COMPARISON OF E-ZSI AND ZSI FOR VOLTAGE SAG AND SWELL MITIGATION

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Abstract:

The Dynamic Voltage Restorer (DVR) is a commercially available, popular device to eliminate voltage sags and swells in the distribution lines. Its basic function is to inject the voltage difference (difference between the pre-sag and sag voltage) to the power line and maintains the pre-sag voltage condition in the load side. A technique based on the Z source inverter and E-Z source inverter for the DVR is proposed in order to enhance the voltage restoration property of the device. Z-source inverters are recent topological options proposed for buck–boost energy conversion with a number of possible voltage- and current-type circuitries. Common feature noted is their inclusion of an *LC* impedance network, placed between the dc input source and inverter bridge. By controlling the shoot through duty cycle, the Z source inverter system using MOSFET provide ride through capability during voltage sags, reduces line harmonics, and improves power factor and high reliability. The proposed control algorithm is investigated through computer simulation by using MATLAB.

Keywords: DVR, E-Z source inverter, ZSI, Voltage sag and swell.

I. Introduction:

The need of the electrical power is increasing and simultaneously the problems while transmitting the power through the distribution system are also increasing. Voltage fluctuations are considered as one of the most severe power quality disturbances to be dealt with. Even a short-duration voltage fluctuation could cause a malfunction or a failure of a continuous process. There are several types of voltage fluctuations that can cause the systems to malfunction, including surges and spikes, sag, swell, harmonic distortions, and momentary disruptions. Among them, voltage sag and swell are the major power quality problems. Voltage swell is the sudden increase of voltage to about more than 110% amplitude of the supply voltage, whereas the voltage sag is the sudden decrease of voltage ton about 90%amplitude of supply voltage. This is caused due to the sudden reduction or addition of the load across that particular feeder. This change of voltage is compensated by injecting the voltage in series with the supply from another feeder at the time of disturbances using DVR

Electronics devices hold substantial promise for making distributed energy applications more efficient and cost effective. There is a need to develop advanced power electronics interfaces for the distributed applications with increased functionality (such as improved power quality, voltage/volt-amperes reactive (VAR) support), compatibility (such as reduced distributed energy fault contributions), and flexibility (such as operation with various distributed energy sources) while reducing overall interconnection costs. The use of voltage source inverters is increasing [1]. They are used both for feeding power from distributed generators to the transmission grid and power to various types of electronic loads. In recent years, the number of different power resources connected to power systems (voltage grids) has increased and there has been a move toward connecting small power resources to the medium and low voltage network [2].

Power quality standards for connection of an inverter to the grid are still under development, since previously there have been a few similar high power applications. In [3] it is stated that the power quality is determined by the voltage quality, when the voltage is a controlled variable. In order to deliver a good ac power the controlled pulse width modulation (PWM) inverter and L-C output filter have to convert a dc voltage source (e.g. batteries) to a sinusoidal ac voltage with low voltage THD and fast transient response under load disturbances. Another important aspect of power quality is harmonic distortion. General requirements for harmonic distortion can be found in standard [4] and particularly for connection of distributed resources to grid in [4].

PWM control is the most powerful technique that offers a simple method for control of analog systems with the processor's digital output [5]. With the availability of low cost high performance DSP chips characterized by the execution of most instructions in one instruction cycle, complicated control algorithms can be executed with fast speed, making very high sampling rate possible for digitally-controlled inverters [6].

The Z-source inverter, utilizing a unique LC network and previously forbiddenshoot-through states, provides unique features, such as the ability to buck and boost voltage with a simple single stage structure The Z-source inverter exhibits new operation modes that have not been discussed before. This analyzes these new operation modes and the associated circuit characteristics[7]. Depending upon the boosting factor capability of impedance network the rectified DC voltage is buck or boost up to the voltage level of the inverter section (not exceed to the DC bus voltage). This network also acts as a second order filter and it should be required less number of inductor and capacitor[8].

