Power Quality Enhancement in Distributed Energy Resources by Four Leg Voltage Source Converter

G. Venkata Suresh Babu
Research Scholar, Dept. of EEE
JNT University
Anantapur
Email id : sureshsireee@gmail.com

V. Ganesh
Professor, Dept. of EEE
JNT University
Pulivendula
Email id : ganivg@gmail.com

***Abstract*— The presented article deals with various issues related to 'Power Quality (PQ) problems'. One of the reason to get these kind of PQ issues were mainly due to intermittent power generation due to Distributed Energy Resources (DER). However, problem may also occurs in non linearites originated from power system, subsequently can often damage the system. All these issues can be addressed with the power electronic converter operating based voltage restorer called ad Dynamic Voltage Restorer (DVR). In this article, a new controlling scheme in conjunction with 3 level inverter has been proposed to maintain the voltage for various harsh conditions. Also, an inherent Selective Harmonic Elimination (SHE) has been implemented to even further reduce the harmonic content in the system. The proposed application is tested under both conditions such as balanced load conditions and unbalanced load conditions and thus obtained results have been explored.**

***Index Terms*— Dynamic Voltage Restorer, Micro grids (MGs), Selective Harmonic Elimination, Power Quality issues.**

I. INTRODUCTION

The main power quality problems in the power distribution systems are Voltage sags. A voltage sag can be defined as the when the root mean square value of a alternating current voltage decreases from 0.9 per unit to 0.1 per unit of the nominal voltage at nominal frequency of 50 Hz which may last from few micro seconds to milli seconds. These nonlinearity in the power system was many due to the occurrence of sag and usage of nonlinear loads. Also, power quality problems may also leads to much power loss in the system and ultimately affects the system efficiency.

Quality to maintain in alternating power is much required for keeping generating stations to be running at stable conditions. However, if the generator gets enough amount of reactive power at their terminals, it tries to maintain the quality voltage supply. This can be achieved by using huge selected capacitor bank at the terminals of the loads and generators. Also, to get good quality voltage supply at the variable load, one has to maintain the switched capacitors/switched inductors to maintain the quality of voltage and current respectively. The quality of the supply can be maintained with Dynamic Voltage Restorer (DVR) as well. The DVR is usually operated with battery energy. This battery can get charged and discharged through a battery charger which is powered by solar power panel. The DVR is operating in a switch mode fashion i.e with the usage of power semiconductor devices especially with the inverter which will subsequently mitigates unbalancing in the load. The Proposed DVR injects voltage on need on basis.

The dynamic voltage restorer composed with dc to ac converter which is four leg converter in this case, and the reactive power is injected with the help of transformers connected in series with the line. The Dynamic Voltage Restorer (DVR) with its back-up battery is a most effective and efficient approach to establish the required voltage by injecting the required reactive power. Generally voltage compensation devices are always connected in parallel with the grid connected system to provide voltage variance mitigation. However the case in DVR different, that it is connected to a grid connected system in series fashion. The DVR is composed with power semiconductor devices such as IGBT's or MOSFETs based on its requirement. IGBT's are preferred for large voltage and current ratings, whereas MOSFET's are preferred for large frequency ratings. A versatile control scheme has also been implemented to control the voltage and current by sliding mode scheme and its results are also has been elaborated [3]. All the important function has been carried out by the control unit. This unit tries to takes the required inputs and maintains the system with required outputs. The control signal is usually generated by the pulse width modulation scheme. Most of the pulse width modulation schemes has been employed such as phase opposition disposition pulse width scheme, space vector control scheme, nearest level scheme

