

A Review on Mitigation of Voltage Sags and Swells by Using Dynamic Voltage Restorer Control Devices for Improving Power Quality

Pankaj Kumar¹, Sanjeev Jarariya²

PG Scholar, Department of Electrical & Electronics, Corporate Institute of Science & Technology, Bhopal, India¹

Associate Professor, Department of Electrical & Electronics, Corporate Institute of Science & Technology, Bhopal, India²

ABSTRACT: This paper presents Brief Review of a Dynamic Voltage Restorer control to mitigate power quality disturbances such as voltage sag, swell and harmonics. DVR is one of the compensating types of custom power devices. The power quality is affected mainly due to the sensitive loads which results in voltage sag and voltage swells. It is necessary to investigate the suitable methods for mitigation of voltage sags. Controller based on Soft computing techniques such as fuzzy logic and ANN is implemented in order to maintain the nominal load voltage and phase angle. This paper, a systematic review of published literature is conducted and a description is given on the design, standards and challenges in the DVR technology.

KEYWORDS: Dynamic Voltage Restorer (DVR), Voltage Sags, Control System, Voltage Source Converter (VSC), Power Quality.

I. INTRODUCTION

Increasing the energy consuming more over the effect of sensitive nonlinear loads in power systems, the optimal operating and high-quality power transferring becomes a considerable issue. There have been different components to reach this purpose such as flexible alternating current transmission systems (FACTS) in high voltage transmission lines and custom power devices in medium and low voltage distribution grids. The voltage dip is usually a three-phase phenomenon in three phase system grid, it can affect both the phase-to-ground and phase to phase voltages. A voltage dip is happen usually because by a fault in the utility system, a fault or a large increase of the load current, like starting an induced motor or energizing of the transformer. Typical faults are single-phase that means single phase to ground or multiple-phase which means phase to phase short circuits [1,2]. The sensitive loads is very demand with this problem of voltage dip phenomena because the sensitive loads such as the controller, variable speed drive at the semiconductor manufacturing place at the industry and computer system can give the bad impact to this equipment. When this magnitude of voltage dropped suddenly higher it can trip this equipment and the system involved. This interrupted happen when the magnitude of the voltage at the distribution grid system to the load is being reduced suddenly from the limit of the operation system [1]. In the last decades, Dynamic Voltage Restorer (DVR) has been investigated as a resource for mitigation of contingencies' effects, with compromise in energy quality [1], [7], [8]. Generally, the DVR is installed between the power electrical grid and a sensitive load. Also, it can be defined as an electronic device capable of detecting and compensating disturbances in electric grid, in some milliseconds, ensure protection for the sensitive loads [9], [10]. Dynamic Voltage Restorer (DVR) can provide the lucrative solution to mitigate voltage sag [10-11] by establishing the appropriate voltage quality level, necessary. It is recently being used as the active solution for mitigation of power quality problems. The DVR is one of the custom power devices which can improve power quality, especially, voltage sags and voltage swells. As there are more and more concerns for the quality of supply as a result of more sensitive loads in the system conditions better understanding of the devices for mitigating power quality problems [12-13] is important. This paper concentrates on power quality, one of the challenges suffered by classical power grid [5]. Power disturbance is defined as any interruption of voltage or frequency that opposes normal operation of the system [3]. Poor power quality results in power failure that causes blowing fuses and tripping circuit breakers, damaging sensitive equipment such as computers and production line control systems, resulting in high running installations costs, leading to production being stopped and major costs being incurred [4]. Methods to improve power quality have been introduced by many researchers. This research looks to improve power quality by considering DVR

method, based on improved DE Algorithm, with two objective functions, to minimize swells and to minimize sags. DVR has been frequently used for compensation of voltage sags and swells due to its ability to be controlled, high efficiency and its fast response [6]. Since in this research the focus is to minimize both voltage sag and voltage swell, therefore a multi-objective DE algorithm will be used, as they are extensively used to solve such conflicting objectives. Due to the conflicting nature of the objective functions, a number of optimal solutions known as Pareto Front will always get results for a multi-objective problem [7].