The voltage source inverter (VSI) topology is mainly used in a conventional DVR, as it gives good output voltage with low harmonic levels. The main disadvantage of this topology is its buck type output voltage characteristics, limiting the maximum voltage that can be attained. This means that the DVR injection capability would be limited, especially when the DC link voltage drops below a certain critical value. Therefore the use of this inverter topology alone in DVR systems with dwindling DC link voltage in the energy storage device, would pose a problem. Most of the applications would require the inverters to have both voltage buck and boost capabilities, for riding through loads current supply voltage variations

To overcome the above problems of the traditional VSI and current source inverter (CSI), an impedance source inverter(Z source inverter) is presented. Z source inverters have been reported recently as competitive alternatives to existing inverter topologies with many inherent advantages. The Z source inverter differs from conventional converters like the VSI and CSI due to the presence of a unique X-shaped impedance network on its DC side, which interfaces the source and the inverter H-bridge. It facilitates both voltage-buck and boost capabilities. It employs a unique impedance network to couple the converter main circuit to the power source, load or another converter, for providing unique features that cannot be observed in the traditional VSI and CSI, where a capacitor and inductor are used respectively.

Therefore, Z-source inverters are in effect safer and less complex, and can be implemented using only passive elements with no additional active semiconductor needed. Believing in the prospects of Z-source inverters, introducing a new family of embedded EZ-source inverters that can produce the same gain as the Z-source inverters, but with smoother and smaller current/voltage maintained across the DC input source and within the impedance network. In this paper the modeling and control of voltage sag/swell compensation using new control technique based dynamic voltage restorer are simulated using MATLAB software. The simulation results are presented to show the effectiveness of the proposed control method.

II. Dynamic Voltage Restorers

A DVR is a device that injects a dynamically controlled voltage $V_{inj}(t)$ in series to the bus voltage by means of a booster transformer as depicted in Figure1. The amplitudes of the injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage $V_L(t)$. This means that any differential voltage 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.

The DVR works independent of the type of fault or any event that happens in the system, provided that the whole system remains connected to the supply grid, i.e. the line breaker does not trip. For most practical cases, a more economical design can be achieved by only compensating the positive and negative sequence components of the voltage disturbance seen at the input of the DVR. This option is reasonable because for a typical distribution bus configuration, the zero sequence part of a disturbance will not pass through the step down transformers because of infinite impedance for this component. For most of the time the DVR has, virtually, "nothing to do," except monitoring the bus voltage. This means it does not inject any voltage ($V_{inj}(t)= 0$) independent of the load current. Therefore, it is suggested to particularly focus on the losses of a DVR during normal operation. Two specific features addressing this loss issue have been implemented in its design, which are a transformer design with low impedance, and the semiconductor devices used for switching

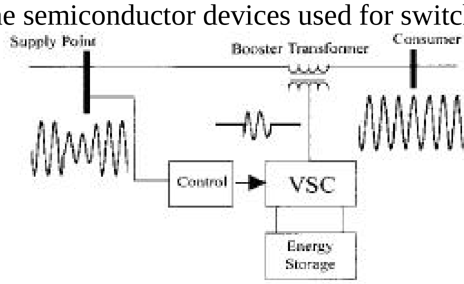

Fig.(1) Schematic diagram of DVR System

III. ZSI and Embedded Z source inverter

There are two traditional converters: the voltage source inverter and the current source inverter. Both the VSI and CSI have the following common problems:

- They have either a boost or a buck convert and cannot be a buck-boost operation. That is their obtainable output voltage range is limited to one either greater or smaller than the input voltage.
- Their main circuits are not interchangeable.
- They are vulnerable to EMI noise in terms of reliability.

The VSI topology is used mainly in the conventional DVR, as it gives good output voltage with low harmonic levels. The main disadvantage of this topology is its buck type output voltage characteristics, limiting the maximum voltage that can be attained. This means that the DVR injection capability would be limited, especially when the DC link voltage drops below a critical value. Therefore the use of this inverter topology alone in DVR systems with dwindling DC link voltage in the energy storage device, would pose a problem.

To overcome this drawback, an intermediate boost converter stage was introduced between the storage device and the VSI DC input terminals. However, the introduction of a boost converter would be increasing the switching component count and necessity control, protection and gate drive circuitry. To overcome the above problems of the traditional VSI and CSI, an Impedance Source inverter is presented. Figure 2. shows the structure of the general Z source inverter.