For active power filters a fuzzy logic has been applied here. Active filters operation and DVR operations are more are similar kind of operation which are mainly depends up on the reference signals given to the system. Various control schemes has been employed such as sliding mode control, Fuzzy logic control, Artificial neural network control and evolutionary control etc., In three-phase supply voltages are transformed into d and q coordinates. However, in all the control schemes, the voltage values are obtained by the refereeing the d-q reference frame, which is working on synchronous reference frame. The usage of proportion and integral control schemes were very helpful to reduce the steady state error and their optimum values would be obtained from the fuzzy logic shcme. Resulting outputs are r compared with a square wave carrier signal to obtain the Pulse Width Modulated signals [4]. This article mainly focuses on the Proportional Integral controller with Fuzzy logic Converter which works further based on Dynamic Voltage Restorer under variable voltage phenomenon. In this article, fuzzy logic controller has been replaced with the conventional proportional integral controller scheme. The important usage of integral controller is to reduce the steady state error and to improve the steady state performance. A direct flux control has been used for voltage sag mitigation in the proposed method [6]. Different control schemes in conjunction with 3 level inverter has been implemented and resulted with sophisticated results [7-15]. Control schemes at fault conditions has been implemented in and resulted in different system conditions [16-20].

This article is composed with five sections. First section gives a brief introduction about DVR. Second section deals with various applications of DVR in DER. Further section deals with application of proposed scheme in DVR. Section-IV deals with its applicability of fault conditions and finally, it is provided with conclusive remarks with its future perspective is given section-V.

II. APPLICATION OF DYNAMIC VOLTAGE RESTORER

The automobile assembly industry, production process plants and many other industry segments, is often enamored by the high speed performance, and effective levels of automation that can be achieved. Although these features and many indirectly related digital system based enhancements are major issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the most dominant in which bonds the foundation blocks. Power quality also affects operating terminals economics, system reliability, environment impacts, and initial investment in power distribution systems to support new system installations. To quote the utility company requirements and previous constrains which accompanied the previous issues of utility billing: 'Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.' As we are all aware, processing plant performance requirements continue to increase at an astounding rate. Next generation systems, already in the bidding process, will require average power demands of thousands of kW to MW – almost double the total average demand of few years ago. The rapid increase in power demand levels, an increase in production plant processing system population, SCR converter based drive retrofits and the large AC and DC drives needed to power and control these systems will increase awareness of the power quality issue in the very near future. The major objectives are to increase the most effective utilization capacity of distribution minimize the losses and these effects the power quality improvement at the load end. However, one of the important parameters that takes in to account is the source voltage variation. Source voltage has a key role on the load as well. Hence one to take the source voltage also in to consideration while designing the controller.

The important implication of could results in the damage of critical loads. The important critical loads which includes the paper mills, food processing industries, induction machines, synchronous machine and distribution systems etc. The most common causes for voltage fluctuations are due to the faults, which may occurred due to either intentionally or un expected. Unintentional faults such as mal function of breaker or due to birds aching etc. Voltage variation results in two types, which generally termed as sag and swell. To mitigate the problems caused by poor quality of power supply, series connected compensators are used.

The primary application of DVR is to reduce the sag and swell that occurs in the system. However, the structure/configuration of DVR is more or less similar to the Static Synchronous Series Compensator with their respective control schemes. When compared with SSSC the proposed voltage restorer responds very quickly i.e less than 0.2m sec. The complete structure and its configuration is shown in fig.1. Where it consists of AC voltage source connected to an inductor with a coupling transformer. Also the system is interconnected with the wind energy system, which is evaluated as the most intermittent power source. The power output form the wind system is uncertain and causes voltage sag and swell.

