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Static Voltage Restorer Based Power Quality Improvement of Distribution System with SRF Control Method: A Review

[1] Ankita Agnihotri, [2] Prof. Anurag Soni,
[1,] M.Tech Scholar, [2]Assistant Professor,
[1,2]Lakshmi Narain College of Technology Excellence (M.P), INDIA,

Abstract—Various power quality issues that exist in electrical power system such as harmonics, transient and sag-swell, effect over entire power network. Sag-swell is one of the most obvious one, occurring in power distribution systems and utility. If a fault occurs, it can damage the power system or user's facility. For sensitive loads, even voltage sags of short duration can cause serious problems in the entire system. Normally, a voltage interruption triggers a protection device, which causes shutdown of the entire system. In order to mitigate power interruptions, this research proposes a scheme called Synchronous Reference Frame (SRF) method based Dynamic Voltage Restorer (DVR) system. The proposed scheme is capable to quickly recognize the voltage sag or swell condition, and correct the voltage by either boosting the input voltage during voltage sag events or reducing the input voltage during voltage swell events with respect to arisen condition. The scheme, based on SRF method applied to all possible voltage level for the required compensation. It provides cost and size advantages over existing methods. Simulations and experiments have been extensively carried out to verify the validity of the proposed method.

Keywords— Sag-Swell, Dynamic Voltage Restorer, Distribution Power System, Voltage Source Inverter, Energy Storage Device, Power System Faults etc.

I. INTRODUCTION

A power distribution system is similar to a vast network of rivers. It is important to remove any system faults so that the rest of the power distribution service is not interrupted or damaged. When a fault occurs somewhere in a power distribution system, the voltage is affected throughout the power system. Among various power quality problems, the majority of events are associated with either voltage sag or a voltage swell, and they often cause serious power interruptions.

A voltage sag condition implies that the voltage on one or more phases drops below the specified tolerance for a short period of time. A voltage swell condition occurs when the voltage of one or more phases rises above the specified tolerance for a short period of time. The causes of voltage sags and swells are associated with faults within the power distribution system. Users located a close distance to the fault experience voltage sags much greater in magnitude and duration than users located farther away, and as the electrical system recovers after removing the fault, voltage swells are produced throughout the system for short periods of time. Often all users who are served by the power distribution system have power interruptions during a fault because of the effects of a voltage sag or voltage swell produced in the system by the fault. The objective of this research is to develop a novel voltage control scheme that can compensate for voltage sag and swell conditions in three-phase power systems.

II. LITERATURE SURVEY

Naeem Abas, et.al (2022). Power Quality is an essential concern in the modern power system that can affect consumers and utility. The integration of renewable energy sources, smart grid systems and extensive use of power electronics equipment caused myriad problems in the modern electric power system. Current and voltage harmonics, voltage sag, and swell can damage the sensitive equipment. These devices are susceptible to input voltage variations created by interference with other parts of the system. Hence, in the modern age, with an increase in sensitive and expensive electronic equipment, power quality is essential for the power system's reliable and safe operation. Dynamic Voltage Restorer (DVR) is a potential Distribution Flexible AC Transmission System (D-FACTS) device widely adopted to surmount the problems of non-standard voltage, current, or frequency in the distribution grid. It injects voltages in the distribution line to maintain the voltage profile and assures constant load voltage [1].

ChunmingTu, et.al (2020) An improved control scheme is proposed to improve the voltage quality of sensitive loads using dynamic voltage restorer. The existing control strategies either put emphasis on the optimal control during steady operation stage of compensation or correct the phase angle jump in the initial stage of compensation. In current researches, the impact of phase jump characteristic of voltage sag on the load side after voltage sag recoveries is widely ignored, further, there are still drawbacks in existing energy self-recovery strategies of DVR. Therefore, to improve the overall voltage compensation time while correcting the phase jump and accelerate the energy recovery of dc link side, this paper aims to 1) Propose the strategies to minimum active power consumption during voltage compensation stage and maximum active power absorption during energy self-recovery stage. 2) Deliver smooth transition in dynamic process to ensure the flexible switching between two stages. Theoretical analysis of proposed strategy is been validated through simulation and experimental results [2].

Arpitha M J, et.al (2019) The quality of power delivering to the consumer is reducing day by day because of semiconductor devices. voltage sag, voltage swell & Harmonics are most commonly occurring power quality problems in the distribution system. Dynamic Voltage Restorer (DVR) is the custom power device which can be the best possible solution to make the power system efficient and effective. In this paper a photovoltaic source-based DVR is proposed with the combination of nonlinear control techniques of inverter such as artificial neural network and hysteresis voltage controller to restore the voltage in sag, swell and fault conditions that occur in the system with the detailed comparative study of Artificial Neural Network (ANN) controller over hysteresis voltage controller [3].

