiting functions.**

Index Terms*— Dynamic Voltage Restorer (DVR), Fault Current Limitation, Series Resonance, Series Transformer, Voltage Compensation.

I. INTRODUCTION

Modern power systems are complex networks, consists of generating stations and load centers interconnected through long power transmission and distribution networks. The main concern of consumers is quality and reliability of power supplies at various load centers. Even the power generation in most well-developed countries are reliable, but the quality of the supply is not consistent. Power distribution systems must provide their customers with an uninterrupted flow of energy with smooth sinusoidal voltage. However, in reality, power systems, especially in the distribution systems, we have numerous nonlinear loads, which significantly affects the quality of power [2]-[5]. The purity of the waveform is lost due to the integration of these nonlinear loads into the system. This ends up producing many power quality issues. Apart from the nonlinear loads, some usual (e.g. capacitor switching, motor starling) and unusual (e.g. faults) events could also impose power quality problems. The consequences of power quality problems could range from a simple nuisance flicker to production shutdown.

Voltage sag is defined as a rapid decrease in supply voltage down 90% to 10% of nominal, after a short recovery time A typical duration of sag is, 10 ms to 1 minute according to the standard. Voltage swell, in contrast, is defined as a sudden increase in supply voltage up 110% to 180% of RMS voltage at the network fundamental frequency within the duration from 10 ms to 1 minute. Turning off a large inductive load or energizing a bulk capacitor bank is a typical system event that creates swells. To recompense the voltage sag/swell in a power distribution system, suitable devices need to be connected at appropriate locations. These devices are installed at the point of common coupling [PCC] which is described as the point where the ownership of the network changes. The DVR is one of the custom power devices which can improve power quality, especially, voltage sags and voltage swells. Nowadays fault current levels are increased and these fault levels may exceed the current rating of system equipment. In this circumstance, the recognition of a fault current limiter (FCL) is going to be expected strongly [6]. FCL arrangements not only are used for effective control of fault current in power system but also are applied to a variety of applications such as power quality and transient stability improvement. However, these structures have two main problems. Firstly, because of high technology and costs (construction and maintenance costs) of superconductors, these are not commercially available. Secondly, by using these structures, the peak of current is not constant during the fault and has increased in variation. So, for the faults that exceed for a long time, it may be harmful to utility equipment, even considering high-speed breakers. Besides, by the increase of fault current, selection of the power rating of breakers will be a great problem. In this paper, a new topology of series resonance type FCL is introduced. Using non-superconducting inductor in this topology tends to low construction and maintenance costs. By the proposed FCL, fault current's peak will be constant. Also, the capacitor of this structure can be used as a series compensator in conventional operation; this is not possible in previously introduced series resonance type FCLs because in those structures inductor and capacitor are in resonance condition under normal operation of power system.

A new concept of fault current limiting dynamic voltage restorer (FCL-DVR) is proposed in this paper. This topology can operate in two operational modes, compensation mode for voltage fluctuation and the fault current limiting mode. It should be noted that only one additional bidirectional thyristor switch is connected across the output terminals of each phase of the conventional DVR, greatly simplifies its implementation. Furthermore, the new FCL-DVR can maintain the same power rating as the conventional DVR without FCL function.

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II. TOPOLOGY AND PRINCIPLE OF OPERATION

A. Topology

The topology of the FCL-DVR is shown in Fig.1. It consists of three single phase bridges. Each single phase topology consists of a shunt transformer, a back-to-back power converter, a series transformer, and a bidirectional thyristor. The input rectifier module of the back-to-back converter is connected to the grid through a shunt transformer (e.g., T1) with L_z to remove the high-frequency ripples, and rectifies the power from the grid to the dc link capacitor. The output inverter module transforms the power from the dc link capacitor is to compensate voltage fluctuation, and connected to the grid through a series transformer (e.g., T4) and an LC output filter. Through the dc link capacitor C_d, the input rectifier module and output inverter module are connected. The bidirectional thyristor in each phase is connected across the output terminals of the output inverter module so as to to provide the short circuit fault current limiting function. u_s, u_{dc}, u_c, u_{DVR}, and u_l represents the supply voltage, dc link voltage, output voltage of FCL-DVR, the output voltage of FCL-DVR at the primary side of the series transformer, and PCC voltage, respectively. I_S denotes the supply current, and i_l is the load current. Z_s and Z_l are the equivalent impedances of the grid and the transmission line, respectively.

