Power Quality Improvement Using Dynamic Voltage Restorer

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ABSTRACT—In today's electricity system, power quality is a critical issue that can impact utilities and consumers alike. Numerous issues with the current electric power system were brought about by the integration of renewable energy sources, smart grid technologies, and a heavy reliance on power electronics technology. Sensitive equipment can be harmed by voltage sag, swell, and harmonics of current and voltage. These components are vulnerable to changes in input voltage brought about by interference from other components in the system. Therefore, power quality is critical to the safe and dependable operation of the power system in the present period due to the rise of expensive and sensitive electronic equipment. A potential Distribution Flexible AC Transmission System (D-FACTS) device that is frequently used to address issues with non-standard voltage, current, or frequency in the distribution grid is the Dynamic Voltage Restorer (DVR). It ensures a consistent load voltage by injecting voltages into the distribution line to preserve the voltage profile.

The MATLAB/Simulink simulations were used to demonstrate the efficacy of the DVR-based suggested technique in smoothing harmonic-induced voltage distortion. Third and fifth harmonics are added using a configurable power source power system model. Both scenarios with and without DVR are considered when evaluating the systems' responsiveness to load voltage. It has been observed that the suggested DVR-based technique has successfully controlled the voltage distortion, leading to the achievement of a smoothly corrected load voltage. When the third and fifth harmonics of the supply voltage were inserted, the load voltage THD percentage was roughly 18% and 23%, respectively. In both situations, the addition of the suggested DVR has resulted in a THD reduction of less than 4%.

INDEX TERMS: Dynamic Voltage Restorer, FACTS, Total Harmonic Distortion, Sag, Swell, Harmonics

1. INTRODUCTION

Electrical energy is a ubiquitous and imperceptible resource that is readily available in most parts of the world. It is widely acknowledged as a basic consumer necessity [1]. The major energy demand in solar, solar thermal, wind, and other energy sources is assisted by Renewable Energy Systems (RESs). Because RESs, harmonics, and reactive power issues are intermittent, they impair the power system's functionality by raising stability issues [2], [3]. Global distribution grids have adopted the Flexible AC Transmission Systems (FACTS) devices extensively for reactive power compensation, voltage stability, and power quality [4], [5]. FACT devices do, however, also modify certain transmission and distribution system properties [6]. This work offers an analysis of power quality with the goal of pinpointing the root reasons of subpar power quality and offering fixes for these issues. Sensitive equipment includes many items such as optical devices, computers, laptops, relays, solid-state devices, adjustable speed drives, and more. These components are vulnerable to changes in input voltage brought about by interference from other components in the system. The power system is separated into three sections: distribution, transmission, and generation. On the distribution side, power systems are fed to various loads through the use of additional transmission lines. When the load is receiving variable power, power quality becomes extremely important in the power system. Subsequently, the domestic and industrial customers with delicate loads are affected by the poor quality of power.

On the distribution side, there are many different kinds of loads, but sensitive loads are more negatively impacted by low power quality than others. There are numerous applications where there is a growing need for sensitive load, such as operating rooms in hospitals, semiconductor systems in processing facilities, database systems, air pollution control devices in crowded areas, data processing facilities that need precise and accurate equipment, and service providers. These gadgets could malfunction and result in a large financial loss if the power supply is the source of the dips and distorted voltages. As a result, power quality affects distribution as well. The power system sets the electrical properties that allow the system to operate in a controlled manner without interfering with its functionality. This study discusses voltage swell and distorted voltage that contains high harmonics. Because of the occurrence of faults, when the load voltage is disrupted, it results in voltage sag, transient, swell, and high distorted voltage with harmonics and Total Harmonic Distortion (THD). The fragile instruments are primarily vulnerable to voltage sags and harmonic issues. A few issues arise from voltage sag, which can also lead to motor torque disruption, device burning, device misfiring, etc. To properly address power quality, the harmonic is a crucial problem. A brief decrease in RMS voltage, also referred to as voltage sag or dips, happens when power system problems arise and result in a significant current being pulled from the power system [7]. The primary reason of sag production, for instance, is the start-up of the load and remote fault clearance performed by the utility instrument when someone turns on an air conditioner or a large motor. The motor draws six times as much current when it first starts. A significant quantity of reactive power is absorbed at the motor's beginning, which causes voltage sag to occur. Figure 1 shows the voltage profile of the voltage sag. The harmonic is one of the most important issues to properly address in power quality. When power system issues occur and a sizable current is drawn from the power system, there is a transient drop in RMS voltage known as voltage sag or dips [7]. When someone turns on an air conditioner or a big motor, for example, the utility instrument initiates the load and performs remote fault clearance, which is the main cause of sag production. When the motor initially begins, it draws six times as much current. When a motor starts, a large amount of reactive power is absorbed, which results in voltage sag. The voltage sag's profile is depicted in Figure 1.

