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Research Paper

Voltage Sag, Swell, and Interruption Compensation Using DVR Based on Energy Storage Device

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Abstract –

The primary objective of this study is to provide a Z-Source Inverter (ZSI)-DVR that incorporates PI controller technology to enhance power quality. In the proposed DVR, conventional VSI is replaced with ZSI, which offers many benefits such as buck/boost, a wider voltage boost gain range, less voltage stress, and fewer passive components. To safeguard the load against fluctuations in the supply voltage, the distribution voltage regulator (DVR) is meant to be attached just after the transformer. To create error signals, the three-phase supply voltages are continuously monitored, transformed into Direct-Quadrature-Zero (DQ0) quantities, and then compared to the reference value. A zero-error indication indicates that the availability voltage is operating at its rated value. Therefore, neither the control circuitry nor the ZSI will provide a compensatory voltage, and neither will produce PWM. Under these circumstances, a breaker will also short circuit the series transformer's secondary winding. A zero-voltage injection into the line is therefore produced by the DVR. Load voltage is therefore kept constant at its rated value, which is identical to supply voltage. Unbalanced and below rated value, the three-phase voltages result from supply-side sags, swells, or interruptions. Consequently, the DQ0 frame is where error signals can be produced. Relying on the inverse DQ0 transformation, these DQ0 frame error signals are transformed into three-stage voltages once again. The three phase signals of error are used to create switching pulses for the ZSI. The load voltage is kept at its rated value by injecting the produced compensating voltage alongside the supply voltage via the series transformer. Maintaining the necessary voltage to the load is achieved by the suggested topology's dynamic compensation of voltage interruptions, swell, and sag. In this case, the performance of the traditional DVR topology has been enhanced by integrating the Hybrid Control method PI. Using solar electricity to compensate for various voltage changes, the model demonstrates how a DVR may operate. The MATLAB/SIMULINK environment is used to simulate the performance of the ZSI-DVR with PI control method.

Keywords – DVR, PI Controller, DQ0, Sag, Swell, Z -Source Inverter.

1. INTRODUCTION

Hundreds of producing stations along with thousands of load storage facilities are linked by extensive power transfer and distribution networks in modern power systems, making them complex networks. The dependability and quality of power supply at different load centers is the primary worry of customers. While the majority of industrialized nations have consistent electricity production, the quality of that power is sometimes questionable. An ideal power distribution system would deliver its consumers a constant supply of energy at a smooth sinusoidal voltage and frequency that are in accordance with the agreed-upon magnitude and level. In order to address power quality issues such as voltage dips, interruptions, surges, harmonic distortions, and so on, the distribution side makes use of specialized power equipment. Depending on the utility, a power quality problem could have different effects. In addition to equipment failures, starting big motors, switching big loads, and activating transformers may create voltage sags. A voltage source inverter (VSI) synthesizes the compensating voltage utilizing the DC power preserved in the battery banks as well as capacitor banks, which are the energy storage devices employed by DVRs that are based on them. The suggested DVR proposes ZSI as an alternative to conventional VSI, which offers many benefits such as buck/boost, a wider voltage boost gain range, less passive components, and reduced voltage stress. Protecting the load from supply voltage variations, the suggested DVR is attached directly after the distribution transformer. Error signals are produced by measuring the three phase supply voltages, converting them to Direct-Quadrature-Zero (DQ0) values, and then comparing them with the reference value. There is no error warning while the supply power is rated at full power. The control circuitry will not create pulse width modulation (PWM), and the ZSI will not provide a compensatory voltage. Even the series transformer's secondary winding will be blown to smithereens under these circumstances. Therefore, the DVR is injecting zero volts into the line. This keeps the load voltage at its rated value, which is the same as the supply voltage. The three-phase voltages are not only imbalanced, but also fall short of their rated values whenever there is an interruption or sag in the supply. There will be mistake signals within the DQ0 frame. Using the inverse DQ0 transformation, these error outputs in the DQ0 frame are turned back into three phase voltages. The ZSI's switching pulses are produced by use of and they phase error signals. In order to keep the load voltage at its rated value, the series transformer injects the produced compensatory voltage alongside the supply voltage. To keep the voltage to the load at the desired level, the suggested design dynamically adjusts for voltage interruptions, swell, and sag. In this case, the inclusion of the Hybrid Control method PI has improved the performance of the typical DVR architecture.

