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Voltage Sag Compensation in Transmission Line using Advanced Dynamic Voltage Restorer with SRF Controller

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Abstract: Electrical apparatus is very sensitive to the voltage distortions in power systems. Due to faults and switching actions various harmonics are produced in transmission lines. In this article, a new Z- Source inverter based Dynamic Voltage Restorer (Z-DVR) is presented for voltage sag compensation in transmission lines with Synchronous Reference Frame (SRF) controller. The proposed SRF controller regulates the DC link voltage effectively and compensates for the voltage sag. This method brings the load voltage and current Total Harmonic Distortion (THD) inside the IEEE standards.

Keywords: Voltage sag, Dynamic voltage restorer, Z-Source inverter, Harmonic distortion.

1. Introduction

Power quality is a serious concern in the integrated power electronic converters. Various types of FACTS devices are used for improving the power quality [1]. DVR is one among the FACTS devices, which is used for the compensation of voltage sag or swell which are raised due to various faults or switching events. Power electronics are the emerging technologies for increasing the system stability and improved performance [2]. DVR is a strong FACTS device, which is used for the compensation of voltage sag in series with the system. It is connected in series with the power supply and the load [3]. The basic operating principle of DVR is, it compensates the voltage deviations in regular conditions by proper injection through injection transformers [4]. The energy storages units in the DVR will inject the active power for voltage sag compensation.

Generally VSI topologies are used along with the DVR for proper operation. The disadvantage of such VSI topology is, due to buck type operation their injection capabilities are limited [5]. Along with this problem, the shoot through effect and Electro Magnetic Interference (EMI) will damage the whole system. Hence to overcome these problems, Z-Source inverters are used in the operation of DVR [6]. Compared to traditional VSI and CSI, in Z source inverters an extra supplementary cross conduction state is presented [7]. Hence the proposed Z-DVR is the best solution for compensation of voltage deviations in power systems for improving the system reliability.

This article presents SRF control based Z-DVR. It includes the transformation of current variables in to synchronously rotating *dq* variables. Again the *dq* variables are transformed into a,b,c variables which generate the switching pulses to the inverter. The strength of the proposed Z-DVR is analyzed for various fault cases in Matlab/Simulink laboratory. The remaining paper is organized as follows. Section II presents about the basic description of Z-DVR system, Section III describes about the SRF control action for proposed system, Section IV presents the results, discussions and lastly in section V the conclusions are presented.

2. Z-DVR description

In electrical energy systems Z-DVR is used to mitigate the voltage sag on load side. The block diagram of the proposed Z-DVR is shown in Fig.1. It majorly consists of a grid, non linear load and SRF controller based Z-DVR [8]. The voltage sags are produced in transmission lines due to switching events and various types of faults. Generally, voltage boosters are used in power systems for voltage sag compensation [9]. The voltage boosters will senses the voltage sag and injects the same amount for compensation. The objective of DVR is to sense the voltage sag and compensate it before reaching the load. Under normal operating conditions, the DVR is in standby mode with very low losses [10]. The secondary winding of the restoration transformer is connected in series with the distribution line, its primary is connected to the Z –Source inverter, filter and supply voltage.