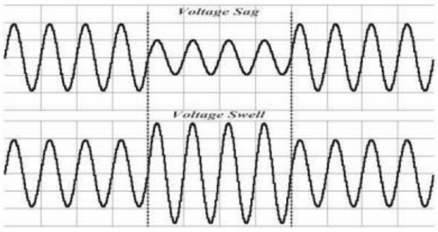


FIGURE 1. Voltage waveform with sag and swell [7].

The voltage issue known as harmonic distortion arises when fundamental frequencies vary three times. For instance, multiplying 50 Hz by three results in 3 × 50 = 150 Hz for the fundamental frequency. According to Figure 2, which displays the waveform with harmonic content, that is the third harmonic of the fundamental frequency. Harmonics are produced by the way power electronics switch. The signs of a harmonic problem include circuit breakers tripping, neutral conductors, transformers, and other power distribution equipment overheating, and circuits being destroyed without adequate management when a clear sine wave activates at the zero crossover point [3], [8].

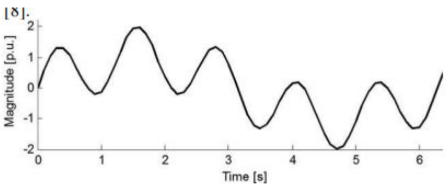


FIGURE 2. Waveform with harmonic content [7].

Below is a summary of the primary contributions made by this research project:

• to reduce the distortion of voltage caused by harmonics, swell, or sags to less than 5% THD.

• to access and evaluate the performance of the proposed model both with and without the usage of DVR, using MATLAB / SIMULINK. By inserting the third and fifth harmonics into the input voltage profile, the power system will be examined.

• to compare the power system's performance with and without a DVR-based system in order to assess how well the DVR-based power system performs with the same third and fifth harmonics inserted.

The remainder of the study is structured as follows: Section II contains a comprehensive assessment of the literature about the use of DVR. Section III presents the mechanism, working principle, and operation of the DVR; Section IV presents and discusses the simulation results; and finally, a conclusion is provided emphasizing the main conclusions of this study. II. A BOOK REVIEW OF DVR In certain nations, the FACTS and DFACTS devices were used to alleviate issues with the distribution and transmission systems. FACTS is defined as [9], "AC transmission systems containing static and power electronics-based controllers to increase power transfer capability and more immeasurable controllability," in accordance with IEEE regulations. Due to resource constraints, economic concerns, and certain environmental restrictions, the demand for electricity has increased significantly in the modern era, outpacing the development of generating and transmission infrastructure. The current transmission system's resource constraints make expansion difficult. Consequently, increasing transmission capacity is a workable alternative. Some limiting variables that impact the transmission line's loading capability prevent it from being completely exploited.

The dielectric, stability, and thermal limit are understood to be these factors. Present-day lines can have their useable capacity increased and electricity controlled using FACTS controllers. Under normal circumstances and during faults, the FACTS controllers allow power to flow down the line and permit a line to transmit power that is almost equal to its thermal ratings [10], [11]. To shield the load from problems caused by voltage swells and sags, DVR is employed on the distribution feeder. In order to reduce voltage sags and swells, a battery energy storage system (BESS) is connected in series with the load through a transformer and inverter. This balances the active and reactive power requirements of the system [12]. DVR introduces voltage into the distribution system via the transformer in order to maintain voltage stability.

The FACTS device, or DVR, corrects for voltage harmonics from loads as well as sags and swells in the voltage. Under typical circumstances, the DVR injects a small amount of voltage in series with the transmission lines. However, using sinusoidal pulse width modulation (SPWM), DVR determines the voltages necessary to safeguard the load in the event of a disturbance.