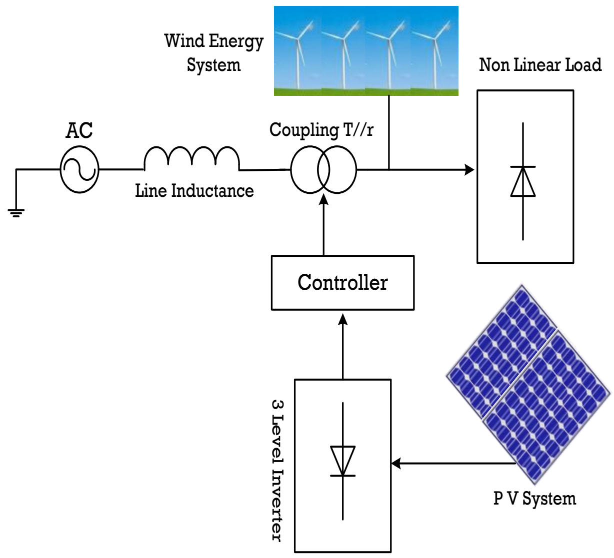

Fig.1. Basic application of DVR with DER

In this article, a selective harmonic elimination based technique with four leg inverters are employed. With the use of this technique, one can able to eliminate the all the lower order harmonics which are dominant by calculating the required notch angles. These notch angles can be found by applying the particle swarm optimization technique. Since, most of the authors has already been implemented with the conventional scheme and found to be less reliable. Hence, in this article an evolutionary based scheme is implemented based on the behavior of the particle and its flow chart is which in fig.2.