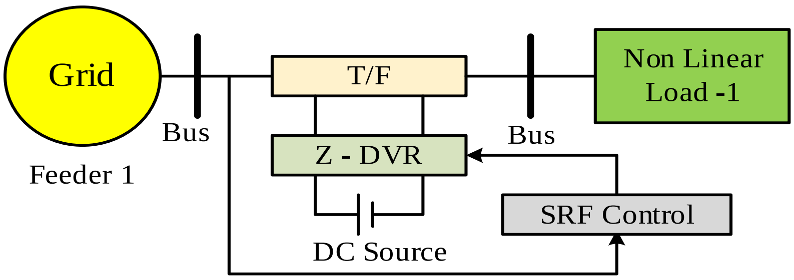

Fig.1: Block diagram of the Z-DVR

The internal structure of Z - Source inverter is depicted in Fig.2. Generally Voltage Source Inverter (VSI) structures are familiar because of their advantage like less harmonic pollutions [11]. The drawback of such VSI under buck type operation is that they limit the maximum voltage that can be obtained. Hence the use of VSI alone with DVR would pose problems on the DC link voltage [12]. The Z-Source inverter is an alternative to VSI to use in combination with DVR with good advantages. It has a unique impedance network with two inductors and two capacitors for connecting the inverter with the power source with unique features which are not obtained in the conventional VSI and current source inverters [13]. The yield voltage of three phase inverter is filtered some removing the harmonics produced due to switching of inverter switches.

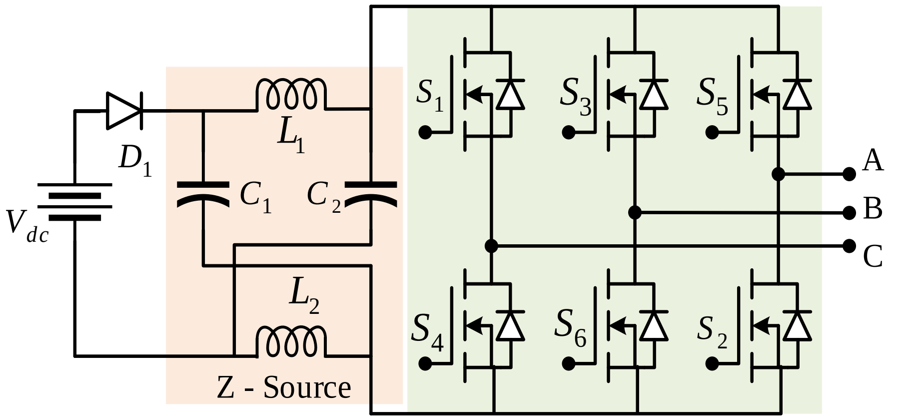

Fig. 2: Z-Source inverter in the DVR System

3. Proposed SRF controller for Z - DVR

The SRF control based Z-DVR shown in Fig.3 is used to mitigate the voltage sags in the transmission lines. The load side reference voltage must be in phase with the zero sequence component voltage [14]. The principle of SRF control theory includes the transformation of current variables into synchronously rotating *dq* variables. The voltage signals are processed by using SRF Phase Locked Loop (PLL) for the generation of unit vectors [15]. As per this theory the current variables are first converted into *dq* frame of reference, later they are converted in to *abc* frame for the production of switching pulses [16]. From three phase a,b,c frame, first the current variables i_a, i_b, i_c are sensed and transformed into $\alpha\beta 0$ frame. Equation (1) represents this transformation