After then, the system is given those voltage injections to keep things stable. When there is a disturbance, DR provides or absorbs the active or reactive power from the dc-link, whereas in the steady-state, DVR either delivers or absorbs the active or reactive power. [13]. According to Martiningsih et al., installing DVR in PT DSS power plants is advised. The DVR serves as a compensator and is connected in series with the distribution line. The suggested PI-based DVR is capable of reestablishing the power quality limitation. [14]. Eltamaly et al. have suggested using DVR to mitigate voltage sag and improve the quality of the power supply. to a decline in electrical device performance. The findings show that DVR implements appropriate voltage adjustment and sufficiently compensates for sag/swell [15]. A unique DVR with a power electronic transformer (PET) has been proposed by Ali et al. to reduce symmetrical and asymmetrical swells and sags. The findings show that the novel design successfully reduces the distribution line's symmetrical and asymmetrical voltage sag and voltage swell [16]. For a renewable power system, a nonlinear adaptive control (NAC) with DVR is suggested to recover the Low Voltage Ride Through (LVRT). The estimation of the perturbation with the NAC, which includes measurement of noise, errors, and disruptions like the intermittent influence of renewable sources and grid faults, compensates for the real perturbation of the system. Robust and adaptive control can be achieved by the NAC without the need for an exact model or comprehensive measurement.

The energy storage system (ESS) is integrated into the DVR. In order to maintain the voltages, ESS-DVR makes up for grid voltage dips. The fuzzy logic controller (FLC) can be applied in that situation, and the LVRT capability is improved by both the FLC and the NAC-based controller [17]. The most important element is that if the ESS-DVR has a low rating, it must have a high rating. There will be a decrease in performance. Benali at al. [18] suggested another FLC-based technique for enhancing DVR power quality. A zero active power strategy has been presented by Danbumrungtrakul et al. [19] to improve DVR performance. With their developed approach, they have achieved better outcomes compared with the traditional In-Phase Compensation with DVR. In [20], a DVR based on the Grasshopper Optimization Algorithm (GOA) is used to provide a power quality improvement method. To adjust the parameters of the conventional proportional integral derivative (PID) controller, a GOA-based method is advised. Table I compares the material that is currently accessible on DVR and its uses.

TABLE I A COMPARISON OF VARIOUS DVR BASED APPROACHES

Type	Control Strategy	Application	Reference
DVR-ESS	FLC and NAC	LVRT	[17]
DVR-OLTC	On-load tap changing transformer	Regulation of voltages, power flow	[21]
DVR	DVR system with DSP control board	Power source, SW5250A/ELGAR	[15]
DVR	PI	PT. DSS Power Plant	[14]
Novel DVR	No control	Power electronic transformer (PET) based DVR	[16]
DVR	FLC	Hybrid Wind-PV LVRT	[18]
DVR	Zero-real power tracking technique	Power system voltage sag and swell	[19]
DVR	GOA based PID	voltage sag and swell	[20]

2 . PROPOSED DYNAMIC VOLTAGE RESTORER

One important indicator of power quality is the frequency of the delivered voltage, which may be used to determine the quality of the power supply. According to IEEE standards [22]–[24], a voltage sag is defined as a dip in the voltage's Root Mean Square (RMS) value that can occur between 10 ms and 60 seconds, with a depth of fall of 0.9 per unit (p.u.) or 0.1 p.u. of a nominal p.u. For a variety of reasons, regular voltage sags are typically verified for the load at the distribution level. In some high-tech industries, certain delicate loads find the voltage sags to be absolutely intolerable. Complicated activities with a precise frequency and voltage sag value could maintain the load voltage requirements while causing distortion and oscillation. Voltage sag is typically the cause of the production sector's destruction and downtime, which is expensive and causes serious issues for consumers. Electric devices, sometimes known as consumer power devices, are used to supply the distribution system with a specified quantity of voltage and energy. One could lessen the complexity of the issue. The DVR is meant to be a more effective way to control distortion and voltage sag than traditional approaches to solving voltage sag problems. The performance of the electricity system is assessed in this work by eliminating voltage sag at the distribution level using a DVR.