2. POWER QUALITY

Any variation in power (current, frequency, or voltage) that interferes with the regular operation of electrical equipment is often defined as power quality, and more specifically, a disturbance of power quality. The ideal power source would be a constant, noise-free sinusoidal wave with both frequency and voltage tolerances that are never out of whack. Power quality refers to the reliability of electric power provided by utilities. When alternating current (AC) voltage drops between half a cycle and one minute next to a certain frequency, this is called a voltage sag. In addition to system problems, large startup currents caused by switching on loads are a common cause of sags.

Fig.1: Voltage Sag

Common reasons for voltage drops include remote fault clearance by utility appliances and beginning heavy loads, such a big air conditioner. Starting big motors in an industrial capacity may also cause a significant voltage drop. Starting a motor requires more than double the convectional operating current, which is six times the maximum. The remainder of the system it is connected to will likely experience a significant voltage drop as a result of the abrupt and massive electrical load it creates. An inverse sag, a swell encompasses a rise in AC voltages over a time ranging from half a cycle to one minute. Rapid (particularly big) load decreases cause swells, high-impedance neutral associations cause a general supply breakdown, and single-phase on a three-phase system is problematic.

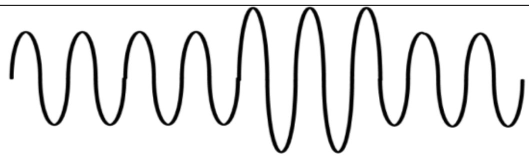


Fig.2: Voltage Swell

Damage to electrical connections, blown semiconductors, inaccurate data, deteriorating insulation, and flashing lights are all possible outcomes. Common solutions include uninterruptible power supply systems, power line conditioners, and resonant "control" transformers. Like swells, sags cannot be seen until their effects become apparent.

3. DVR

The most noticeable disruptions in power quality are voltage sags and swells. Custom power devices based on power electronic converters have since been created to address these issues. The DVR is particularly cost-effective and efficient component inside these devices for protecting sensitive loads from voltage dips and spikes. In a system, a DVR is a series-connected device that acts as a voltage sag/swell detector and an injector of regulated voltage. It is installed between the sensitive load and the grid. The existing literature also suggests using it to reduce transient voltage as well as fault current restrictions and to compensate for harmonics. In order to maintain the power quality, DVR uses an injection transformer to inject a regulated voltage in series alongside a source voltage in phase. Figure 3 depicts the fundamental architecture of a standard DVR. The inverter, dc-link capacitor, filter/injection transformer, and the other two types are the four main ways it is classified. Changing direct current storage into alternating current requires an inverter system. The inverter's undesirable harmonic components are removed by the passive filter. The inverter's pwm output is then transformed into a sinusoidal waveform in this manner. Energy storage units, which might be batteries, super capacitors, SMES, etc., are another part that is used to provide the DC energy that is needed. Finally, a transformer isolates the load from the system and injects regulated voltage.

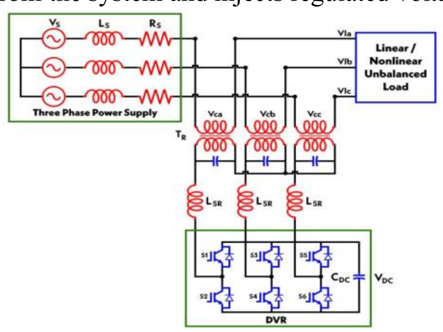


Fig. 3: DVR Structure.

It is the fundamental principle of DVR to move the voltage sag corrective value from the DC input of the inverter towards the injected transformer beyond the filter. Max voltage injection strength and active power provided by a DVR determine its compensating capacity. Direct voltage regulation (DVR) requires active power injection into the distribution system in the event of a voltage disruption. A big capacitor stores energy in a direct current system that is linked to the inverter input. Within malfunctioning circumstances, it supplies reactive energy to the load. Depletion of energy storage capacitors causes a drop in voltage at their terminals. Accordingly, the DVR inverter cannot provide the necessary voltage below a certain minimum, making the size as well as rating of the capacitor crucial to the DVR power circuit. One may determine the DC capacitor benefit to a three-phase system. You can deliver high current pulses periodically for tens of thousands of cycles, which is the most essential benefit of these capacitors. We talk about how to choose a capacitor's rating based on its rated voltage, peak current, and root-mean-square (RMS) value.

