Power Quality Improvement in Hybrid Sources Using DVR

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***Abstract*—This paper explains the importance of power quality improvement in modern grid-connected hybrid renewable energy systems that combine solar and wind energy sources. Since renewable sources are intermittent in nature, problems such as voltage sag, voltage swell, harmonics, and power interruptions can occur, affecting sensitive electrical loads and reducing system efficiency. To overcome these issues, a Dynamic Voltage Restorer (DVR) is used as an effective custom power device. DVR injects compensating voltage during disturbances to maintain constant load voltage and ensure uninterrupted power supply. The study highlights that DVR improves voltage stability, system reliability, smooth power transfer, and overall power quality in hybrid energy systems.**

I. INTRODUCTION

The increasing demand for clean and sustainable energy has led to the widespread use of renewable energy sources such as solar and wind power. Hybrid renewable energy systems combine these sources to provide reliable and continuous electricity supply. These systems are often connected to the main grid to improve reliability and manage variations in renewable power generation. When renewable energy production is low, power is supplied from the grid, while excess generated energy can be transferred back to the grid. However, due to the intermittent nature of solar and wind energy, several power quality issues such as voltage sag, voltage swell, harmonics, and power interruptions arise in the system. These disturbances can reduce efficiency, affect sensitive equipment, and decrease overall system performance.
To overcome these power quality problems, custom power devices are used in hybrid systems. Among them, the Dynamic Voltage Restorer (DVR) is an effective and widely used solution for voltage-related disturbances. DVR is a series-connected device that injects compensating voltage into the system during disturbances to maintain a constant load voltage. This paper discusses the application of DVR in a grid-connected hybrid solar-wind energy system and explains different compensation techniques used for power quality improvement. The study concludes that DVR effectively improves voltage stability, smooth power transfer, system reliability, and overall performance of modern hybrid renewable energy systems.

II. COMPENSATION TECHNIQUES

- *Series Compensation:*

Series compensation involves connecting a compensating device in series with the transmission line. It helps in controlling voltage and improving power transfer capability. By injecting voltage in series, it compensates for voltage drops caused by faults or disturbances.
This technique is effective for mitigating voltage sag and maintaining voltage stability in the system. Devices like DVR use this principle to inject voltage and protect sensitive loads.

- *Shunt Compensation:*

Shunt compensation is connected in parallel with the system and is mainly used for reactive power compensation. It helps in improving voltage profile and power factor.
Devices like DSTATCOM are used in shunt compensation to regulate voltage and reduce harmonics. It improves system stability and efficiency.

- *Hybrid Compensation:*

Hybrid compensation combines both series and shunt compensation techniques to achieve better performance. It uses both DVR and DSTATCOM for effective power quality improvement.

This method is highly suitable for hybrid renewable systems where both voltage and current disturbances occur simultaneously.

- *Passive Compensation:*

Passive compensation uses components like capacitors, inductors, and filters to reduce harmonics and improve power quality.

Although simple and cost-effective, it lacks flexibility and cannot respond quickly to dynamic disturbances.

- *Active Compensation:*

Active compensation uses power electronic devices to inject compensating signals into the system. It provides better control and fast response. Active filters and converters are used to eliminate harmonics and improve voltage quality effectively

- *DVR Compensation*

Dynamic Voltage Restorer (DVR) is a series-connected custom power device used to maintain constant voltage at the load side in case of disturbances. In a grid-connected hybrid system, DVR plays a critical role in ensuring smooth power exchange between renewable sources and the main grid. When voltage sag or swell occurs due to faults, renewable fluctuations, or grid disturbances, DVR injects the required voltage through an injection transformer. This ensures that sensitive loads receive stable voltage regardless of variations in solar, wind, or grid supplied uses a Voltage Source Converter (VSC), energy storage system, and control unit. Advanced control strategies like feed-forward control and GPI control provide fast and accurate compensation. Hence, DVR significantly improves the reliability and performance of hybrid grid-connected systems.