A. THE PRINCIPLES OF DVR USE

A DVR is made up of an injection transformer, a capacitor bank, an energy storage device, and a voltage source inverter (VSI) based on GTO or IGBT. Another name for the DVR is an electrical switching device with solid-state power. Figure 3 shows a DVR attached to a distribution bus. The DVR's operational guidelines are based on injecting transformer techniques; a forced commuted converter creates a control voltage in relation to the bus voltage. For droop-controlled converters, various converter control topologies are shown in [25], [26]. As seen in Figure 4, the DC voltage source functions similarly to the energy-storage device provided by the DC capacitor. When there is no voltage sag problem under ideal circumstances, the DVR does not effectively minimize the problem of voltage drop. When a distribution system is present, the DVR will generate the necessary controlled high frequency voltage and phase angle to guarantee that the load is sustained and flawless. In this case, the capacitor will be discharged in order to maintain the constancy of the voltage supply to the load. It is important to remember that while the DVR is capable of producing and absorbing reactive power, reactive power injection requires an outside energy source. The DVR's reaction time is shortened by the voltage sag detection time and power electronics components. For instance, the tap-changing transformers response time of DVR is less than 25 milliseconds, in contrast to the traditional methods of voltage correlation.

B. CONSTRUCTION OF DVR

The DVR is composed of two separate circuits: the control circuit and the power circuit. The DVR system injects the control signal, which contains complex parameters such as phase shift, frequency, and amplitude. The switches are employed to generate a voltage-dependent control signal in the power circuit. This part will also go over the basic design of the DVR by the power circuit. Figure 4 [27] depicts the DVR's fundamental configuration and construction.

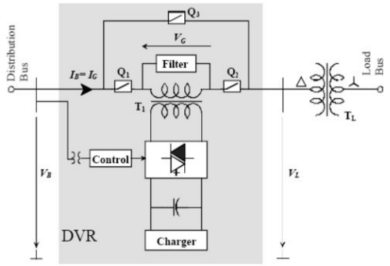


FIGURE 3. Principle design of DVR connected at distribution end [15].

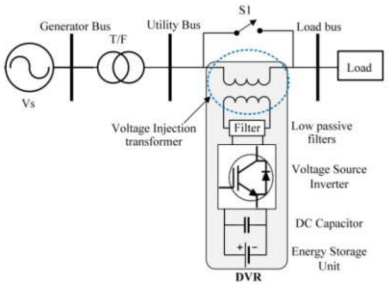


FIGURE 4. Basic Configuration of DVR.

1) POWER SUPPLY UNIT

Superconducting Magnetic energy storage (SMES), flywheels, lead-acid batteries, and super-capacitors are a few examples of systems used to store energy [28]. Since this is the storage unit's principal purpose, it supplies the necessary actual power when the occurrence voltage drops. The active power generated by the energy storage device determines the DVR's compensatory capabilities. Lead batteries are being employed in place of alternative storage systems because of their quick charging and discharging times. The internal area available for energy storage is determined by the rate of discharge, which is dependent on a chemical reaction [29], [30].

2) POWER SUPPLY INVERTER

Pulse-Width Modulated VSI (PWMVSI) is widely used. As was covered in the previous section, a device for energy storage has produced a DC voltage. The source of the voltage conversion from DC to AC is a VSI. A stepup voltage injection transformer of the DVR power circuit was utilized to boost the voltage magnitude at the time of the sag occurrence. Thus, a minimum voltage of VSI is sufficient.

3) PASSIVE FILTERS

This technique, which transformed the PWM inverted pulse waveform into a sinusoidal waveform, makes use of low passive filters. High-value harmonic components must be eliminated from the DC-AC transition in VSI in order to achieve this conversion, which will also alter the corrected output voltage. An integral component of a voltage inverter is a passive filter. For this reason, it can be used on either the high voltage side (load side) or the low voltage side (inverter side) of the injection transformer (Figure 5). The filters can prevent maximum value harmonics from passing through the voltage transformer if they are placed on the inverter side. Thus, it also lessens the tension on the injection transformer. The filter's drawback occurs when it is positioned on the inverter side, where it induces phase shift and inverted voltage drop. Thus, this issue can be resolved by placing the filter on the load side. Because a transformer with high values is required, the secondary side of the transformer allows high valued harmonic currents.

4) BY-PASS SWITCH

DVR is a series-connected device. The current pass through the inverter if the fault exists in the downstream causes a fault current. For the protection of the inverter, the By-pass switch is being used. Commonly, to bypass the inverter circuit, a crowbar switch is used. Whenever the current is in the range of parts of the inverter, the crowbar would detect the scale of the current and deactivate it in the end. On the other side, it will allow bypassing the components of the inverter if the current is high [15].