Muhammad M. Roomi, et.al (2020), A best solution to mitigate the power quality problem like voltage sag is by restoring the load voltage to the desired magnitude and frequency. This paper proposes two closed loop current control methods for protecting sensitive rectifier loads using Dynamic Voltage Restorer. The new control methods involve an additional control loop to generate the actual current signals. These signals are compared with the reference signals to activate the Dynamic Voltage Restorer during voltage compensation. The performance of the control system is analyzed by comparing the generated reference signals with the actual signals in abc and dq frames. [4].

Manik Pradhan,et.al (2018) This paper deals with the protection of critical loads from voltage related power quality issues using Dynamic Voltage Restorer (DVR). A generalized control algorithm based on Instantaneous Space Phasor (ISP) and dual P-Qtheory has been proposed to generate the instantaneous reference voltages to compensate the load voltages with direct power flow control. The proposed algorithm adapts energy optimized series voltage compensation, which results in a reduction of energy storage requirement. The proposed DVR control scheme can support the load from voltage related power quality issues irrespective of the load current profile. Each leg of the three-phase three-leg split capacitor inverter is used to inject series compensation voltage in respective phases of the system. Model-based computer simulation studies and real-time experimental results validate the effectiveness of the proposed control algorithm [5].

Ogunboyo Patrick Taiwo, et.al (2017) Dynamic Voltage Restorer (DVR) is a series connected power electronics based custom power device that is used to improve voltage disturbances in low voltage electrical power distribution network. Power quality requirement is one of the most important concerns for power system. The parts of the DVR is made up of voltage source inverter, injection/booster transformer, a harmonic filter, an energy storage device and a bypass switch. The DVR is used to inject three phase voltage in series and in synchronism with the network voltages in order to compensate voltage disturbances with a benefit of active /reactive power control. This paper presents a review of the researches on the dynamic voltage restorer application for power quality improvement in low voltage electrical power distribution networks. It describes power quality issues, principle of operation of DVR, basic components of DVR, DVRs control topologies in distribution network, DVR control strategies and compensation techniques [6].

Rini Ann Jerin, .et.al (2016) Increasing sensitivity of the loads with respect to power quality has gained the interest of power system analysis and power quality improvement techniques. The voltage sags or swells which are characterized by rms voltage variations outside the normal operating range of voltages due to faults may lead to improper disconnection of wind turbines. This paper deals with the effective voltage sag/swell mitigation using Dynamic Voltage Restorer (DVR), to regulate the terminal voltage of the wind farm. The DVR utilizes a feed forward vector control-based algorithm to generate the PWM based firing signals for injecting appropriate compensation voltages. The actual wind farm field data of the voltage sag and swell events during fault conditions are re- created using MATLAB/Simulink and restored by employing the DVR. The simulation results are shown to verify the operation of DVR during balanced voltage sag and swell conditions [7].

Rakeshwri Pal, et.al (2015) Improved and controlled power quality is one of the essential and fundamental need in any power-driven industry for optimum utilization of resources. However critical problems in power quality have been recognized such as sags, swells, harmonic distortions and other interruptions. Out of these sags and swells are predominantly found and have severe impact on the electrical devices or electrical machines and therefore needs to be compensated at an earliest to ensure any mal-operation or failure. To crack these problems custom power devices are used like unified power-quality conditioner (UPQC), distribution STATCOM (DSTATCOM) and dynamic voltage restorer (DVR). The DVR is a one of the custom power devices used for the compensation of voltage sag and swell with an advantage of active/reactive power control. A major volume of literature reported in past several years on different configurations of DVR and different control technique used in it. In context of this a detailed review on DVR has been presented with different possible power circuit topologies and control techniques available to reconcile these power quality issues [8].

Abdul Mannan Rauf.et.al (2014) This paper deals with improving the voltage quality of sensitive loads from voltage sags using dynamic voltage restorer (DVR). The higher active power requirement associated with voltage phase jump compensation has caused a substantial rise in size and cost of dc link energy storage system of DVR. The existing control strategies either mitigate the phase jump or improve the utilization of dc link energy by (i) reducing the amplitude of injected voltage, or (ii) optimizing the dc bus energy support. In this paper, an enhanced sag compensation strategy is proposed that mitigates the phase jump in the load voltage while improving the overall sag compensation time. An analytical study shows that the proposed method significantly increases the DVR sag support time (more than 50%) compared with the existing phase jump compensation methods. This enhancement can also be seen as a considerable reduction in dc link capacitor size for new installation [9].