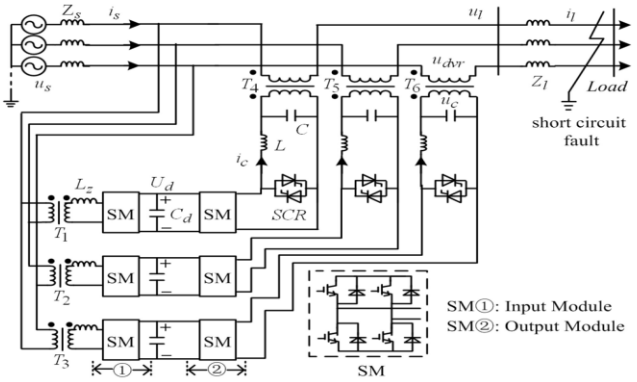

Fig. 1.The topology of FCL-DVR.

As shown in Fig. 1, the major difference between new FCL-DVR and conventional DVR is the addition of the three crowbar bidirectional thyristors. The bidirectional thyristor for each phase will be deactivated or activated depending on the operating conditions. When the grid is in normal operation, the bidirectional thyristor is deactivated, and the new system operates in the voltage compensation mode so as to compensate voltage fluctuations. When a short-circuit fault occurs, the bidirectional thyristor is activated to insert the inductor into the main current path through the series transformer. Simultaneously the insulated gate bipolar transistors (IGBTs) of the pulse width modulation (PWM) inverter will be switched off to deactivate the inverter fully. The FCL-DVR thus operates in the FCL mode. The maximum fault current can be controlled by adjusting the firing angle of the thyristor, the series transformer ratio k and the reactor L. Consequently, both voltage compensation and the fault current limiting functions can be provided by the FCL-DVR at the same power rating of a conventional DVR. When a short circuit fault or a voltage sag occurs, the fluctuation of supply voltage influences the stability of dc link voltage. If three shunt transformers are delta connected on the high-voltage side, then the voltage fluctuation on the low-voltage side will be smaller than the Y-connection mode. Meanwhile, delta-connection can also suppress the 3rd harmonics which caused by the fluctuation of dc link voltage. So in this paper, the shunt transformers are delta-connected in the high-voltage sides.

B. Principle of operation

1) Voltage Compensation Mode: When the FCL-DVR operates in the voltage compensation mode, the bidirectional thyristor is deactivated. Then the FCL-DVR operates as a conventional DVR, so it is similar to a voltage controlled voltage source, as shown in Fig. 2. When voltage fluctuation or an unbalance occurs, FCL-DVR can be controlled as a compensation voltage $u1$, which is in series with supply voltage. So the load voltage is maintained, and the power quality can be improved. The input module of the back-to-back converter is used to supply dc link voltage.

2) Fault Current Limiting Mode: When a short circuit fault happens, the faulty phase of the inverter is turned off, and the bidirectional thyristor is activated. At this condition, the reactor L is inserted into the grid on the secondary side of the series transformer so that fault current can be limited by the reactor.

Z_{eq2} is the equivalent impedance of secondary side of the series transformer

$$Z_{eq2} = \omega_0 L * \frac{\pi}{2\pi - 2\alpha + \sin 2\alpha}$$

α is the firing angle of crowbar thyristors

$$Z_{eq} = k^2 Z_{eq2}$$

K is the ratio of series transformer

$$I_l^F = \frac{U_S}{Z_S + Z_{eq} + Z_l}$$

The fault current is mainly limited by Zeq. By selecting the parameters of k, L and adjusting the conduction angle of crowbar bidirectional thyristor.

II. PROPOSED CURRENT CONTROL SCHEME

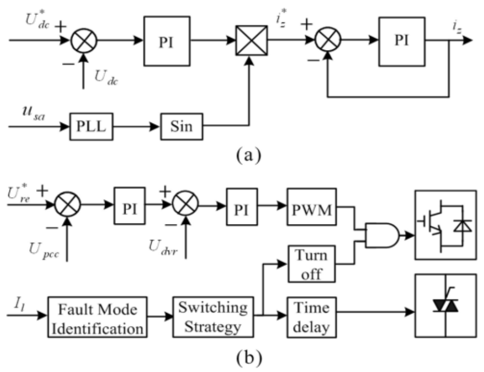

Fig. 2.Control block diagram of the FCL-DVR. Control block diagram of (a) rectifier to maintain the dc link voltage and (b) inverter and crowbar bidirectional thyristor.