III. DYNAMIC VOLTAGE RESTORER

The basic configuration structure of DVR is shown in Fig. 1 where DVR is connected in series with the main system with help of an injection transformer. Whenever there is occurrence of voltage sag in the system, DVR will inject a controlled voltage which is generated by Voltage source converter in series with the bus voltage by means of injection transformer for diminishing the sag [1]. DVR has three operating modes. In standby mode there is no voltage sag or swell occurrence and is the normal operating condition of the system. In this mode the injected voltage is very less to overcome the losses of injection transformer. In the Injection mode the DVR will operate under sag or swell conditions and inject the required voltage to diminish or mitigate the sag. When the current on load side will exceed a permissible limit, due to short circuit in the system or some fault, DVR operates in the protection mode and will isolate from the system using bypass switches.

A. Operating Principle:

The fundamental principle of DVR operation is that it will inject a voltage through injection transformer that is the difference between sagged voltage and pre-sag voltage. The maximum capability of DVR injection depends upon the injection transformer turns ratio and ratings of energy storage device.

B. Fundamental components of DVR:

The DVR consists of following fundamental components:

1) Injection Transformer:

The injection transformer fulfils the basic purpose of connecting the DVR to distribution feeder and injection of voltage as per the sag and swell detection by the control unit which is generated by the VSI. The performance of DVR is affected and dependent upon the rating of the injection transformer.

2) Voltage Source Converter:

VSI is a device based on power electronics comprising of DC link energy storage device and is of two levels or can be multilevel. Its basic function is the conversion of DC voltage supplied by the DC link or energy storage device into AC voltage and this voltage will be fed by the injection transformer.

3) Harmonic filter:

The VSI itself is a device based upon power electronics so it will generate harmonics during the switching action. So, it is necessary to suppress out those harmonics which is obtained using the harmonic filter.

4)DC energy storage:

The requirement of the real power for voltage compensation is fulfilled using the DC energy storage devices. Flywheels, batteries, (SMES), Ultra Capacitors can be used as an energy storage device.

5)Control system:

The control system comprises of the control strategy used in the operation of DVR In the proposed paper the DVR based on PI controller along with dO theory is used. DVR to distribution feeder and injection of voltage as per the sag and swell detection by the control unit which is generated by the VSI. The performance of DVR is affected and dependent upon the rating of the injection transformer.

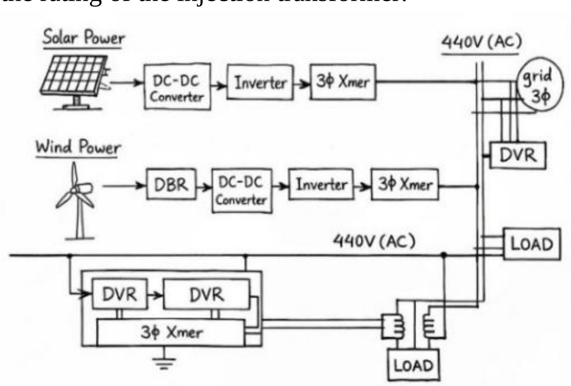

Fig. Block diagram of DVR connected to microgrid.

IV. DVR CONTROL TOPOLOGIES

1)The Dynamic Voltage Restorer (DVR) is a fast and efficient power electronic device used to solve voltage sag and swell problems by injecting a controllable voltage into the system, ensuring that the load voltage remains stable and at its nominal value. It works within milliseconds and can handle both balanced and unbalanced conditions effectively, making it suitable for protecting large industrial loads. Various configurations and control methods enhance its flexibility and performance. Overall, DVR provides reliable voltage compensation and maintains power quality, but its main limitation is that it cannot protect against complete power interruptions. [1,3,9]