Smriti Dey et..al. (2013) Power quality improvement has become a major area of concern in present era. Due to the increase in modern sensitive and sophisticated loads connected to the Distribution System it has been very important to improve the quality of power because nonstandard voltage, current or frequency results a failure of the loads connected to the systems. Power electronics and advanced control technologies have made it possible to improve the quality of power and operate the sensitive loads satisfactorily. One of the major problems dealt in this paper is the voltage quality which is very severe for the industrial customers as it can cause malfunctioning of several sensitive electronic equipments. Dynamic Voltage Restorer (DVR) is a solution to improve voltage quality, which is connected in series with the network. This paper presents modeling, analysis and simulation of DVR in MATLAB SIMULINK, which includes PI controller and discrete PWM generator for control purpose of DVR. Simulation results of performance of DVR under different fault conditions such as single line to ground fault (SLG), double line to ground fault (DLG), line to line fault (L-L), three phase to ground fault etc [10].

Anita Pakharia,.et.al (2012) The power quality (PQ) requirement is one of the most important issues for power companies and their customers. The power quality disturbances are voltage sag, swell, notch, spike and transients etc. The voltage sag and swell is very severe problem for an industrial customer which needs urgent attention for its compensation. There are various methods for the compensation of voltage sag and swell. One of the most popular methods of sag and swell compensation is Dynamic Voltage Restorer (DVR), which is used in both low voltage and medium voltage applications. In this paper, the comprehensive reviews of various articles, the advantages and disadvantages of each possible configuration and control techniques pertaining to DVR are presented. The compensation strategies and controllers have been presented in literature, aiming at fast response, accurate compensation and low costs. This review will help the researchers to select the optimum control strategy and power circuitconfiguration for DVR applications. This will also very helpful in finalizing the method of analysis and recommendations relating to the power quality problems [11].

III. PROBLEM STATEMENT

In order to increase the reliability of a power distribution system, many methods of solving power quality problems have been suggested. The development and improvement of power switching devices capable of carrying large current with high voltage enable power electronics technologies to be applied to this area. In addition, self-commutable devices, i.e., gate turn-off device such as GTOs and high power IGBTs, give rise to a variety of schemes to mitigate power quality problems. Much research has been performed in an effort to solve power quality problems. Many voltage mitigation schemes are based on inverter systems consisting of energy storage and power switches. The main goal of this research is the development of a voltage sag mitigation scheme with high reliability at low-cost. This research proposes a scheme called “Dynamic Voltage Restorer.” The proposed scheme is able to quickly recognize the voltage sag and swell conditions and can correct the voltage by either boosting the input voltage during voltage sag events or reducing the input voltage during voltage swell events.

As a first step, this research reviews the statistical surveys of power quality problems in order to determine the specifications of the target system, and this research evaluates existing methods used to compensate for voltage sags and swells. Since the majority of voltage sag events occur under severe weather conditions, the voltage distribution of the system under lightning surge must be investigated. From the power quality surveys, it is known that most voltage sag events last for less than 2 seconds. Hence, it is necessary to operate this device only for a short period. Therefore, to increase the system efficiency and to provide the means of bypass of a short current, the system employs another switch in addition to the PWM switch, which is a bypass switch implemented with thrusters. The bypass switch is in the on-state most of time, and the PWM switch, which is actually a high voltage bidirectional AC switch, operates only during a voltage sag condition and regulates the output voltage according to the PWM duty-cycle.

IV. POWER QUALITY

Power Quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive equipment and non-linear loads are now more commonplace in both the sectors and the domestic environment. Because of this a heightened awareness of power quality is developing amongst electricity users.

Occurrences affecting the electricity supply that were once considered acceptable by electricity companies and users are now often considered a problem to the users of everyday equipment. This article introduces the subject of power quality and outlines the increasing relevance of a range of issues discussed in more depth in this Special Feature on power quality. A wide diversity of solution to power quality problems is available to the both the distribution network operator and the end user. More sophisticated monitoring equipment is ready affordable to end-users, who empower themselves with information related to the level of power quality measurable quantities or occurrences. Power quality problems are divided into two types, namely continuous and event-based power quality problems. Continuous power quality problems include voltage deviation, frequency deviation, voltage unbalance, power harmonics and voltage fluctuation and flicker. While event based power quality problems include voltage sag, voltage swell, temporary over-voltage or transient over-voltage, short interruption and long interruption.