4. PROPOSED SYSTEM

Installing the DVR shortly after the transmission transformer installation safeguards the loads from supply voltage fluctuations since it is a bespoke power device. Figure 4 depicts the configuration of the suggested DVR. A battery bank serves as the energy storage device for the suggested DVR. The VSI receives its DC power from the battery via a specific connection. The main winding of the series transformer receives the voltage output of the VSI via LC filters. A breaker is attached to the series transformer's secondary winding. On a constant basis, source voltage is checked against the specified reference value. No error indications will be generated while the voltage from the source is at its rated value. Regarding the VSI, not changing pulses will be produced. This means the DVR will not provide any compensatory voltage. The breaker remains in the closed position at this moment. A short circuit will occur in the series transformer's secondary winding. At rated value, the load voltage is the same as the supply voltage.

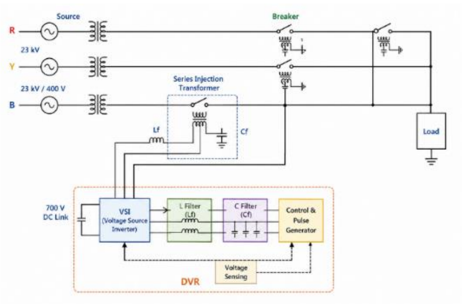


Fig. 4: Topology of the Proposed DVR.

The voltage of the supply will deviate from its rated value in the event of a power dip, surge, or interruption. As a result, message errors will be produced. Through its control circuitry, the DVR will provide the necessary compensatory voltage. An opening will be made in the breaker panel of the series transformer. In order to reduce voltage dips, spikes, and interruptions, the compensating voltage and supply voltage will be provided to the line via the series transformer. There is constant vigilance over the supply voltage. An important part of the DVR is the controller. The DVR system was controlled using closed-loop technology in a revolving dq reference frame. In response to the disturbances, the PI controller pulsed the PWM generator as needed. In Figure 5, we can see the DVR's PI controller circuit. The following equations are used to convert the abc coordinate system into the dq0 coordinate system, which is then expressed as

$$V_d = \frac{2}{3}\left[V_a sin\omega t + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + V_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right]$$

$$V_q = \frac{2}{3}\left[V_a cos\omega t + V_b \cos\left(\omega t - \frac{2\pi}{3}\right) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right]$$

$$V_0 = \frac{1}{3}\left[V_a + V_b + V_c\right]$$

To determine the disturbance in the dq coordinates, the dq values had been contrasted to the reference values. We also use a phase-locked loop (PLL) to detect the system's frequency.

$$error_d\,(t) = V_{dref} - V_{dact}$$

$$error_q\,(t) = V_{qref} - V_{qact}$$

In Fig. 5, we can see the associated control circuit that takes as inputs the aforementioned error signals that arise between the reference and real values of dq voltage. The measured and converted Source voltage to the dq0 coordinates is denoted by VSource. The difference between the real as well as reference dq voltages served as the input for the PI controller. The appropriate ZSI pulses are generated by converting the outputs into abc positions and applying them to the PWM circuit. Parameter adjustment improved the PI controller's performance. Traditional techniques for tweaking the PI parameters do exist, but they have their drawbacks and nonlinearities.

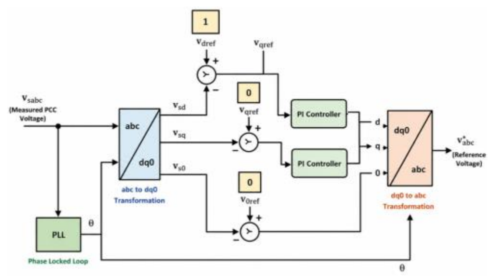
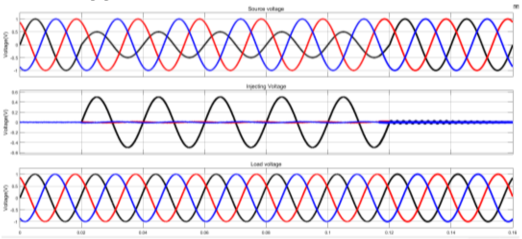


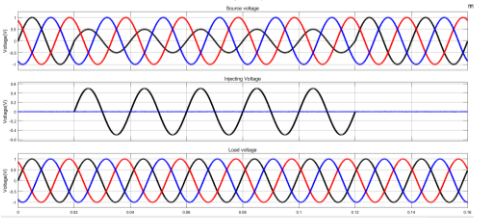
Fig. 5: Control diagram of DVR with PI controller.