As mentioned before, the FCL-DVR can operate in one of the two operation modes according to the grid state. There is two main aspect that influences the performance of the FCL-DVR: the operation mode switching strategy and fault current detection method. When the FCL-DVR is in the voltage compensation mode, it operates as a conversational DVR. As shown in Fig. 2(a), a control method based on the instantaneous value of dc link voltage, the input current of PWM rectifier, and PCC voltage is adopted in this paper [20]. Using this control method, a fast response, low steady state error of voltage compensation can be achieved. The three-phase topology is composed of three single phase bridges, and each phase can be controlled individually, so the unbalance compensation can be carried out easily. When a short circuit fault happens (e.g., a three-phase to ground fault) the fault current will be 6–10 times that of the normal load current. Assuming the fault current in steady state is λ times of the load current. When a short-circuit fault occurs, the ratio of change of fault current is $\lambda * \omega$ times larger than that of the normal current [21]. So by sensing the ratio of change of current, short circuit fault can be detected with fast speed. But it is easy to be influenced by disturbances. To make sure that the fault current can be detected fast and accurately, a fault current detection method by sensing the load current and its rate of change is developed, as shown in Fig. 5. i_{re} is the reference value of fault detection, which is larger than the peak value of load current. T is the sampling period. i_l and $i^F{}_l$ are the differences between the adjacent sampling values of load current and fault current, respectively.

III. SIMULATION RESULTS AND OBSERVATIONS

The simulation model of the FCL-DVR in grid connected mode is built by MATLAB simulation software to verify the effectiveness of the proposed current controller. The supply voltage is set at 13kV with a 1MW resistive load. The maximum fault current is permissible to be six times of the nominal load current. Table I shows the system parameters. Two cases are taken into account in the simulation,

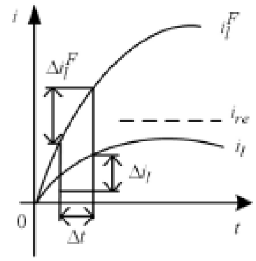

Fig. 3. Fault current detection by sensing load current and its rate of change.

1) Case I: Voltage sag and unbalanced voltage event
2) Case II: Fault conditions-
   a) Single-phase to ground fault
   b) Phase-to-phase fault
   c) Two-phase to ground fault
   d) Three-phase to ground fault

In Cases I and II, grid voltage is assumed to be a pure sinusoid.

PARAMETERS	VALUES
Compensation capacity/KVA	132
DC Link voltage (V)	800
Series transformer ratio	8:1
DC link capacitance/ μF	15000
Shunt transformer ratio	23.5
Output reactor of PWM rectifier/mH	1
Reference value of fault detection i_{re}/A	100
Reference value of change of ratio I_{op}/KA	30.76

Table 1: System Parameters

A. Voltage Compensation Function of FCL-DVR

Fig.5(a) and (b) shows the voltage compensation performances of the FCL-DVR for voltage sag and unbalance voltage event respectively.Fig.4. (a) Voltage sag happens between 0.4 and 0.5s with a depth of 20%. When the FCL-DVR is put into operation at 0.4s, the inverter of FCL-DVR output is a compensation voltage absorbing active power from the rectifier through the dc link capacitor. The load voltage at the point of common coupling can be kept without interruption. So the load can be operated regularly with little influence by the supply voltage sag. In fig. 4. (b) three phase disturbance occurs between 0.4 and 0.5s. The voltage of phase A is not varied, the voltage of phase-B drops 1 kV, the voltage of phase-C rise 1 kV and phase angle keeps invariant. The FCL-DVR put into operation at 0.4 s. When the FCL-DVR is adopted, load voltage at the point of common coupling is nearly kept unchanged, and the dc link voltage has fluctuation when power grid voltage swells or sags, but soon will be able to steady around 800 V.