Continuous power quality problems reflect the degree of deviation between the actual waveform and the desired waveform. The change ranges of them are often small, and in their existence duration, voltage and/or current changes more consistently, which can be considered as steady-state or quasi steady-state problems. However, event-based power quality problems reflect the severity of power disturbances, and the changes of event-based power quality problem are often sudden and obvious from the occurrence to the end.

V. MATHEMATICAL MODELLING &CONTROL OF DVR

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

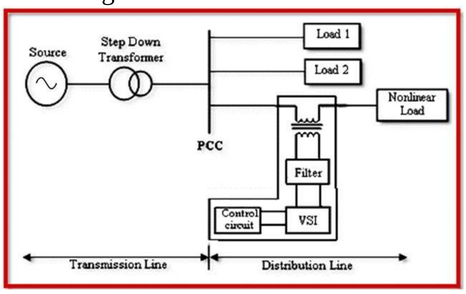

Fig.1 Location of DVR

A. BASIC CONFIGURATION OF DVR

The general configuration of the DVR consists of:
i. An Injection/ Booster transformer
ii. A Harmonic filter
iii. Storage Devices
iv. A Voltage Source Converter (VSC)
v. DC charging circuit
vi. A Control and Protection system

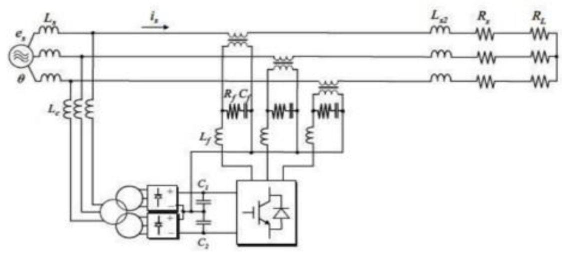

Fig.2 Schematic Diagram of DVR

Injection/ Booster transformer The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are: I. It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the -voltage source converters to the incoming supply voltage. II. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off thrusters (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices.

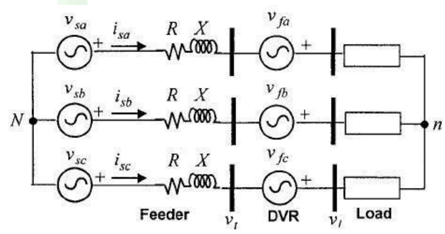

Fig. 3 Equivalent circuit diagram of DVR

To make the magnitude of the load voltage equal to that of the source voltage, the RIs drop must be less than NM. If the drop is less than this limiting value, the DVR must compensate the entire reactive drop in the feeder and provide additional injection such that the source voltage becomes V per unit. Itcan be seen from Fig. 4 that there are two possible intersection points with the arc – one at A and the other at B. This implies that two possible values of DVR voltage can be obtained for each feeder drop. For the first value, the source voltage will be along OA, while for the other value, it will along OB. It is needless to say that the best choice is the A intersection requiring much smaller voltage injection from the DVR.

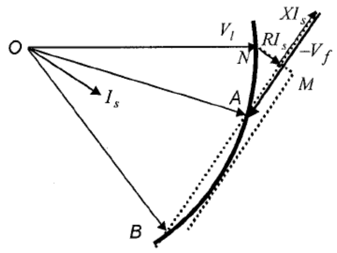

Fig. 4.Phasor Diagram Showing Multiple Solutions

B. Operating Modes of DVR

The basic function of the DVR is to inject a dynamically controlled voltage VDVR generated by a forced commutated converter in series to the bus voltage by means ofa booster transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage VL. This means that any Differential voltages caused by transient disturbances in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer.

VI. CONCLUSION

The purpose of this research was to develop voltage sag and swell mitigation device with low cost and high reliability. The scheme consisting of a linear control scheme has been proposed. This topology, a more cost-effective and reliable sag and swell supporter has been achieved primarily by reducing the number of switching components. A literature survey and a discussion of various existing methods were presented. The usage and operation principles were addressed, and deficiencies in the existing methods were mentioned, as well. The use of Dynamic voltage restorer gives rise to many possibilities for controlling the voltage and regulating power. From the literature survey, it was found that FACTS devices such as DVRs and STATCOMs yield good performance in controlling the output voltage.

This research has as its first priority, the development of a low-cost system that has a performance that is competitive to the FACTS devices. Therefore, an alternative topology from an inverter-based system was devised. The simulations have been done to show that the proposed voltage sag and swell supporter scheme regulates the output voltage with quick reaction and high precision during voltage sag and swell events. It was also shown that because of the voltage detection delay, there exists an output voltage overshoot transient at the moment of the voltage recovery.

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