5. SIMULATION RESULTS

The suggested technique is tested using a 23kV grid supply voltage. Directly following the distribution transformer is where the DVR is attached. The battery bank has a voltage of 700 volts. Reduce the effects of power dips, spikes, single-phase outages, and three-phase outages with the help of the suggested DVR. Below, you can see the simulation results broken down by unit value. The efficacy and dependability of the suggested DVR may be easily understood from the results, which are shown as a per-unit value. If you look at the simulation results below, you can see how various scenarios' percentages of sag and swelling compare to both current and suggested solutions.

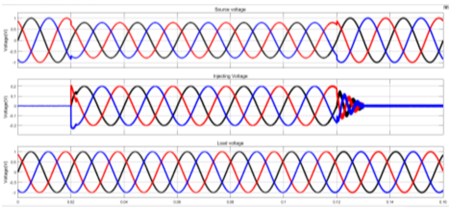


Existing system



Proposed system

Fig. 6 Single phase voltage sag mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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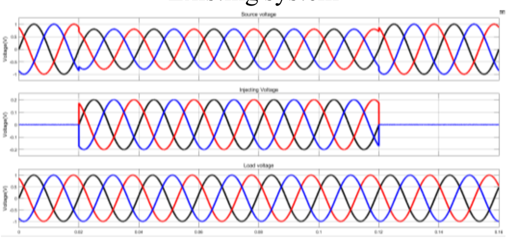
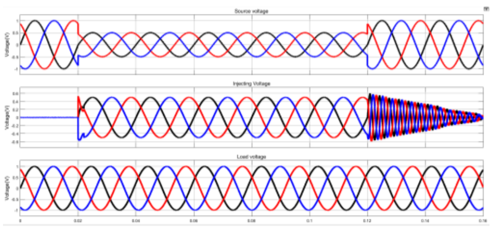


Proposed system

Fig. 7: Balanced voltage sag mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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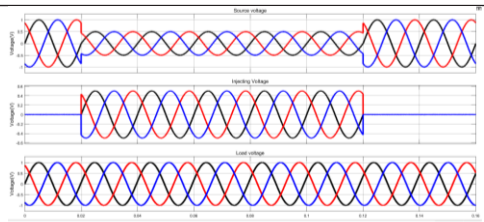
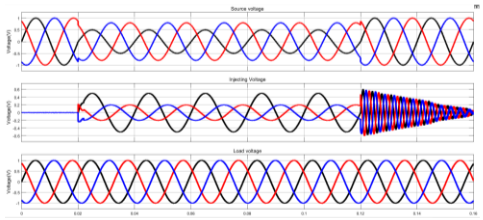


Proposed system

Fig. 8: Balanced voltage sag mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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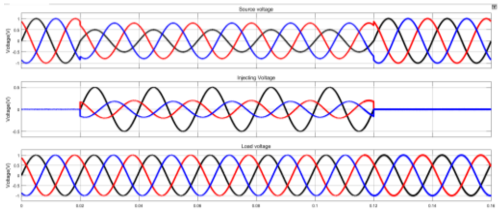
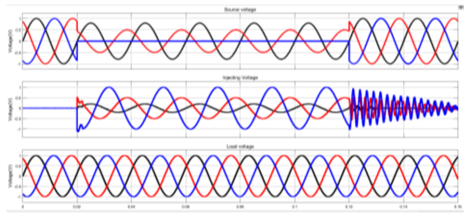


Proposed system

Fig. 9: Unbalanced voltage sag mitigation (a) Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.

In figure 6, we can see the measures taken to reduce the 50% drop in voltage in phase 'a'. See Figure 7 for a 20% reduction and Figure 8 for a 50% reduction in the balanced voltage sag. Phase 'a' mitigates a 20% imbalanced voltage sag, phase 'b' 50%, and phase 'c' 25%. This is seen in figure 9.



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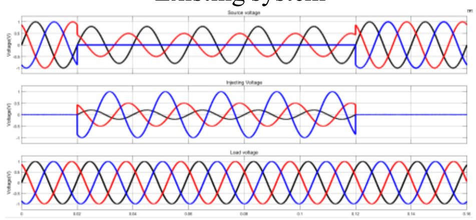
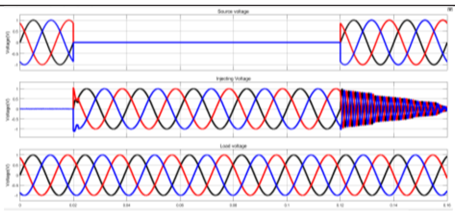