5) VOLTAGE INJECTION TRANSFORMERS

There are two sides of the voltage injection transformer, as one is the primary side linked with a distribution line in a series. The other one is the secondary side that is connected with the power circuit of DVR. For the three-phase DVR, one 3-phase transformer or three single-phase transformers could be used, but for one phase DVR, only one singlephase transformer is allowed. The “Delta-Delta” type connection is being used at the time of contact between 3 phase DVR and three single-phase transformers [31].

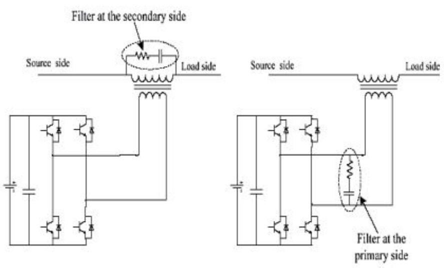


FIGURE 5. Different filter placements in DVR [15]

Usually, the amount of voltage that is supplied by the filtered VSI output to a needed range also simulates the DVR circuit from the transformation network caused by the setup transformer. According to the required voltage at the secondary side of voltage, the pre-examined and significant values are winding ratios. The parts of inverter circuits are affected by the high cost of winding ratio with highfrequency currents—the primary side current with highfrequency ratios of high windings that could affect the parts of the inverter circuit. The value of the transformer is an important reason when determining the working efficiency of the DVR. The significance of the winding ratio of the injection transformer concerns on the upward distribution transformer. If there should arise an occurrence of a Δ-Y association with the grounded unbiased, there won't be any zero-grouping current streaming into the auxiliary during an unbalance deficiency or an earth shortcoming in the high voltage side. In this manner, just the positive and negative arrangement segments are rewarded by the DVR [32].

C. OPERATING MODES 1) A VOLTAGE SAG/SWELL ON THE LINE

When there is a difference between the pre-sag voltage and the sag voltage, the energy sources elements are employed to supply the storage power and use reactive energy to inject the power in the DVR. The estimations of storing DC energy and the voltage insertion transformer ratio limit the maximum capacity of the DVR. When dealing with three single-phase DVRs, each one's degree of injected voltage can be calculated separately. Comparable frequency and phase angle between the injected voltages and the system voltages are being composed [33].

2) IN NORMAL FUNCTIONING DVR

would not apply voltage to the load during a typical process if there is no sag present. If the power storage device is eventually charged, the gadget will operate in standby mode or by self-charging. The energy storage device can be charged from a variety of self-supply sources.

3) A SHORT CIRCUIT OR FAULT

A bypass switch will be simulated during the downstream movement of the distribution line, and to prevent the inverter's electric parts, it will bypass the inverter circuit [15].

3. GRAPHICAL RESULTS AND DISCUSSION

The Intel (R) Core(TM) i5-7200U @ 2.5 GHz processor and Windows 10 operating system are used for simulations. The software environment MATLAB/Simulink is modified to analyze the suggested configuration. A load with a power factor of 0.75 and a capacity of 10 kVA is regarded as sensitive. The 415V load and 50Hz frequency to a 3-phase supply system supply the sensitive load. Figure 7 displays the test system's single line diagram without the DVR. This indicates that the test system has a three-phase, an RL source, a programmable voltage source, and a sensitive active and reactive load attached to it. The testing system's parameters and values are shown in Table II below. This chapter follows a convention where the same line design is used for all three phases in the colors black, red, and blue. Figure 7 shows the suggested DVR model with the power system in Simulink after the simulation was run using a 3-phase test system without a DVR connected to sensitive loads in MATLAB/Simulink. In MATLAB/Simulink, three-phase test systems with and without DVRs coupled to sensitive loads were used for the simulations. Figure 8(a) displays the test system and DVR's single line diagram; Figure 8(b) shows the Simulink representation of the diagram.

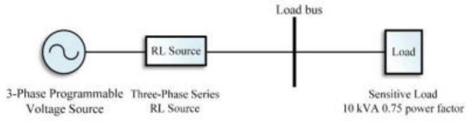


FIGURE 7. Single line diagram of test system without DVR.