II.DYNAMIC VOLTAGE RESTORER (DVR)

The Dynamic Voltage Restorer (DVR) is a series connected device analogous to a SSSC. The main function of a DVR is to eliminate or reduce voltage sags seen by sensitive loads such as semiconductor manufacturing plant or IT industry. DVR that have been installed so far are modular with ratings of 2 MVA per module. They have been designed to compensate three phase voltage sags up to 35% for duration of time less than half a second (depending on the requirement). If the voltage sag occurs only in one phase (caused by SLG faults) then the DVR may be designed to provide compensation for sags exceeding 50%. The energy storage required in capacitors is typically in the range of 0.2 to 0.4 MJ per MW of load served. A DVR is connected in series with the feeder using a transformer. The low voltage winding is connected to the converter. If the objective of a DVR is mainly to regulate the voltage at the load bus, it remains for most of the time in stand-by mode during which the converter is bypassed (no voltage is injected). Only when sag is detected, the DVR injects a series voltage of the required magnitude. It is necessary to protect a DVR against the fault currents (as in the case of a SSSC). A DVR with IGBT/IGCT devices can be controlled to act as a series active filter to isolate the load from voltage harmonics on the source side. It is also possible to balance the voltage on the load side by injecting negative and/or zero sequence voltages in addition to harmonic voltages, Figure 1 shows DVR block diagram.

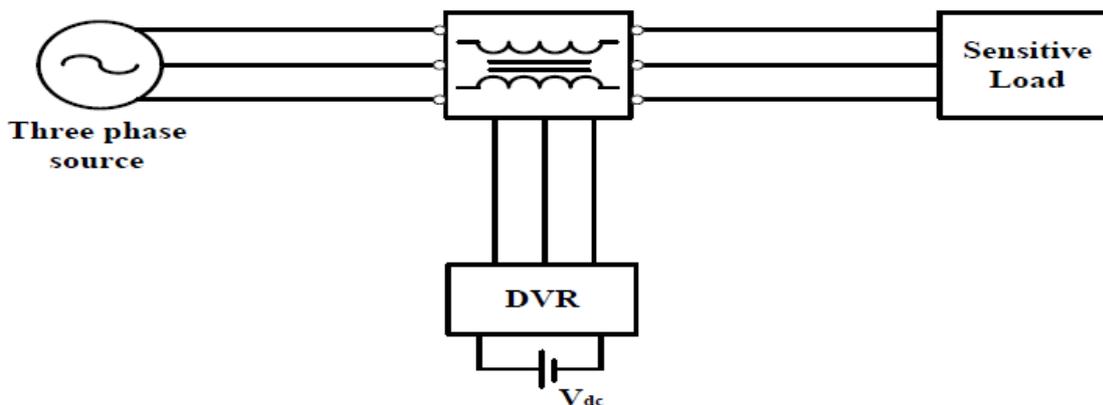


Fig.1.DVR block diagram

Its operation mode is bisected as standby and injection (boosting mode). Standby status illustrates the acceptable range of voltage in the system and it looks like on the shelf condition because DVR has been bypassed ideally. The standby status could adjust to compensate the voltage drop of transformers in line. Injection status is under fault occurring situation and DVR should inject voltage to point connected couple (PCC) under voltage sag circumstances and absorb the additional voltage from PCC during voltage swells. By reduction of magnitude during a voltage sag, DVR ought to inject rested magnitude to restore nominal voltage signal. That's necessity to have an accurate controller for reverting voltage signal considering phase, magnitude and frequency. This process could carry out in three phase. This compensating device has various virtues comprising of line voltage harmonics compensation, fault current limitations and reduction of transient in voltage Banaei et al. (2006). The main structure of DVR contains storage devices, injection transformer (down-step), harmonic filter (low-pass), control and protection system, voltage source converter (VSC) and DC charging circuit.