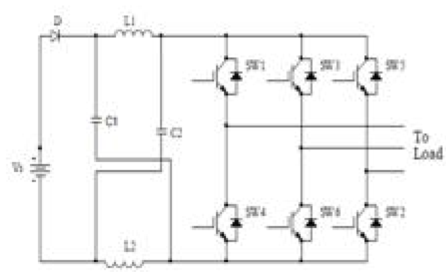

Figure 2. General structure of the Z source inverter

Z source inverters have been reported recently as competitive alternatives to existing inverter topologies with many inherent advantages. The Z source inverter differs from conventional converters like the VSI and CSI due to the presence of a unique X-shaped impedance network on its DC side, which interfaces the source and the inverter H-bridge.

It facilitates both voltage-buck and boost capabilities. It employs a unique impedance network to couple the converter main circuit to the power source, load or another converter, for providing unique features that cannot be observed in the traditional VSI and CSI, where a capacitor and inductor are used respectively. Therefore, Z-source inverters are in effect safer and less complex, and can be implemented using only passive elements with no additional active semiconductor needed.

Believing in the prospects of Z-source inverters, introducing a new family of embedded EZ-source inverters can produce the same gain as the Z-source inverters, but with smoother and smaller current / voltage maintained across the DC input source and within the impedance network. These latter features are attained without using any additional passive filter, which surely is a favorable advantage since an added filter will raise the system cost, and at times can complicate the dynamic tuning and resonant consideration of the inverters. Figure 3 shows the structure of the general EZ source inverter

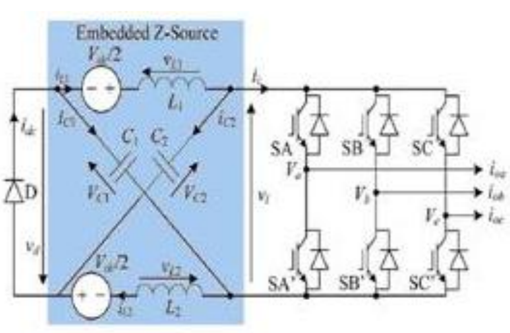

Figure 3 General structure of the EZ source inverter

On the basis of recent developments in impedance source (Z-source) inverters the paper proposes another new technique that is termed as switched inductor(SL) Z-source inverter. To enlarge voltage adjustability, the proposed inverter employs a unique SL impedance network to couple the main circuit and the power source. Compared with the classical Z-source inverter, the proposed inverter increases the voltage boost inversion ability significantly.

Only a very short shoot through zero state is required to obtain high voltage conversion ratios, which is beneficial for improving the output power quality of the main circuit. In addition the voltage buck inversion ability is also provided in the proposed inverter for those applications that need low AC voltages.

IV Simulation Results

The SIMULINK model of the closed loop controlled DVR with an impedance source inverter using PI controller in a simple power system to protect a sensitive load in a large distribution system is shown in Figure 4. The block diagram of the control system is shown in Figure 5.

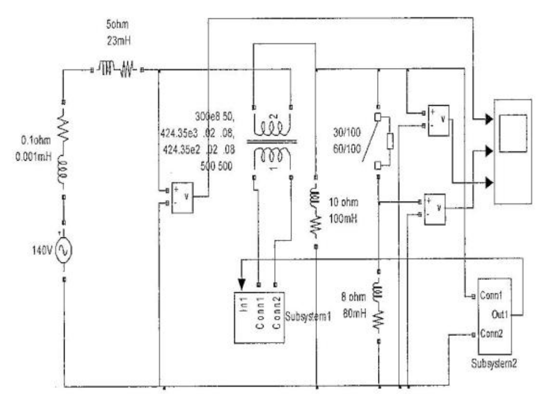

Figure 4 closed loop controlled DVR with Z source inverter

The proportional integral (PI) controller is a feedback controller, which drives the plant to be controlled with a weighed sum of the error (difference between the output and the desired set point), and the integral of that value. The integral term in a PI controller causes the steady state error to be zero for a ramp input.