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

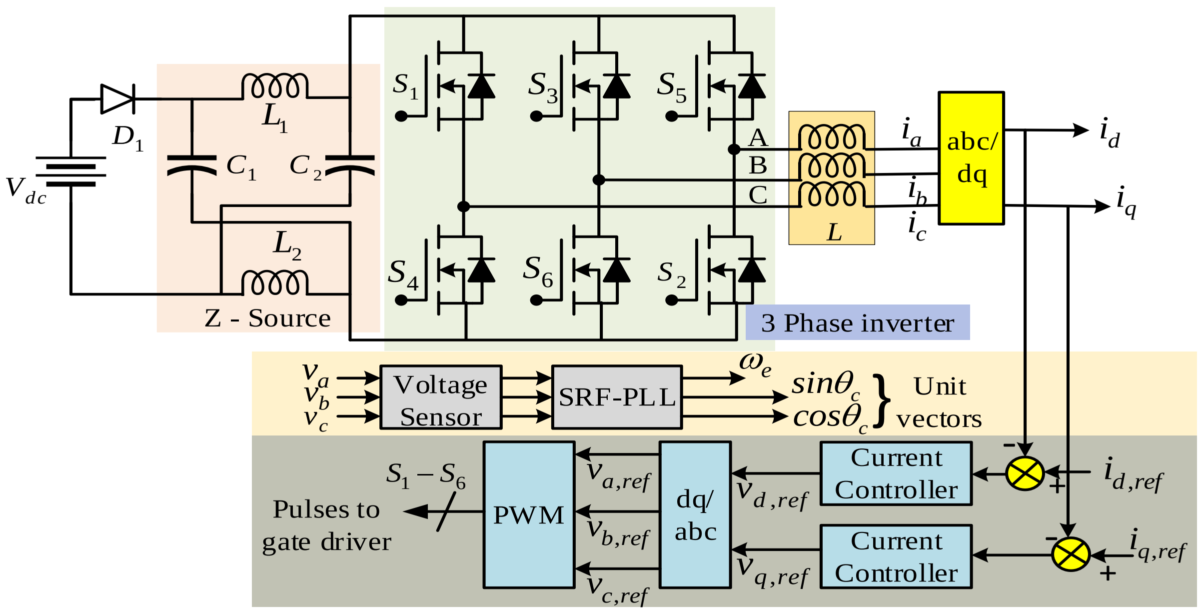

Fig.3: SRF controller based Z-DVR

For obtaining the dq components of currents, the two stationary currents i_α and i_β are transformed into synchronous frame (2)

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

For transforming the dq components into $\alpha\beta$ variables, inverse transformation is used, which is used in the equation (3)

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \tag{3}$$

According to the SRF theory, the $\alpha\beta 0$ components are again transformed into a,b,c (4)

$$\begin{bmatrix} i_{ca^*} \\ i_{cb^*} \\ i_{cc^*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \tag{4}$$

In this control action, the major role of PLL is to obtain the phase angle required for a,b,c and dq transformations [17]. This component also used for grid synchronization. The main advantage of this approach is continuous supply is fed to the load by transformation of DC variables into AC variables.

4. Simulation Results

This section presents the simulation results of the proposed system. The grid is connected to the normal RL load. Under fault occurrence on feeder at t=0.2 sec, the voltage sag is produced and is eliminated at t=0.35 sec. When voltage sag occurs, the Z-DVR senses the same and injects the active power through injection transformer. The compensating waveforms and compensated waveforms With and without ZDVR performance are depicted in below figures . The THD of load voltages after compensation is 3.06, which is far below the IEEE standards.