B. Fault Current Limiting Function of FCL-DVR

The simulations of FCL-DVR of Line to ground fault (phase A), line-to-line short-circuit fault (Phases A and B), double line to ground fault (Phases A and B), and three-phase to a ground fault are given in Fig. 4.(c)-(f). In Fig. 4(c), single phase (phase A) to ground fault occurs at 0.4 s and disappears at 0.5s. When single phase to ground fault occurs at 0.4 s, the PCC voltage of the healthy phase rise to the line voltage, and

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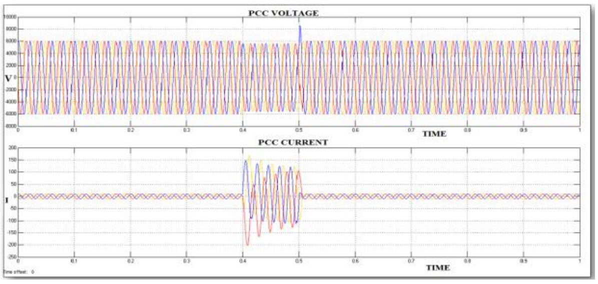
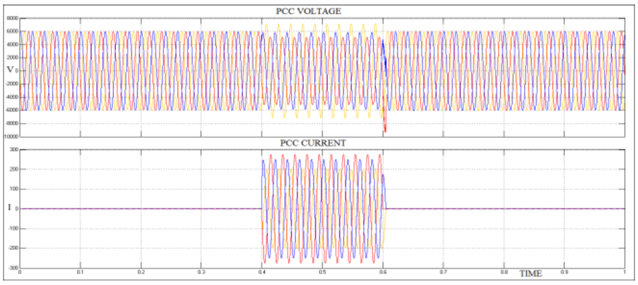
the fault voltage is zero. The line voltage of PCC and the load current keep unchanged. As the shunt transformers are delta-connected, the voltage on the low-voltage side of the shunt transformers is not influenced. So the dc link voltage is stable when single phase to ground fault occurs, and the healthy phases are not interrupted. After the fault disappears at 0.5 s, the load current returns to be balanced. FCL-DVR still operates in the voltage compensation mode, and the dc link voltage is stable.

In Fig. 4(d), phases A to B short circuit fault occurs between 0.4 and 0.5 s. When the short circuit fault was detected by FCL-DVR, FCL-DVR will switch to fault current limiting mode. From Fig. 4(d), we can see that when to short-circuit fault occurs, the load current of the faulted phase will increase immediately. But when the FCL-DVR is put into operation, the fault current of phases A and B can be limited to 880.4A in about two cycles with an inrush current around 2 kA (Peak current), which is related to the time of putting into operation. And the steady state fault current is determined by the phase to phase voltage, the equivalent impedance of the grid, the equivalent impedance of transmission line, and L. Fig. 4(d) also illustrates that only the fault phases (phases A and B) are controlled by the FCL-DVR, and the healthy phase (phase C) is not interrupted. The healthy phase could operate normally. When the FCL-DVR is inserted into operation at 0.4 s, the dc link voltage rises less than 3%, which means the FCL-DVR can work stably in the limiting process. When the fault disappears at 0.5 s, the faulted phase of FCL-DVR switches to voltage compensation mode immediately, with a5% rise of dc link voltage. The dynamic limiting process and recovery process will be discussed in dynamic simulations.

In Fig. 4(f), three phases to ground fault occurs between0.4 and 0.5 s. Similarly as phase-to-phase short circuit fault and two-phase to ground fault, the FCL-DVR can immediately switch to fault current limiting mode while the fault occurs, and also can switch to voltage compensation mode while the fault disappears. The dc link voltage is stable with less than 3% rise in the limiting and recovery process. From Fig. 4, we can see that FCL-DVR could realize a good steady performance when different kinds of transient short circuit fault happen.



(a)



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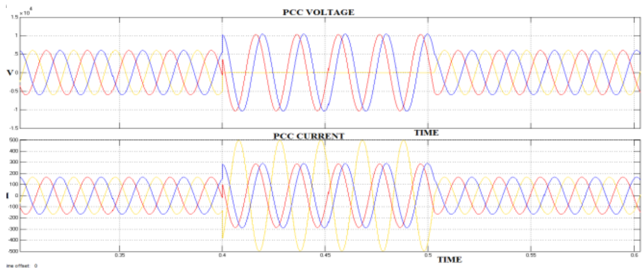