III. CONTROL STRATEGIES OF DVR

1)Conventional control units of DVR

The control unit aims to make a steady form of the voltage signal in disturbances either system normal operating at PCC. The common infrastructure of control unit consists voltage correction processing. Pulse width modulation (PWM) is the later stage after control unit to prepare the signal for VSI/VSC stage. The difference of reference voltage

and PCC measured voltage has been determined by the control unit and it orders to inject given voltage to the system. Proportional-integral (PI) is the most common controller type utilizes in DVR as the vice is no efficiency in promoting system transients the virtue is simple implementation and flexibility in steady state fault duration .

2)Synchronous Reference Frame Control

The operation of the power electronics converters grid connected must be synchronized with the mains. Thus, it necessary a detection system of frequency and phase in PCC. This synchronize scheme is responsible for to tracking the angle from fundamental voltage of electric grid and, consequently, reject any disturbance type [33]. The synchronize algorithm most of utilized is the Phase Locked Loop (PLL), and in this work was implemented the PLL based in Synchronous Reference Frame (SRF-PLL).For PLL's controller (CPLL(S)) design purposes, was considered that three-phase voltages on PCC to be symmetrical, balanced, with V amplitude, angular frequency and phase angle.The controller used in PLL is a Proportional-Integral (PI), already that he it's sufficient for to track a constant signalwith steady state error null. Known the transfer function of PI controller.

3)Modified Synchronous Reference Frame Controller

implementation of interline dynamic voltage restorer (IDVR) system using three-phase inverter integrated with PLL based MSRF controller for regulating the DC link voltage, and reducing the voltage sag. Voltage variation that frequently occurs either in the form of voltage sag or swells and it can cause major damage to the environment and distribution station.Provide Control methods of IDVR are two types: voltage compensation mode (discharging) and replenishing (charging) mode. The whole function can be controlled by the method of modified synchronous reference frame controller as represented in figure 5. The control method utilized for extracting the essential elements of source voltage and source current is called a modified synchronous reference frame theory and its version of a typical synchronous reference frame method. PLL is used to calculate the voltage and phase angle, which is used to generating the reference for the MSRF controller.The function of this MSRF method is shifting the frequency (δ) and transforms the frequency of the phase lock loop in DC at the same time other element keeping as AC. During this time of transformation, the signal is generated, and the resulting signal passes through the filter. This method consists of orthogonal signal ($\sin\omega t$, $\cos\omega t$) produced by the PLL block. After the generation of source current and voltage, the phase difference between two orthogonal signals is detected, calculated, and compared with a reference phase difference. The control signal (C) is produced by PI, related to the PWM generator that shifts the source waveform. After that power is flowing through converter, and it charges/discharges the DC link. DC link voltage is not constant because the compensation range of DVR can oscillates the DC link. By the method of MSRF Harmonics current in the converter is separate from the fundamental element.

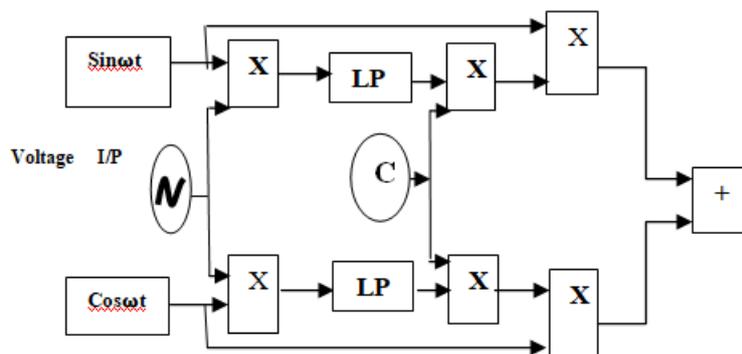


Fig. 2. Modified reference frame based controller

The concept and implementation of IDVR which is the cost-effective method, to improve the quality of power, reducing the settling time of dc link voltage, and mitigate/compensate the voltage sag in feeders using PLL based MSRF controller has proposed in this paper. In this paper, two DVR's are connected to the common DC link, and one of the DVR compensates the voltage sag/swell another one performing the voltage replenish process by DC link capacitor has analysis and implemented. MSRF based PLL controller is designed and controls the process of IDVR setup, and it has connected with a non-linear load.