Proposed system

Fig. 10: Single phase outage and Unbalanced voltage sag mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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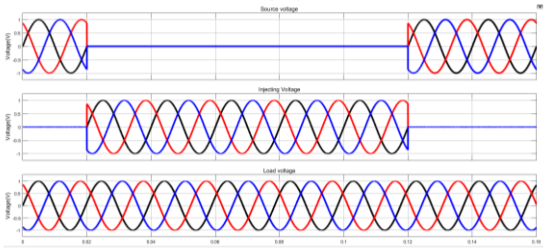
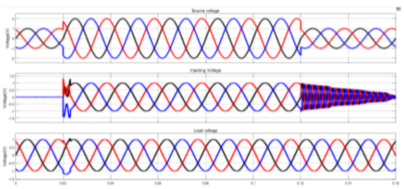


Proposed system

Fig. 11: Three phase outage mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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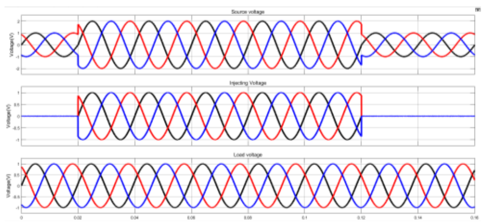
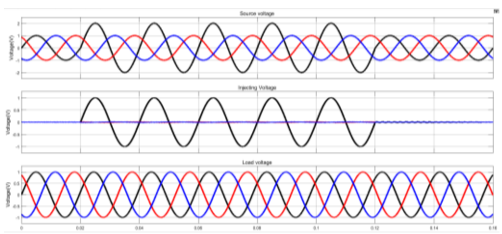


Proposed system

Fig. 12: Balanced voltage swell mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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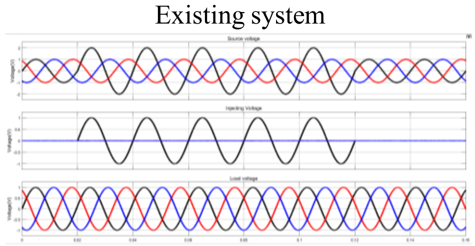
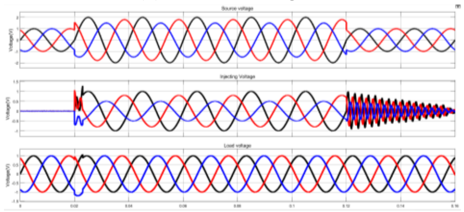


Proposed system

Fig. 13: Single phase voltage swell mitigation (a) Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.



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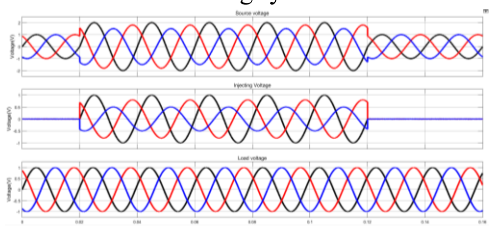

Proposed system

Fig. 14: Unbalanced voltage swell mitigation (a)Source Voltage in Per Unit (b) Compensating voltage generated by the DVR in Per Unit (c) Load voltage in Per Unit.

The figure 10 shows the mitigation of a single-phase outage in phase 'c' as well as a 20% imbalanced voltage sag in phase 'a' and a 50% sag in phase 'b'. Figure 11 illustrates a three-stage approach to downtime mitigation. Figure 12 shows the proposed DVR's capacity to adjust a balanced voltage swell of 100% and Figure 13 shows the same information for a single-phase swell of 100% in phase 'a'. Figure 14 depicts an imbalanced voltage swell of 100% in phase 'a,' 75% in phase 'b,' and 50% in phase 'c.'.

CONCLUSION

The above-mentioned simulation findings demonstrate that the suggested DVR, which utilizes energy storage devices as battery banks, can minimize equal voltage sag, imbalanced voltage sag, single phase outage, three phase outage, equal voltage swell, and unbalanced voltage swell of 100%, in accordance with DQ0 theory. Since a voltage source inverter employs only six IGBT switches for a three-phase system, the control is straightforward, robust, and quick to install. Several topologies have been proposed in the literature to address voltage sag, swell, and interruption with DVR; however, all of them have relied on controllers such as P, PI, PID, fuzzy logic, neural network, or algorithms. There is no need for a controller in the suggested approach since it effectively reduces voltage sag, swell, and outages. The suggested solution minimizes sag, swell, and outages by producing the PWM pulses necessary to provide compensatory voltage without the need of controllers or algorithms, all based on DQ theory. Results from the simulations proved that the suggested system could compensate for 100% voltage sag, swell, single phase outage, and three phase outages employing DVR-based energy storage devices without the need for controllers.

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