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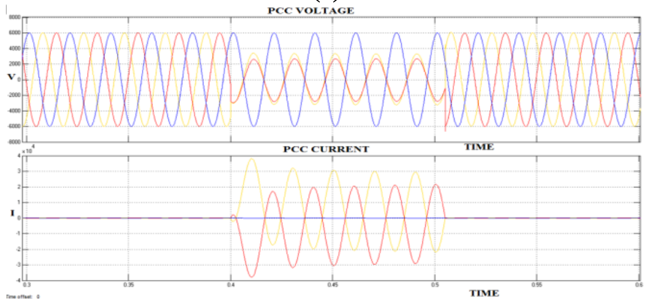
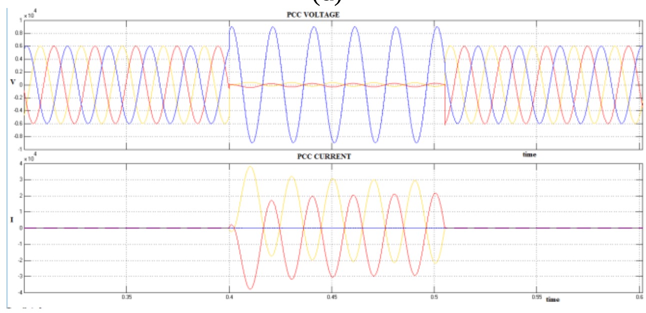
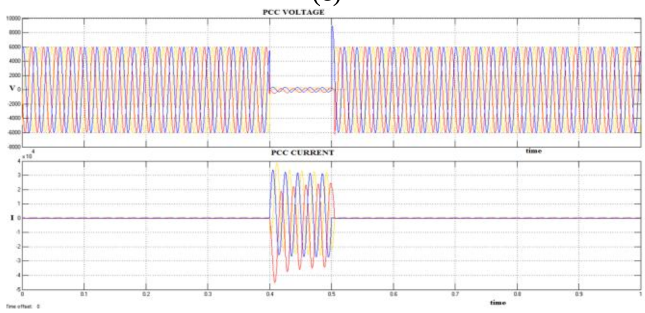


(d)



(e)



(f)

Fig.4. Simulation results without DVR. Waveforms of PCC voltages and PCC currents during (a) voltage sag event (b) unbalanced voltage event (c) single-phase to ground fault,(d) phase-phase fault, (e) two-phase to ground fault, (f) three-phase to ground short circuit fault.

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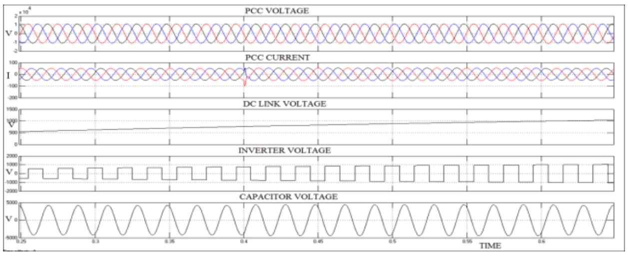
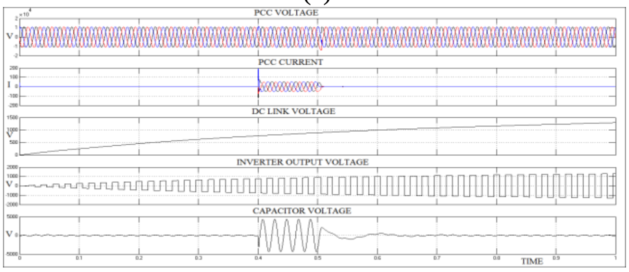


(a)



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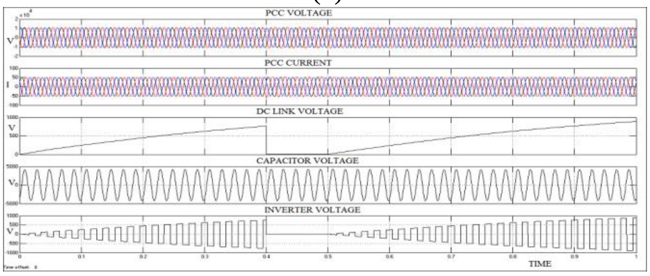