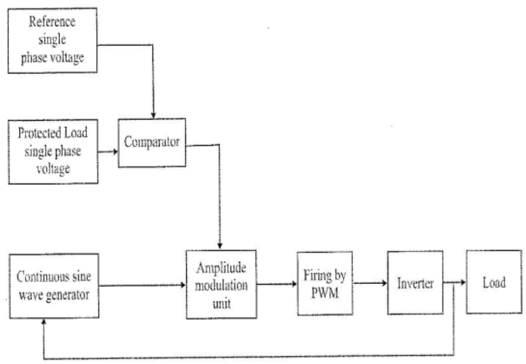

Figure 5 Block diagram of the control system

The inverter is a four pulse switch controlled bridge. The currents follow in different directions at outputs depending on the control scheme, eventually supplying AC output power to the critical load during power disturbances. The control of the bridge lies in the control of the switch firing angles.

The time to open and close the gates will be determined by the control system. To model a DVR protecting a sensitive load against voltage sags, a simple method of using the measurement of a single phase RMS output voltage for controlling signals can be applied. The amplitude modulation is then used. In addition to providing appropriate firing angles to switches, a switching control using the PWM technique is employed.

The subsystem1 of the closed loop DVR is shown in figure 6. It consists of a full bridge inverter with a filter. Subsystem2 consists of a rectifier with a capacitor filter, as shown in figure 7. The output of the load voltage is rectified using a rectifier circuit. The rectifier output voltage is compared with the reference voltage. To correct the error between a measured process variable and a desired set point, PI controller is used.

To decrease the error signal, it is compared with a ramp signal to produce multiple pulses PWM. The pulse width modulation technique was used to control the H-bridge inverter. Varying the width of the pulses, controls the output voltage. The multiple PWM control technique is used to reduce the harmonic content at the output voltage.

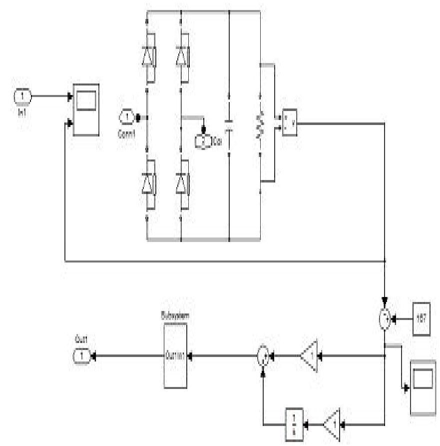

Figure 6 Subsystem 1 of the closed loop DVR with ZSI

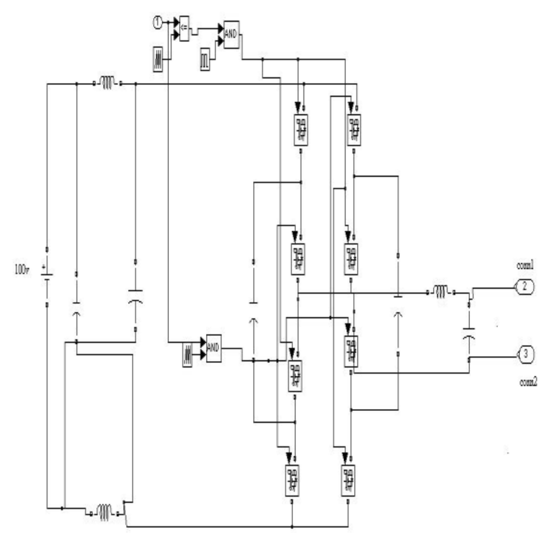

Figure 7 Subsystem 2 of the closed loop DVR with ZSI.

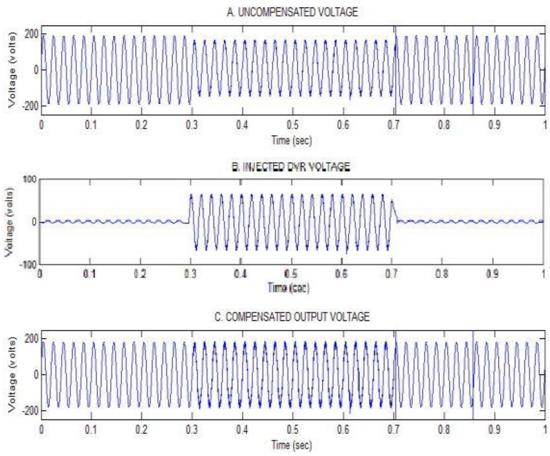

Figure 8 Response of the DVR to a voltage sag

a. Uncompensated voltage(v),
b. Injected voltage(v)
c. Compensated voltage(v)