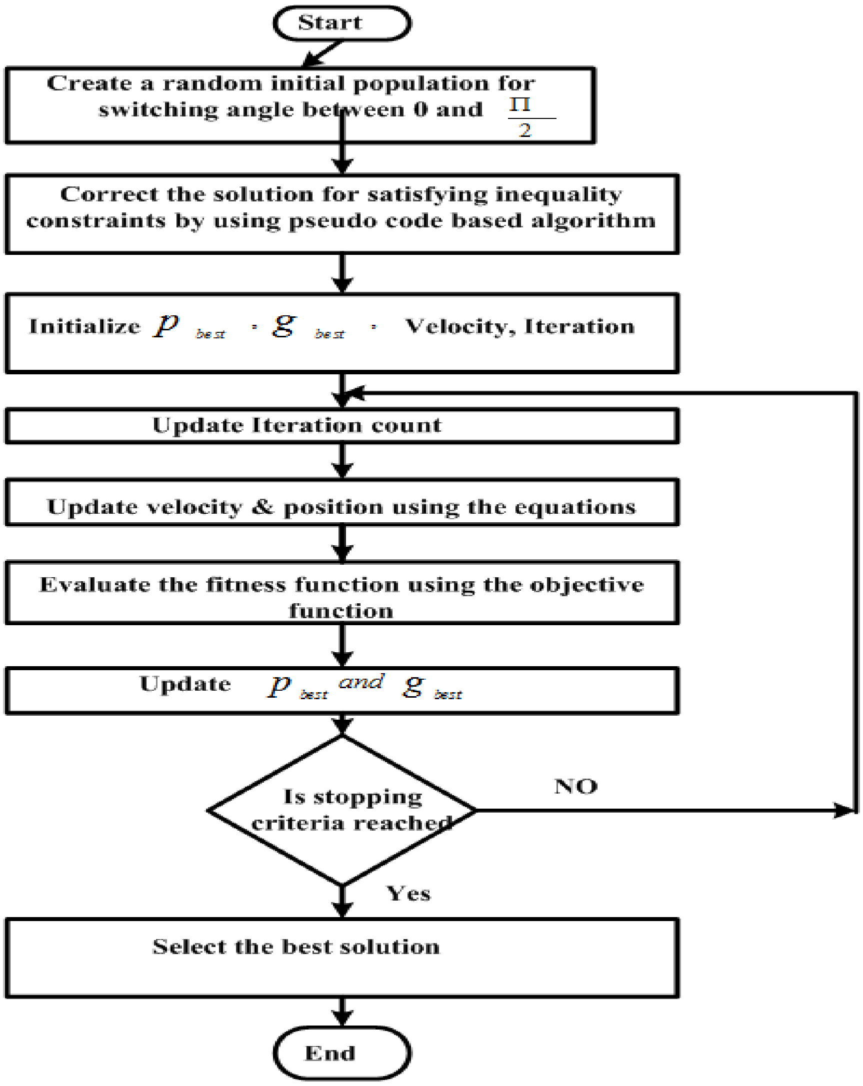

Fig.2. Implementation of PSO for SHE problem

The output of the inverter can be given by the obtained switching angles and system has been implemented. Considering that in many applications, the required line output voltages should be balanced and 120^0 out of phase, the multiple of third harmonics could be present in phase voltage will not be present in the load voltages. Therefore, these harmonics are not required to be eliminated, thus the chopping angles are used to eliminate the frequencies h=5, 7, 11, 13. After finding the switching angles it has implemented in the set of THD equations taken up to 39^{th} harmonics. The same results is verified by implementing in SIMULINK.

III. SIMULATION AND RESULTS ANALYSIS

The main aim of the controller scheme is to regulate the output voltage/and or frequency with a less steady state error, low peak over shoot/under shoot but with high efficiency. All these design performance can be achieved through proper implementation of control strategies.

The most important factors that influence the controller are
(i) Switching frequency
(ii) Energy storage elements and
(iii) Controller gains.

Ideally, if the switching frequency is very high, then ideal control of the converter is possible. But, achieving infinite switching frequency is not achievable due to its time delay and slew rate limitation. As the switching frequency increases, the switching losses in the system also increase. Hence most of the high frequency dc-dc converters are employing with Sout switching technique such as zero voltage switching on zero current switching to minimize the loss. Also, other effects of increased switching frequency are eddy current loss, skin effect and resistive power loss may also get affected, another important influence, parameter is storage element i.e., either inductor or capacitor. Choosing correct energy storage element is a typical basic, because low valve of inductor/capacitor leads to higher ripple current, smaller voltage over shoot and smaller output voltage undershoot respectively. Choosing correct value of energy storage elements decides the dynamic behavior of the system.

Another important aspect is to choose the correct value of controller gains. These gains are chosen based on the feedback controlled parameters such as inductor current or capacitor voltage. These gains has to be chosen based on their required dynamic output mainly these types of controllers are used in the system such as proportional controlling. Integral controlling and derivative controlling, choosing the proper propositional controller leads to better transient response and better steady state error. To remove the steady state error completely, one has to be used with integral controller; however poor integral controller leads to reduce to the stability. However better derivative controller increase of the overshoot and oscillation. The performance of the controller is implemented in Matlabd and its results has been explored.

The system has been tested with various conditions and its results has been plotted in fig.3 and fig.4. In fig.3, the system has been prone to forced sag and swell conditions. Even though, in such situations, the voltage at the terminals remains constant. Its DC current and its compensation current has been shown in fig.4. From which it is evident that, the system is maintaining a constant voltage without any deviation. The system with and without fuzzy have been executed and results are explored. The system is subjected to 10% sudden change in factory load. Which effects the DC link voltage. The DC link voltage decreased from 26kV to 25kV, which subsequently effect the load current. Whereas system with fuzzy shows DC voltage to be constant maintained at 26 kV and its AC currents are constant without any distortion.