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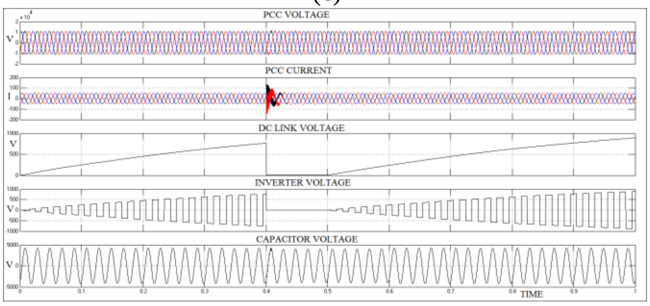
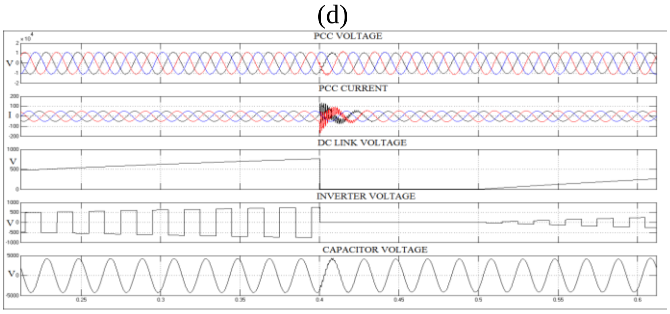
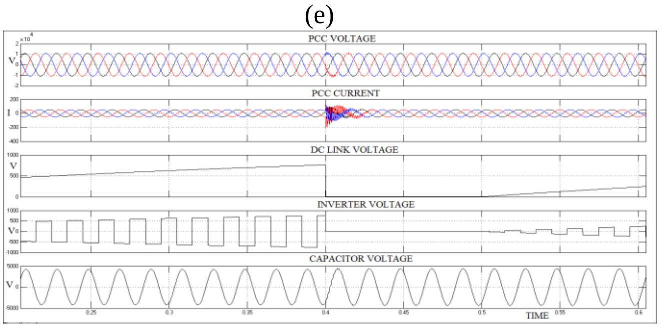


(d)



(e)



(f)

Fig.5. Simulation results of voltage compensation operation of FCL-DV. Waveforms of PCC voltages, PCC currents, DC link voltage, inverter output voltage and voltage across capacitor of FCL-DVR during (a) voltage sag event (b) unbalanced voltage event (c) single-phase to ground fault,(d) phase-phase fault, (e) two-phase to ground fault, (f) three-phase to ground short circuit fault.

IV. CONCLUSION

A new concept of FCL-DVR is proposed to deal with both voltage fluctuation and short current faults. The topology uses a crowbar bidirectional thyristor switch across the output terminals of a conventional back-to-back DVR. At the time of fault occurrence, the DVR controller will turn off the faulty phase of the DVR and turn on its bidirectional thyristor to insert the filter reactor into the grid to limit the fault current. The FCL-DVR operates with different protection strategies under different fault conditions. With the crowbar bidirectional thyristor across the output terminal of the inverter, the FCL-DVR can compensate voltage fluctuation and limit fault current and it can be used to deal with different types of short circuit faults with minimum influence on healthy phases. The FCL-DVR has the similar power rating as a conventional DVR. The delta-connection mode of the shunt transformers reduces the influence of dc link voltage fluctuations and suppresses the 3rd harmonics. With the proposed control scheme DC Link stabilization is achieved. Based on MatLab simulation and experimental study, concludes the following:

- The load current sensor and voltage sensor which is more simple are used here which is easier to install and is economical.
- DC Link voltage stabilization is achieved. As the time moves it becomes more stable without having any disturbances.
- With the novel control design, THD is minimized much and obtained the better sine references for the modulation.

Minimization and evaluation of THD with the different modulation scheme and more multilevel inverter topology can be realized in future.

REFERENCES

[1] ZhikangShuai, *Peng Yao, Z. J. Shen,* ChunmingTu, *Fei Jiang, and Ying Cheng* " Design Considerations of a Fault Current Limiting Dynamic Voltage Restorer (FCL-DVR)" *IEEE Trans. on smart grid*, vol. 6, no. 1, Jan 2015.

[2] U. Supatti and F. Z. Peng, "Z-source inverter with grid connected for wind power system," in *Proc. Energy Convers. Congr. Expo. (ECCE)*, San Jose, CA, USA, 2009, pp. 398–403.

[3] L. Sainz, J. J. Mesas, R. Teodorescu, and P. Rodriguez, "Deterministic and stochastic study of wind farm harmonic currents," *IEEE Trans.Energy Convers.*, vol. 25, no. 4, pp. 1071–1080, Dec. 2010.