4)Feed-forward voltage controller

A voltage control loop is responsible for generating VSC modulating signals (m_a , m_b , m_c) so that reference voltages (V_{dref} and V_{qref}) are adequately followed (Fig. 7). The VSC's voltages are controlled in the dq synchronous reference

frame, reducing the number of variables and facilitating the controller design. a PI controller was used for this function because, as already commented, it is sufficient to track constant signals with steady null state error. In the voltage control loop in PCC there are controllers $C_d(s)$ for component "d" and $C_q(s)$ for "q", and both have the same transfer function, in other words, will be realized just one controller design. This tuning method was used since it is a second-order plant with difficult linearizing and approximation for the first order, since traditional tuning methods use this approach in the controller designs [35]. This method has one advantage that is the performance criterion associated with closed-loop time constant and with open-loop time constant (7). Thus the IMM permits to clearly define the desired performance.

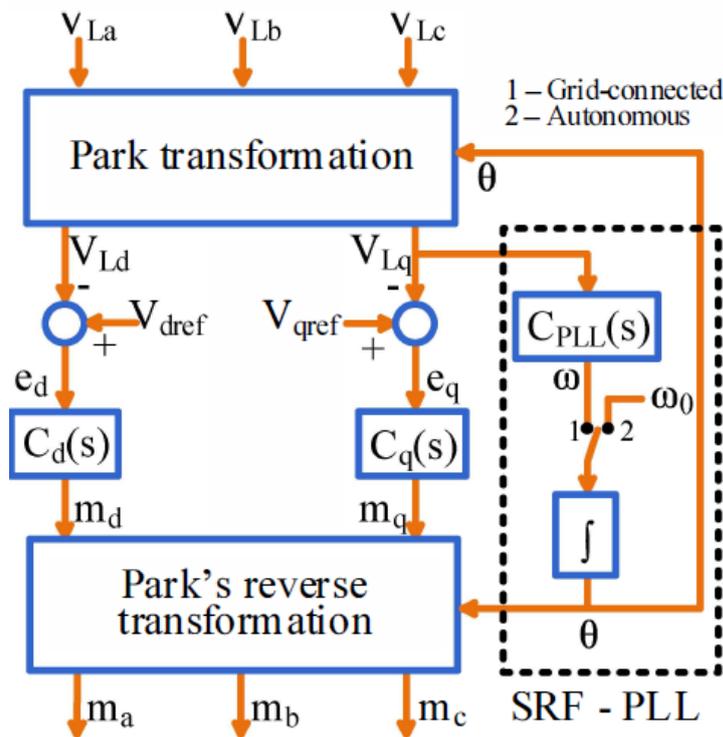


Fig. 3. Voltage control loop.

5) Fuzzy-based controller

The fuzzy logic (FL) comes as a vital and viable solution method in various engineering fields which mutates the optimal point in many engineering issues. Conventional PI controller could not react to the abrupt alternations of ϵ due to it has no ability to sense ascending either descending content of ϵ . Furthermore, the conventional PI controllers could diagnose instant amount of ϵ instead of analysing its difference. The fuzzy logic controller (FLC) is a remedy to overcome reported shortcomings (2017). FLC rules define as $\{ \text{if } \epsilon \text{ and } \Delta\epsilon \text{ then } K_i \text{ and } K_p \}$. The variables of the fuzzy subset are NB, NM, NS, Z, PS, PM and PB. In consideration of overlapping, sensitivity and stability for mother-set, left side, centre side and right side subsets imagine as Z-, Delta- and S-shaped respectively. Also, subsets of the membership function for output variables (K_i and K_p) are triangular.