Figure 8 shows the simulation result for the closed loop DVR system response to the voltage sag. Initially, the system was subjected to a sag of 26% magnitude and 0.4sec duration. The first graph shows the input supply voltage. The second graph indicates the injected voltage and the third graph shows the compensated load voltage after voltage injection

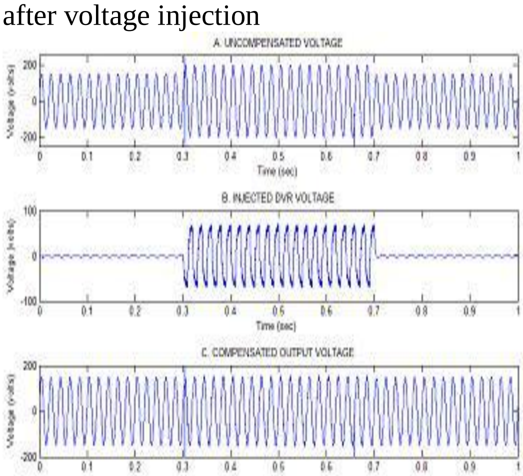

Figure 9 Response of the DVR to a voltage swell

a. Uncompensated voltage(v),
b. Injected voltage(v),
c. Compensated voltage(v)

Figure 9 shows the response of the closed loop DVR system to the voltage swell. The system was subjected to a swell of 130% magnitude and 0.4sec duration. simulation is done and the transient performance at the swell front and recovery was observed. The first graph shows the swell in voltage. The second graph indicates the injected voltage and the third graph shows the compensated load voltage after voltage injection. It is seen that the DVR has successfully compensated the swell.. Figure 10 shows the FFT analysis of the closed loop DVR system. The THD value is found to be 2.39%.

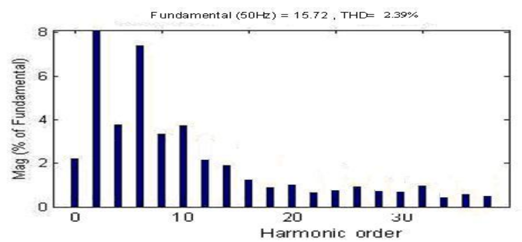

Figure 10 FFT analysis of the DVR

A typical closed loop controlled DVR with the voltage type EZ source inverter in a simple power system to protect a sensitive load in a large distribution system is presented in figure11.

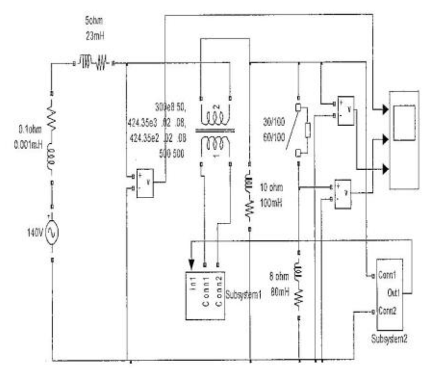

Figure 11. Closed loop controlled DVR with an EZ source inverter

Subsystem1 contains the rectifier and the inverter as shown in figure12. The pulse width modulation technique was used to control the E Z source inverter. Subsystem2 consists of PWM pulse generation blocks as shown in figure 13The simulation is done using MATLAB and the results are presented here.