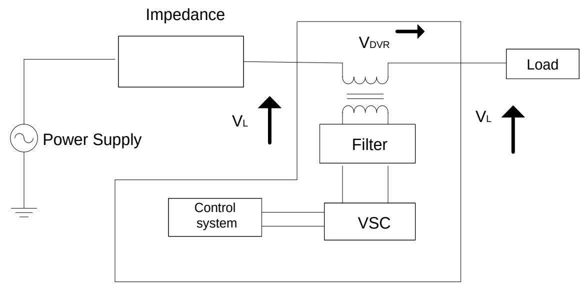

Figure: Schematic diagram of DVR

2)This paper explains how a Dynamic Voltage Restorer (DVR) can effectively reduce voltage sags and swells in low-voltage distribution systems using a control method based on the DQO algorithm (DQO is a planning process that ensures collected data is reliable and suitable for decision-making). The proposed control scheme quickly detects disturbances and corrects them by injecting the required voltage, ensuring stable supply to the load. MATLAB/Simulink simulations confirm that the DVR performs well in maintaining voltage quality, even for long-duration disturbances. The system is also cost-effective and simple to control, making it practical for real applications, although future work aims to validate these results through experimental testing. [2,10]

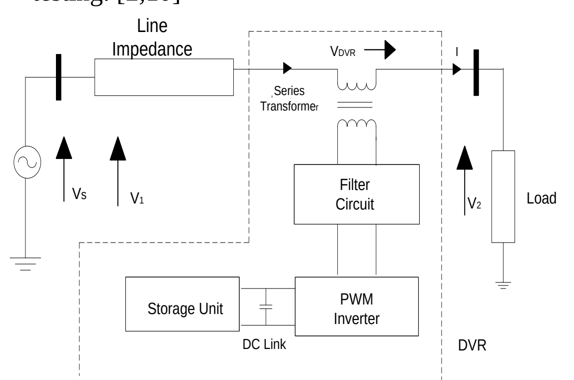

Fig. Schematic diagram of DVR

3)This paper focuses on improving the performance of a Dynamic Voltage Restorer (DVR) for mitigating voltage sags under distorted and unbalanced grid conditions. It introduces a *Delayed Signal Cancellation (DSC)-based Positive and Negative Sequence Extractor (PNSE)* to accurately detect voltage disturbances by eliminating harmonics and extracting symmetrical components. A multiloop feedforward PI controller is proposed to enhance

DVR response, consisting of outer voltage and inner current control loops. Simulation results using PSCAD/EMTDC show that the PI controller provides better stability and lower overshoot compared to a P controller, even though the latter has a slightly faster response. Overall, the proposed method ensures improved sag detection, stable operation, and effective voltage compensation in both balanced and unbalanced conditions. [11,13]

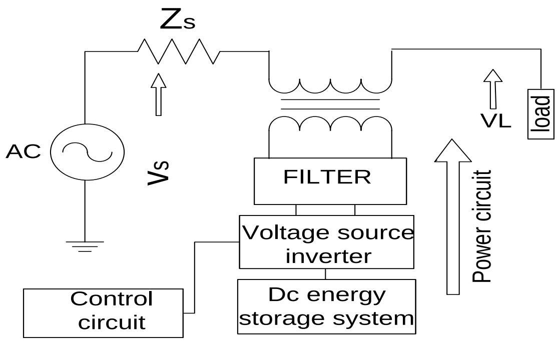

Fig. Schematic diagram of DVR

4) This paper presents a Dynamic Voltage Restorer (DVR) enhanced with Superconducting Magnetic Energy Storage (SMES) to effectively mitigate voltage sags and improve power quality in distribution systems. The SMES unit, known for its high energy density and fast response, acts as a reliable energy source that allows the DVR to quickly restore real power and maintain stable voltage during disturbances. The system is modeled and simulated in MATLAB/Simulink, demonstrating that the SMES-based DVR provides rapid compensation, excellent voltage regulation, and efficient performance under both balanced and unbalanced conditions. Overall, the proposed approach significantly improves DVR capability in handling voltage fluctuations and protecting consumers. [7,8,12]