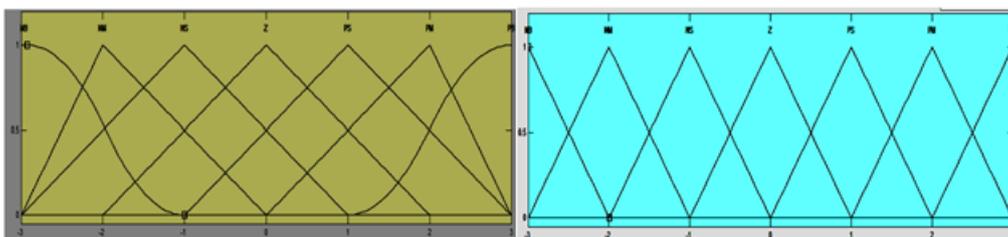


Fig. 4. (a) the membership of ϵ and $\Delta\epsilon$;

(b) the membership of K_i and K_p .

6)Multi-Objective Differential Evolution algorithm

Multi-objective optimization is a procedure that minimizes or maximizes objectives that are under imposed constraints. It is a mathematical or algorithmic tool that is characterized by two or more objectives [16]. In multi-problem optimization, two or more objectives are usually on conflict, therefore the evolutionary algorithm are required to search the best optimal solution [17]. Different multi-objective strategies have been applied to the problems where the correct clustering solution corresponds to a trade-off between two or more clustering metrics [18]. One strategy used in multi-objective optimization is Pareto Front. Pareto front is the set of all Pareto efficient allocations, conventionally shown in graph. It allocates resources from an impossible situation, making one individual or preference criterion best optimal without making individual or preference criterion worse optimal [19]. Pareto front is represented by Pareto-optimal solutions. With Differential Evolution Algorithm (DE) being one of the robust and effective Evolutionary Algorithm, smart grid optimization will look to employ DE in order to fulfil power quality that is efficient and reliable to the society and industries. According to [14], mutation, crossover and selection function are the three DE evolutionary stages that the objective function passes through during problem optimization. Mutation function randomly generates variations to existing individuals to present new information into the population. The functioning creates mutation vectors at each generation, based on the population of the current parent. The crossover function performs an exchange of information between different individuals in the current population. The final trial vector is formed by binomial crossover operation. The selection function passes a driving force towards the most favourable point by preferring individuals of better fitness. Based on results, it is noticed that the DVR does not take part in the power network during normal operational, it only takes part when it senses operational disturbance from the sensitive load, therefore it does not waste electric power unnecessary and instead it operates efficiently. It is also noticed that Improved Differential Evolution is able to do multi-objective optimization efficiently and without experiencing stagnation and conflict amongst the two objective functions. The proposed DE achieved robust and effective convergence in less than 30 iterations. That indicates efficiency, reliability and fast convergence speed of the improved DE. It can be concluded that robust, efficient, sustainable, economical and reliable power quality optimization in smart grid is achievable when DVR and improved DE are included in smart grid’s mission.

7)Sinusoidal pulse width modulation (SPWM) Control technique

Static power converters are used to produce an ac output voltage from a dc power supply. This methodology is mostly used in the uninterruptible power supplies (UPS), flexible AC transmission system (FACTS). In the proposed control scheme, firstly the output voltage and the reference voltage are being tuned by performing series of operation as shown in the figure 5. After tuning the both waveforms now the two signals are being compared and the difference is given to the PI controller block which produces constant output that is being fed to SPWM circuit to generate triggering pulses for the inverter circuit. With the help of the SPWM technique, valves in same branch are not triggered at the same time. In normal conditions as there will be no difference between the reference and the output voltage, the output of PI controller will be zero which clearly says that no triggering pulses will be generated by SPWM block for the inverter. The block diagram of the phase locked loop (PLL) is illustrated in Figure 4. The PLL circuit is used to a unit sinusoidal wave in phase with mainsvoltage.