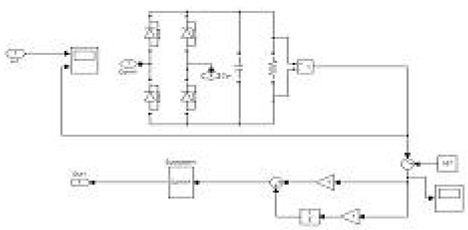

Figure 12 Subsystem 1 of the closed loop DVR with an E-ZSI

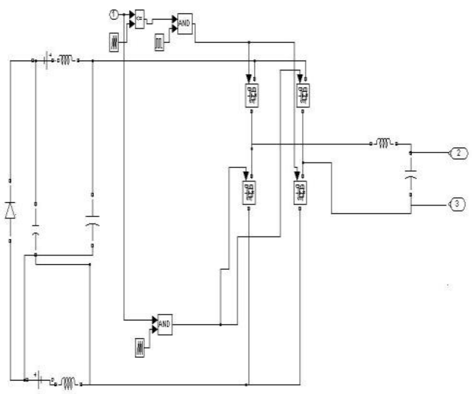

Figure 13 Subsystem 2 of the closed loop DVR with an E-Z source inverter

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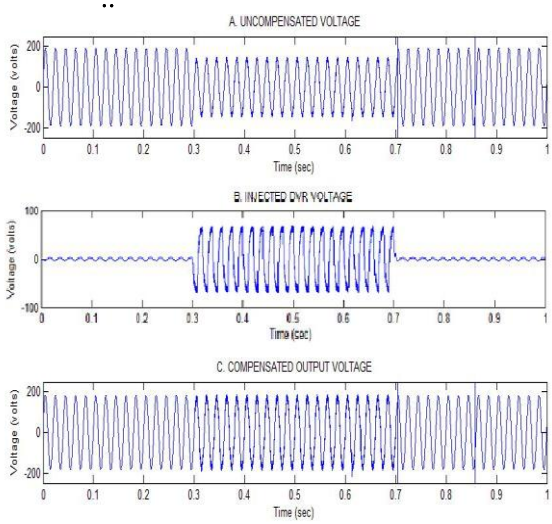

Figure 14Response of E-ZSI based DVR to a voltage sag
a. Uncompensated voltage(v)
b. Injected voltage(v)
c. Compensated voltage(v)

Initially, the system was subjected to a sag of 26% magnitude and 0.4sec duration. Simulation is done and the transient performance at the swell front and recovery was observed. Figure 14 shows the response of the closed loop DVR system to the voltage sag. The first graph shows the sag in voltage. The second graph indicates the injected voltage and the third graph shows the compensated load voltage after voltage injection.

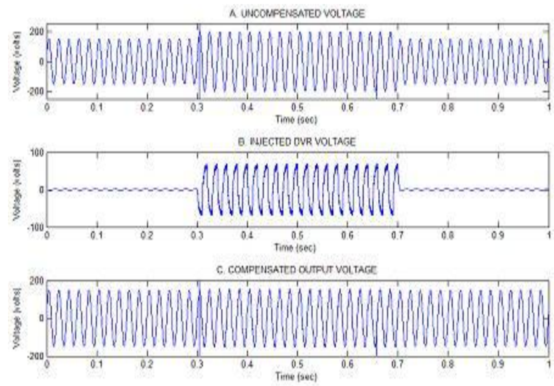

Figure 15 Response of E-ZSI based DVR to a voltage swell
a. Uncompensated voltage(v)
b. Injected voltage(v)
c. Compensated voltage(v)

The system was subjected to a swell of 130% magnitude and 0.4sec duration. Simulation is done and the transient performance at the swell front and recovery was observed. Figure 15 shows the response of the closed loop DVR system to the voltage swell. The first graph shows the swell in voltage. The second graph indicates the injected voltage and the third graph shows the compensated load voltage after voltage injection.

Figure 16 shows the FFT analysis of the closed loop DVR system with an EZ source inverter. The total harmonic distortion (THD) value is 1.36. The THD is very low in the case of the EZ source inverter when compared with conventional Z source inverter

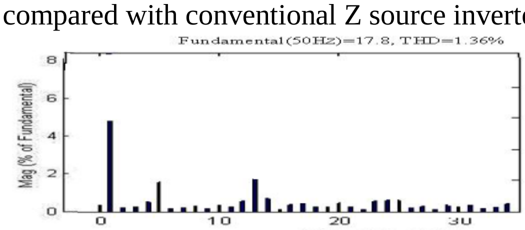

Figure 16 FFT analysis of the E-ZSI based DVR

Table 1 shows the summary of the THD values.

Table 1 Summary of the THD values

Type	THD (%)
Single phase Z source inverter	2.39
Single phase E -Z source inverter	1.36

V. CONCLUSION

The Dynamic voltage restorer is used to mitigate the voltage sags and swell problems caused by increased in loads. This paper presents a new DVR topology derived from Z-source inverter, which enhances the capability of the DVR through better utilization of the stored energy. The DVR handled the voltage sag and swell situations without any difficulties and injected the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. The efficiency and the effectiveness in voltage sags and swell compensation showed by the DVR makes it an interesting power quality device compared to other custom power devices

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