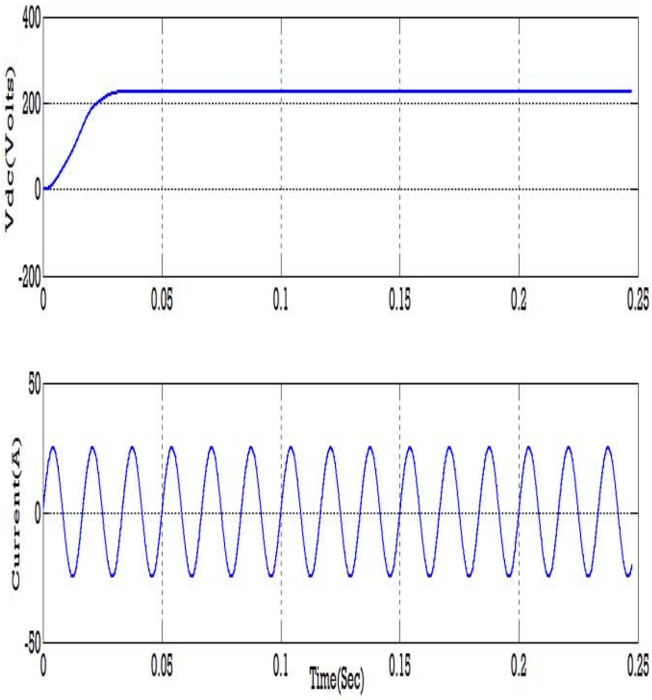

Fig.4(a) Applied DC voltage and its compensation current in simulation

The executed system results are shown in fig.4(a) and fig.4(b) respectively. With the proposed system the resulst are explored with DC volatge and current. Even though DC volateg is flucatued, but the out output voltage is not getting fluctuated and its getting perfect Ac output has come. The harmonic content for various swcithing frequeny has been tested and found the all the lower order harmoicns has been eliminated ccompletly.

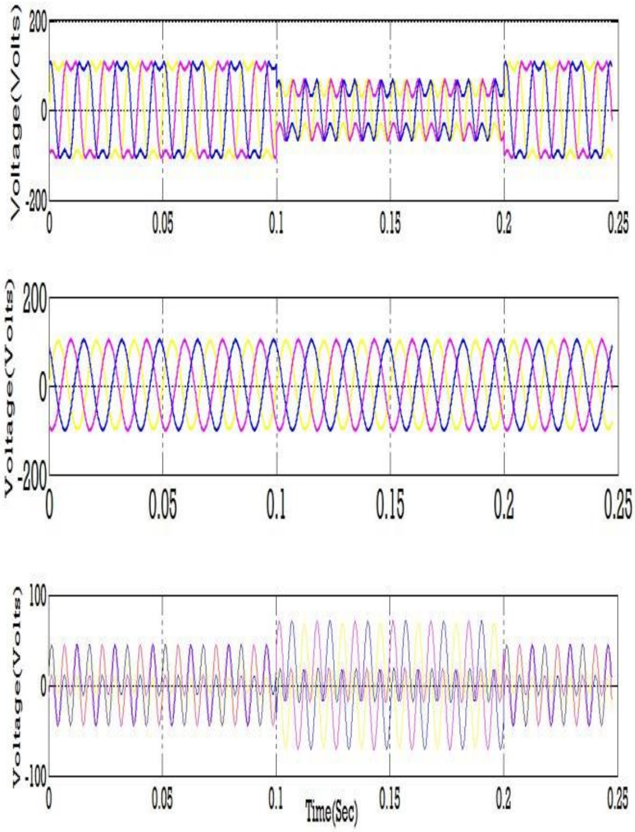

Fig.4(b) Load voltage and its compensation current in simulation

However, the system with DVR is shown in fig.4(b). Even though the fluctuations has been given in the source voltage, the load voltage is constant and is shown in fig.4(b) and where in the lower figure, the injection current is shown at various conditions.

IV. CONCLUSION

The presented article was proposed with selective harmonic based technique to distributed energy resource system.With the applied technique, the system is giving the stable voltage at various sag, swell conditions. In this article, a new controlling scheme in conjunction with 3 level inverter was proposed and implemented to maintain the voltage for various harsh conditions. Also, an inherent Selective Harmonic Elimination (SHE) has been implemented to even further reduce the harmonic content in the system. The performance of the DVR has been tested with both in balance and unbalance conditions of voltages and results has been explored.