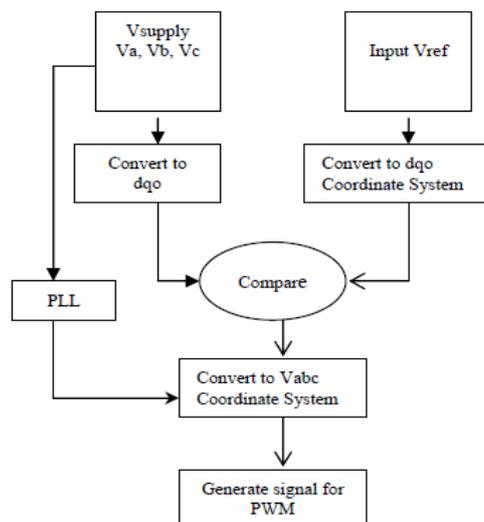


Fig.5 : Flow chart of SPWM control

8) ANN(Artificial neural Network)Controller

The compensation strategy is based on pre-sag compensation. Controller based on dq0 transformation technique and ANN is implemented in order to maintain the nominal load voltage and phase angle. Simulation studies under three phase rectifier with parallel resistive/capacitive dc load as a non linear load is carried out. The three basic compensation strategies of Dynamic voltage restorer are the pre-sag compensation [6], the in-phase compensation [6] and the energy-optimized compensation [7]. In this paper, presage compensation is considered as typical solution for compensating voltage disturbances and to restore the load voltage with exact amplitude and phase. This pre-sag compensation strategy leads to the low distortion at the load side. Fig.2 shows the DVR control based on ANN, the significant role of the controller is to detect the disturbance in voltage, inject the voltage difference and turn off the DVR system, when the disturbances are removed.

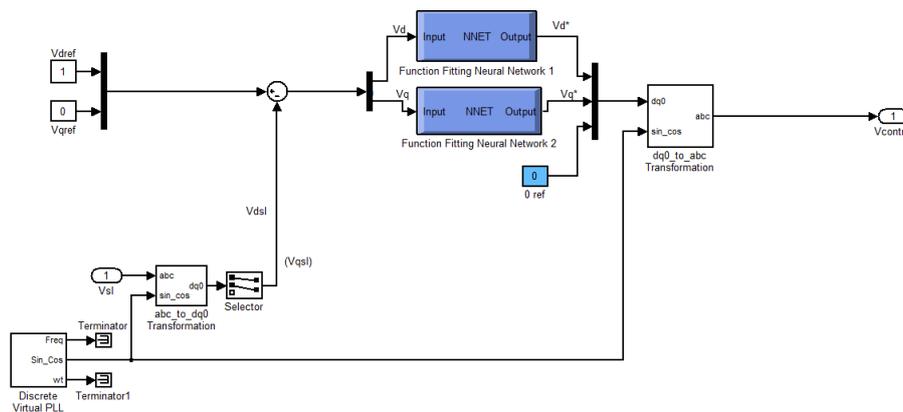


Fig. 6 DVR control based on ANN controller

The sag and swell mitigation are performed with a smooth, stable, and fast DVR response; no transient overshoots are observed when the DVR is in operating mode. The response and performance of the designed DVR were evaluated by applying three test cases. THD and per unit values of the load voltage are always kept below the standard limits by using proper control strategy. Thus, ANN based controller for DVR found to be alternate tool for mitigation of power quality disturbances such as voltage sag, swell and harmonics.

IV.CONCLUSION

While the dynamic voltage restorers can effectively solve the voltage sags and other issues, however, due to their own limitations, there are still many issues which need to be improved, for example, directly obtaining energy from the grid instead of the energy storage unit. But compared to the other compensating devices, DVR is the most economical and efficient equipment. ANN based controller, Fuzzy logic controller and other soft computing techniques for DVR found to be alternate tool for mitigation of power quality disturbances such as voltage sag, swell and harmonics.