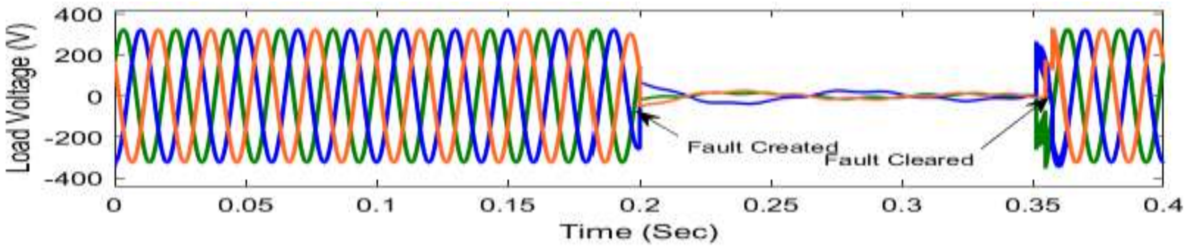

Fig.4: Voltage sag on feeder Without Z DVR RL LOAD LLLG Fault

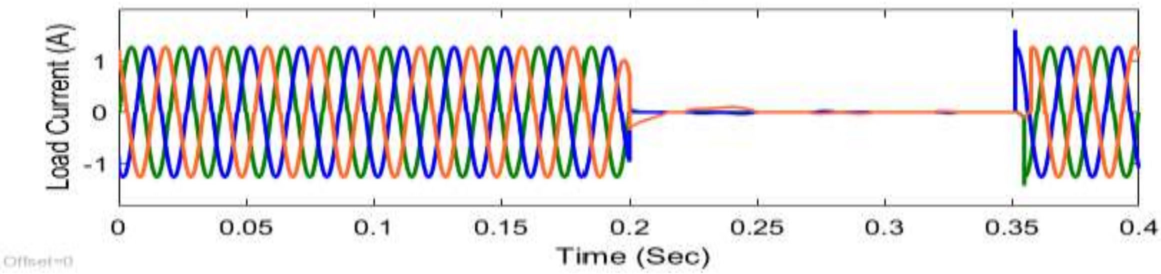

Fig.5: Sag on feeder Without Z DVR RL Load LLLG Fault

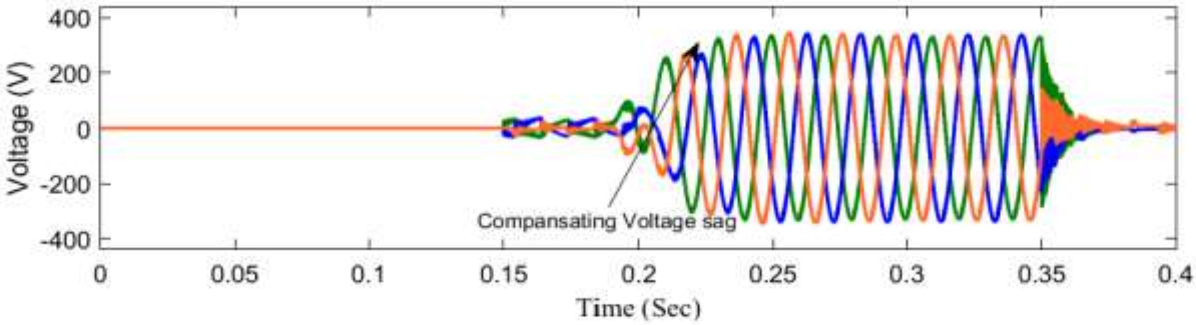

Fig.6: Compensating Voltage RL Load LLLG Fault

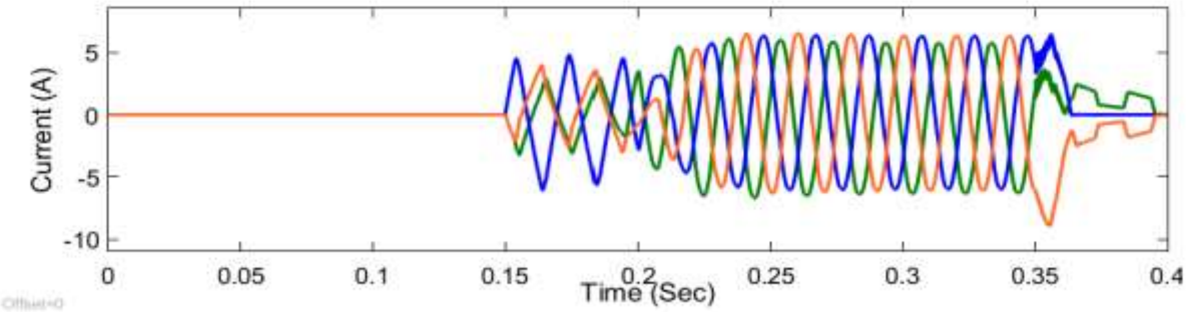

Fig.7: Compensating Current wave form RL LOAD LLLG Fault

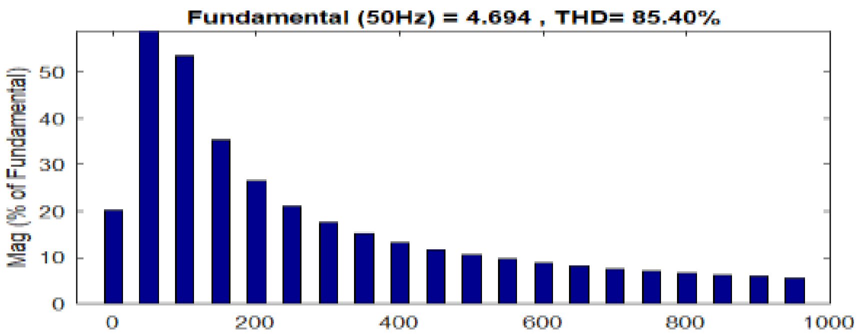

Fig.8: Without ZDVR THD VALUE RL LOAD LLLG Fault