REFERENCES

[1].S. Galeshi and H. Iman-Eini, "Dynamic voltage restorer employing multilevel cascaded H-bridge inverter," in *IET Power Electronics*, vol. 9, no. 11, pp. 2196-2204, 9 7 2016.doi: 10.1049/iet-pel.2015.0335

[2].S. Biricik and H. Komurcugil, "Optimized Sliding Mode Control to Maximize Existence Region for Single-Phase Dynamic Voltage Restorers," in *IEEE Transactions on Industrial Informatics*, vol. 12, no. 4, pp. 1486-1497, Aug. 2016. doi: 10.1109/TII.2016.2587769

[3].M. Shahabadini and H. Iman-Eini, "Improving the Performance of a Cascaded H-Bridge-Based Interline Dynamic Voltage Restorer," in *IEEE*

Transactions on Power Delivery, vol. 31, no. 3, pp. 1160-1167, June 2016.doi: 10.1109/TPWRD.2015.2480967

[4].F. Jiang, C. Tu, Z. Shuai, M. Cheng, Z. Lan and F. Xiao, "Multilevel Cascaded-Type Dynamic Voltage Restorer With Fault Current-Limiting Function," in *IEEE Transactions on Power Delivery*, vol. 31, no. 3, pp. 1261-1269, June 2016. doi: 10.1109/TPWRD.2015.2474703

[5].G. A. d. A. Carlos, C. B. Jacobina and E. C. dos Santos, "Investigation on Dynamic Voltage Restorers With Two DC Links and Series Converters for Three-Phase Four-Wire Systems," in *IEEE Transactions on Industry Applications*, vol. 52, no. 2, pp. 1608-1620, March-April 2016. doi: 10.1109/TIA.2015.2490040

[6].S. Gao, X. Lin, S. Ye, H. Lei and Y. Kang, "Transformer inrush mitigation for dynamic voltage restorer using direct flux linkage control," in *IET Power Electronics*, vol. 8, no. 11, pp. 2281-2289, 11 2015. doi: 10.1049/iet-pel.2014.0640

[7].G. A. de Almeida Carlos, E. C. dos Santos, C. B. Jacobina and J. P. R. A. Mello, "Dynamic Voltage Restorer Based on Three-Phase Inverters Cascaded Through an Open-End Winding Transformer," in *IEEE Transactions on Power Electronics*, vol. 31, no. 1, pp. 188-199, Jan. 2016. doi: 10.1109/TPEL.2015.2404798

[8].E. Ebrahimzadeh, S. Farhangi, H. Iman-Eini, F. BadrkhaniAjaeiand R. Iravani, "Improved Phasor Estimation Method for Dynamic Voltage Restorer Applications," in *IEEE Transactions on Power Delivery*, vol. 30, no. 3, pp. 1467-1477, June 2015. doi: 10.1109/TPWRD.2014.2366241

[9].C. Kumar and M. K. Mishra, "Predictive Voltage Control of Transformerless Dynamic Voltage Restorer," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 5, pp. 2693-2697, May 2015. doi: 10.1109/TIE.2014.2365753

[10].A. M. Rauf and V. Khadkikar, "An Enhanced Voltage Sag Compensation Scheme for Dynamic Voltage Restorer," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 5, pp. 2683-2692, May 2015. doi: 10.1109/TIE.2014.2362096

[11].D. Somayajula and M. L. Crow, "An Integrated Dynamic Voltage Restorer-Ultracapacitor Design for Improving Power Quality of the Distribution Grid," in *IEEE Transactions on Sustainable Energy*, vol. 6, no. 2, pp. 616-624, April 2015. doi: 10.1109/TSTE.2015.2402221

[12].A. M. Rauf and V. Khadkikar, "Integrated Photovoltaic and Dynamic Voltage Restorer System Configuration," in *IEEE Transactions on Sustainable Energy*, vol. 6, no. 2, pp. 400-410, April 2015. doi: 10.1109/TSTE.2014.2381291