REFERENCES

- [1] H.-K. Chiang, B.-R. Lin, and K.-w. Wu, "Study of dynamic voltage restorer under the abnormal voltage conditions," in 2005 International Conference on Power Electronics and Drives Systems, vol. 1. IEEE, 2005, pp. 308-312.
- [2] M.R. Banaei, S.H. Hosseini, G.B. Gharehpetian, "Inter-Line Dynamic Voltage Restorer Control Using A Novel Optimum Energy Consumption Strategy" Volume 14, Issue 7, Pages 989-999, October 2006.
- [3] Po-Tai Cheng, Jhao-Ming Chen, and Chia-Lung Ni, Design of a State Feedback Controller for Series Voltage-Sag Compensators, IEEE Transactions on Industry Applications, vol. 45, No. 1, January (2009), pp 260-267.
- [4] A. Teke K. Bayindir M. Tu'may, Fast sag/swell detection method for fuzzy logic controlled dynamic voltage restorer, IET Gener. Transm. Distrib., (2010), Vol. 4, Iss. 1, pp. 1-12
- [5] Francisco Jurado, Neural Network Control for Dynamic Voltage Restorer, IEEE Transactions on industrial Electronics, June (2004), vol 51, No. 3, pp 727-729.
- [6] J. G. Nielsen and F. Blaabjerg, Control strategies for dynamic voltage restorer compensating voltage sags with phase jump, in Proc. Annu. Appl. Power Electron. Conf. Exposition, (2001), no. 2, pp. 1267-1273.

- [7] M.Vilathgamuwa, R. Perera, S. Choi, and K. Tseng, "Control of energy optimized dynamic voltage restorer," in *Proc. IECON*, (1999), vol. 2, pp.873–878.
- [8]. Vilathgamuwa, D. Mahinda, H. M. Wijekoon, and S. S. Choi, "Interline dynamic voltage restorer: A novel and economical approach for multi-line power quality compensation," *In 38th IAS Annual Meeting on Conference Record of the Industry Applications Conference*, vol. 2, pp. 833-840. IEEE, 2003.
- [9]. Ho, Carl Ngai-Man, and Henry Shu-Hung Chung, "Implementation and performance evaluation of a fast dynamic control scheme for capacitor-supported interline DVR," *IEEE transactions on power electronics*, vol.25, no. 8, pp.1975-1988, 2010.
- [10]. Jayaprakash, Pychadathil, Bhim Singh, D. P. Kothari, Ambrish Chandra, and Kamal Al-Haddad, "Control of reduced-rating dynamic voltage restorer with a battery energy storage system," *IEEE transactions on industry applications*, vol. 50, no. 2, pp.1295-1303.
- [11]. V. Vasudevan, and K. Balaji, "Performance of Cuk-KY Converter Fed Multilevel Inverter for Hybrid Sources," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 10, no 2, pp.436-445, 2018, doi:10.11591/ijeecs.v10.i2.pp%p
- [12]. Andrews, Sajitha, TG Subhash Joshi, A. Saravana Kumar, A. S. Manju, and A. K. Unnikrishnan. "Modified SRF-PLL to operate under unbalance grid for grid synchronization of DVR." *In 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, pp. 1-6. IEEE, 2014.
- [13]. N. Suresh and R.S.R Babu, "Review on harmonics and its eliminating strategies in power system," *Indian Journal of Science and Technology*, vol. 8, no 13, pp.56641, 2015.
- [14]T.Ohnishi and H. Okitsu, "A novel PWM technique for three phase inverter / converter," *international power electronics conference*, pp-384-395, 1983.
- [15]F. A. L. Jowder, "Design and analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation", *IET Generation, Transmission & Distribution*, vol. 3, pp. 547 – 560, June 2009.
- [16] H. Ezoji, A. Sheigholeslami, M. Tabasi, M. Saeednia, "Simulation of dynamic voltage restorer using hysteresis voltage control", *European Journal of Scientific Research*, ISSN 1450-216X Vol.27 No.1 (2009), pp. 152-166. 2009.
- [17] B. Ferdi, C. Benachaiba, S. Dib, R. Dehini, "Adaptive PI control of dynamic voltage restorer using fuzzy logic" *Journal of Electrical Engineering: Theory and Application* (Vol.1-2010/Iss.3), pp. 165-173, 2010.