[4] M. H. Ali and B. Wu, "Comparison of stabilization methods for fixed speed wind generator systems," *IEEE Trans. Power Del.*, vol. 25, no. 1,pp. 323–331, Jan. 2010.

[5] R. F. Arritt and R. C. Dugan, "Distribution system analysis and the future smart grid," *IEEE Trans. Ind. Appl.*, vol. 47, no. 6, pp. 2343–2350, Nov. 2011.

[6] Alexander Abramovitz And Keuye Ma Smedley, " Survey Of Solid-state Fault Current Limiters," *IEEETrans. On Power Electronics*, *Vol.* 27, No. 6, June 2012.

[7] S. S. Choi, T. X. Wang, and D. M. Vilathgamuwa, "A series compensator with fault current limiting function," *IEEE Trans. Power Del,*vol. 20, no. 3, pp. 2248–2256, Jul. 2005.

[8] Y. Li, D. M. Vilathgamuwa, P. C. Loh, and F. Blaabjerg, "A dual functional medium voltage level DVR to limit downstream fault currents,"*IEEE Trans. Power Electron*., vol. 22, no. 4, pp. 1330–1340, Jul. 2008.

[9] F. BadrkhaniAjaei, S. Farhangi, and R. Iravani, "Fault current interruption by the dynamic voltage restorer," *IEEE Trans. Power Del., vol. 28,*no. 2, pp. 903–910, Jun. 2013.

[10] EsmaeilEbrahimzadeh, ShahrokhFarhangi, HosseinIman-Eini, FirouzBadrkhaniAjaei, and Reza Iravani, " Improved Phasor Estimation Method for Dynamic Voltage Restorer Applications" *IEEE Trans. Power Del.*, 0885-8977 (c) 2013

[11] Z. Shuai, "A dynamic hybrid var compensator and a two-level collaborative optimization compensation method," *IEEE Trans. PowerElectron.*, vol. 24, no. 9, pp. 2091–2100, Sep. 2009.

[12] R. K. Smith *et al.*, "Solid state distribution current limiter and circuit breaker: Application requirements and control strategies," *IEEE Trans.Power Del.*, vol. 8, no. 3, pp. 1155–1162, Mar. 1993.

[13] A. M. S. Atmadji and J. G. J. Sloot, "Hybrid switching: A review of current literature," in *Proc. Energy Manage. Power Del. (EMPD)*, Singapore, 1998, pp. 683–688.

[14] A. R. Fereidouni, B. Vahidi, and T. H. Mehr, "The impact of solid state fault current limiter on power network with wind-turbine power generation," *IEEE Trans. Smart Grid*, vol. 4, no. 2, pp. 1188–1196, Jun. 2013.

[15] T. Ghanbari, I. Shiraz, and E. Farjah, "Development of an efficient solid-state fault current limiter for microgrid," *IEEE Trans. Power Del.*, vol. 27, no. 4, pp. 1829–1834, Oct. 2012.

[16] F. BadrkhaniAjaei, S. Farhangi, and R. Iravani, "Fault current interruption by the dynamic voltage restorer," *IEEE Trans. Power Del.*, vol. 28, no. 2, pp. 903–910, Jun. 2013.

[17] D. M. Divan, "Inverter topologies and control techniques for sinusoidaloutput power supplies," in *Proc. Appl. Power Electron. Conf. Expo. (APEC)*, Dallas, TX, USA, 1991, pp. 81–87.

[18] K. Nagaraju, P. S. V. S. T. Varma, and B. R. K. Varma, "A current-slopebased fault detector for digital relays," in *Proc. India Conf. (INDICON)*, Hyderabad, India, 2011, pp. 1–4.

[19] Y. Qiu, "Research on the series cascaded multilevel H-bridge voltage quality device," M.D. dissertation, School Elect. Eng., North China Elect. Power Univ., Beijing, China, 2009, pp. 16–17.

[20] S. Guo and D. Liu, "Analysis and design of output LC filter system for dynamic voltage restorer," in *Proc. Appl. Power Electron. Conf.Expo. (APEC)*, Fort Worth, TX, USA, 2011, pp. 1599–1605.

[21] H. Kim and S.-K. Sul, "Analysis on output LC filters for PWM inverters," in *Proc. Power Electron. Motion Control Conf. (IPEMC)*, Wuhan, Chian, 2009, pp. 384–389.