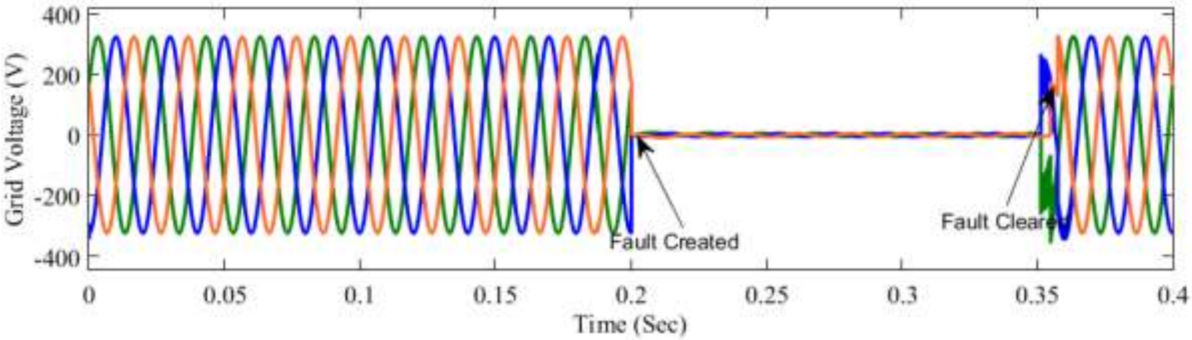

Fig.9: Voltage sag on feeder With Z DVR RL LOAD LLLG Fault

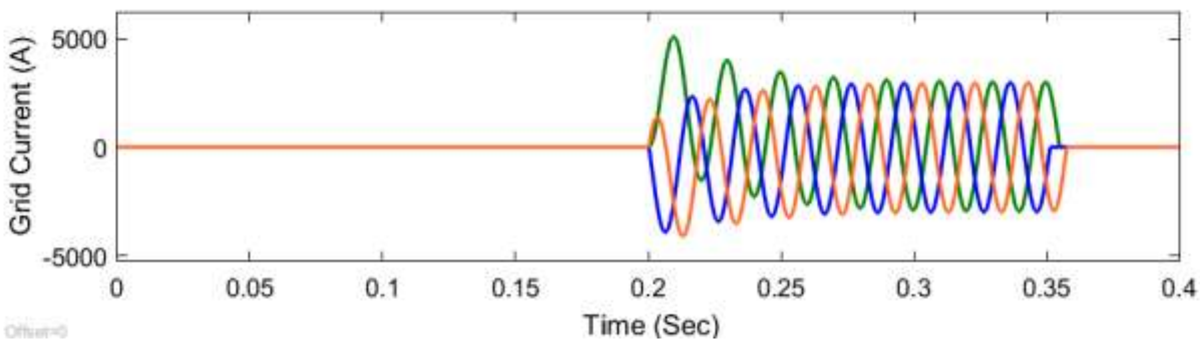

Fig.10: Current sag on feeder Without Z DVR RL LOAD LLLG Fault

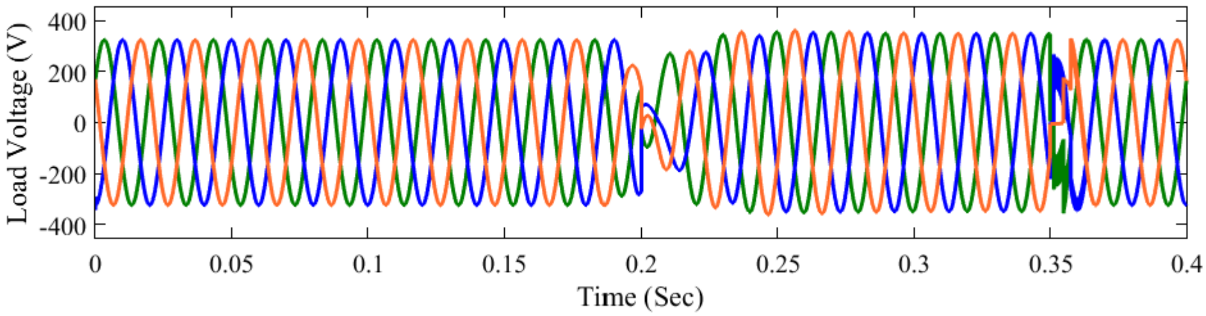

Fig.11: With ZDVR Output Load Voltage (V)

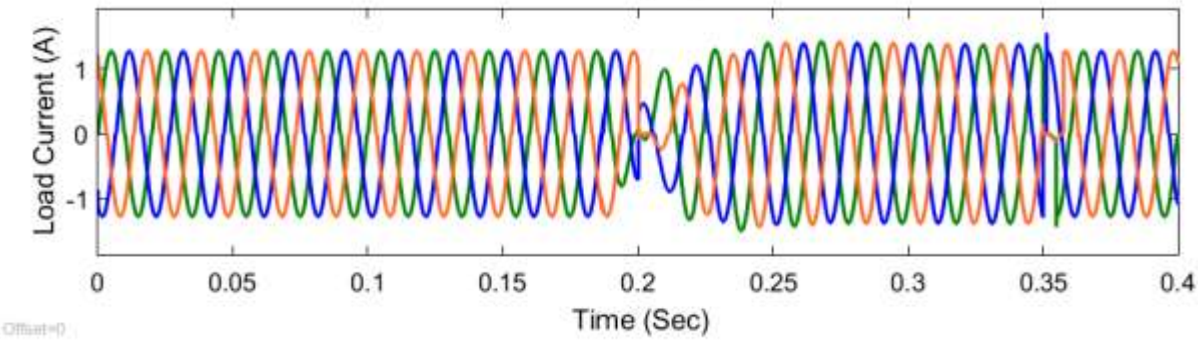

Fig.12: With ZDVR Output Load Current (A)

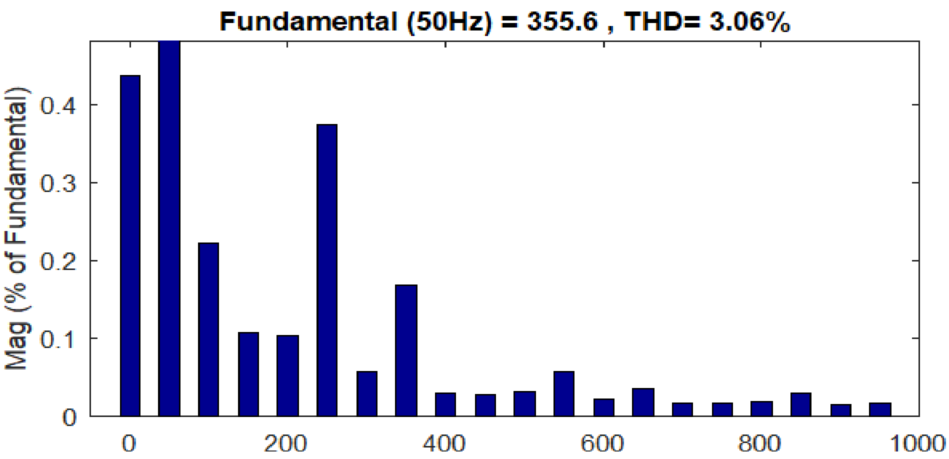

Fig. 13: THD of load voltage after compensation

5. Conclusion

In this paper a new advanced Z-DVR is presented for voltage sag compensation in transmission lines using SRF-PLL control strategy. The unit vectors and phase angle are generated from the PLL which are also used for the grid synchronization. The proposed controller senses the voltage sag and triggers the Z-DVR for injecting the voltages. From the results it is found that the proposed SRF controller efficiently compensates the voltage sag with very low THD of 3.06%.

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