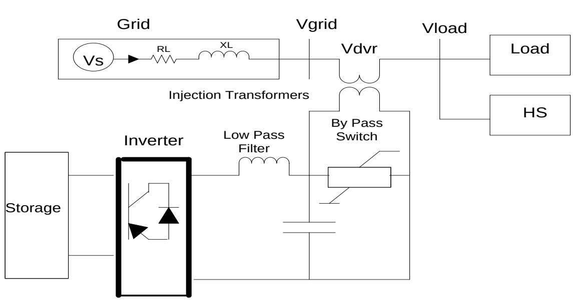

Figure : Simulated system in MATLAB

5) Models and compares Dynamic Voltage Restorer (DVR) and DSTATCOM using MATLAB/Simulink on a three-phase system with transformers, transmission line, and different loads. Performance is tested under various faults (three-phase, double line-to-ground, and single line-to-ground) to evaluate voltage sag mitigation.

Highlights the importance of power quality, focusing on voltage sag caused by weather and system disturbances, which can lead to equipment damage, energy loss, and system disruption. This paper uses a Delayed Signal Cancellation (DSC) pre-filter with a Positive and Negative Sequence Extractor (PNSE) to separate the grid voltage into its components and remove harmonics from the dq voltages. Since the performance of the Dynamic Voltage Restorer (DVR) depends on the controller, the paper proposes a multi-loop PI feed-forward controller to improve DVR performance under distorted grid conditions. Models and compares Dynamic Voltage Restorer (DVR) and DSTATCOM using MATLAB/Simulink on a three-phase system with transformers, transmission line, and different loads. Performance is tested under various faults (three-phase, double line-to-ground, and single line-to-ground) to evaluate voltage sag mitigation. Highlights the importance of power quality, focusing on voltage sag caused by weather and system disturbances, which can lead to equipment damage, energy loss, and system disruption.

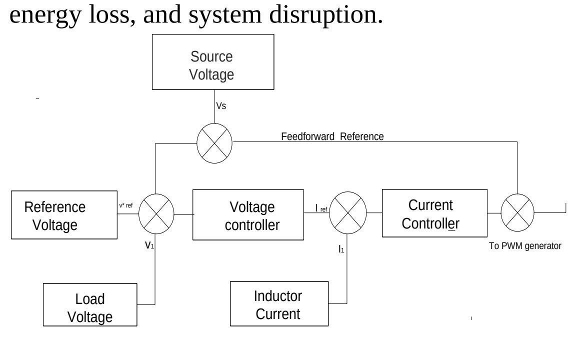

Fig. General control scheme for DVR

6) This paper presents a new control strategy for a Unified Power Quality Conditioner (UPQC) designed to improve power quality in a three-phase, four-wire system by combining series and shunt active power filters sharing a common DC link. The proposed method uses simple control techniques, such as a zero-crossing detector and the real component of load current (IcosΦ), to reduce

computational delay and minimize the number of sensors required. Simulation results in MATLAB/Simulink show that the UPQC effectively improves power factor, balances load, reduces neutral current, and mitigates voltage and current harmonics, maintaining them within IEEE-519 standards. Compared to conventional SRF control, the proposed method offers better performance with lower harmonic distortion and improved efficiency, making it a reliable and practical solution for enhancing overall power quality.[6]

V. CONCLUSION

Hybrid Renewable Energy Systems Face Power Quality Challenges:
The integration of solar and wind energy into hybrid power systems offers environmental and economic benefits but poses challenges like voltage sag, swell, and harmonics due to their intermittent nature. The main grid enhances reliability but introduces additional disturbances, making power quality improvement crucial.

DVR: A Reliable Solution:
The Dynamic Voltage Restorer (DVR) is identified as the most effective solution, ensuring stable voltage and smooth power exchange. Advanced control strategies like feed-forward and GPI control enhance DVR performance. Simulation studies using MATLAB demonstrate its effectiveness in handling voltage sag and swell conditions, making DVR essential in modern power distribution networks.

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