[13].Z. Shuai, P. Yao, Z. J. Shen, C. Tu, F. Jiang and Y. Cheng, "Design Considerations of a Fault Current Limiting Dynamic Voltage Restorer (FCL-DVR)," in *IEEE Transactions on Smart Grid*, vol. 6, no. 1, pp. 14-25, Jan. 2015. doi: 10.1109/TSG.2014.2357260

[14].G. Chen, M. Zhu and X. Cai, "Medium-voltage level dynamic voltage restorer compensation strategy by positive and negative sequence extractions in multiple reference frames," in *IET Power Electronics*, vol. 7, no. 7, pp. 1747-1758, July 2014. doi: 10.1049/iet-pel.2013.0520

[15].M. R. Khalghani, M. A. Shamsi-nejad and M. H. Khooban, "Dynamic voltage restorer control using bi-objective optimisation to improve power quality's indices," in *IET Science, Measurement & Technology*, vol. 8, no. 4, pp. 203-213, July 2014. doi: 10.1049/iet-smt.2013.0084

[16].E. Babaei, M. F. Kangarlu and M. Sabahi, "Dynamic voltage restorer based on multilevel inverter with adjustable dc-link voltage," in *IET Power Electronics*, vol. 7, no. 3, pp. 576-590, March 2014. doi: 10.1049/iet-pel.2013.0179

[17].P. Jayaprakash, B. Singh, D. P. Kothari, A. Chandra and K. Al-Haddad, "Control of Reduced-Rating Dynamic Voltage Restorer With a Battery Energy Storage System," in *IEEE Transactions on Industry Applications*, vol. 50, no. 2, pp. 1295-1303, March-April 2014. doi: 10.1109/TIA.2013.2272669

[18].F. BadrkhaniAjaei, S. Farhangi and R. Iravani, "Fault Current Interruption by the Dynamic Voltage Restorer," in *IEEE Transactions on Power Delivery*, vol. 28, no. 2, pp. 903-910, April 2013. doi: 10.1109/TPWRD.2012.2220864

[19].J. C. Rosas-Caro, F. Mancilla-David, J. M. Ramirez-Arredondo and A. M. Bakir, "Two-switch three-phase ac-link dynamic voltage restorer," in *IET Power Electronics*, vol. 5, no. 9, pp. 1754-1763, November 2012. doi: 10.1049/iet-pel.2012.0252

[20].A. O. Ibrahim, T. H. Nguyen, D. C. Lee and S. C. Kim, "A Fault Ride-Through Technique of DFIG Wind Turbine Systems Using Dynamic Voltage Restorers," in *IEEE Transactions on Energy Conversion*, vol. 26, no. 3, pp. 871-882, Sept. 2011. doi: 10.1109/TEC.2011.2158102

[21]. S. Madichetty, A. Dasgupta, S. Mishra, "Application of an Advanced Repetitive Controller to Mitigate Harmonics in MMC With APOD Scheme," in ***IEEE Transactions on Power Electronics*****,** vol. 31, no. 9, pp. 6112-6121, Sept. 2016. doi: 10.1109/TPEL.2015.2501314

[22]. K. Venkat Ram Reddy, MadichettySreedhar, Circulating current mitigating scheme in MMC based HVDC system with H∞ repetitive controllers, **International Journal of Electrical Power & Energy Systems, Elsevier**, Volume 85, February 2017, Pages 143-152, ISSN 0142-0615,

[23]. Sreedhar, M.; Dasgupta, A.; Mishra, S., "New harmonic mitigation scheme for modular multilevel converter – an experimental approach," ***Power Electronics, IET*** , vol.7, no.12, pp.3090,3100, 12 2014 doi: 10.1049/iet-pel.2014.0028 [24].J. Nanda, Anew technique in hydro thermal interconnected automatic generation control system by using minority charge carrier inspired algorithm, **International Journal of Electrical Power & Energy Systems Elsevier**, Volume 68, June 2015, Pages 259-268, ISSN 0142-0615, doi: 10.1016/j.ijepes.2014.12.025