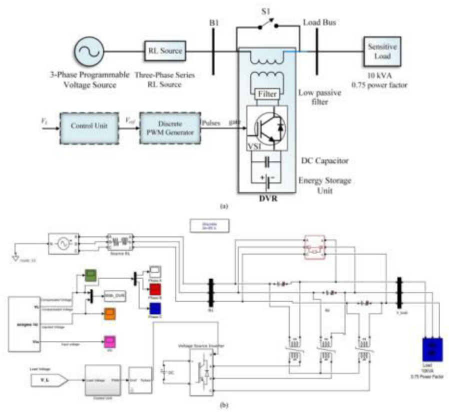


FIGURE 8. (a) Single line diagram of test system with DVR (b) Simulink model of the test system with DVR

TABLE II

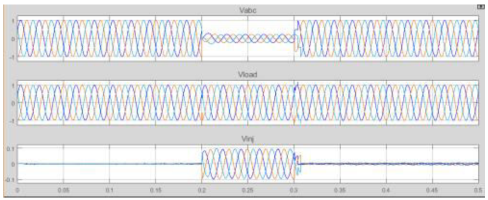
PARAMETERS AND VALUES OF TEST SYSTEM

Parameters	Values
Supply Voltage	415 kV
Frequency	50 Hz
Load Power Factor	0.74
Converter	IGBT (3arm-6 pulses)
Load active power	7.5 kW
Load reactive power	6.6 kW

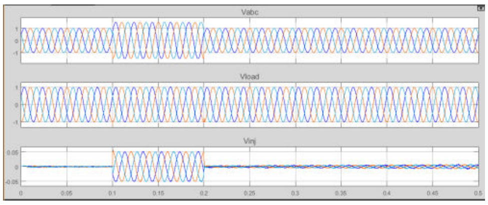
TABLE III

THD% OF TEST SYSTEM WITH AND WITHOUT DVR

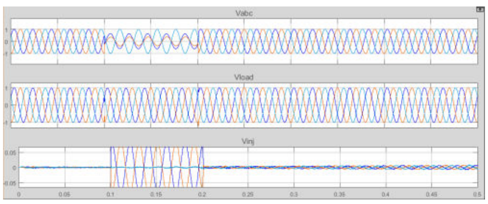
Phases	Scenario 1 THD (%)		Scenario 2 THD (%)	
	without DVR	with DVR	without DVR	with DVR
Phase A	18.49	2.69	22.56	4.06
Phase B	18.49	2.40	22.56	3.55
Phase C	18.50	2.69	22.57	3.74



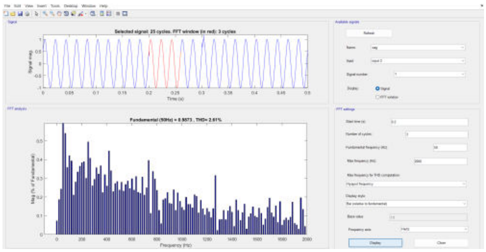
voltage sag waveform



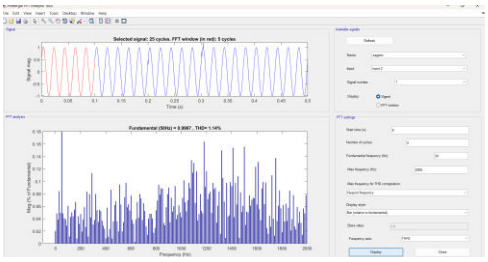
Voltage swell waveform



Waveforms during fault condition



Load voltage thd using pi



Thd using ann

Conclusion

The most notable gadget to improve power quality, according to this proposal, is the DVR, which has shown to be a practical and effective tool. By constructing and simulating the control circuit and power system with a sensitive load, a DVR with a power circuit can be simulated using the MATLAB/Simulink platform.

The DVR is tested both with and without the test system in place of the DVR. A programmable voltage source is utilized to provide a distorted voltage by inserting the fifth harmonic into the supply voltage after first adding the third harmonic. The suggested DVR-based control approach produced a better, more constant, and smooth voltage profile with very little harmonic content by compensating for the distorted load voltage. When the DVR injects the appropriate voltage component into the voltage supply, any issues can be corrected to keep the load voltage normal and steady at the ideal range. The THD was brought down to about 4% while the voltage profile adjustment was kept in place. Similar to scenario 1, where the voltage profile showed THD values of 2.69%, 2.40%, and 2.69%, and situation 2, where the THD values were 3.74%, 4.04%, and 3.60%. The success of the DVR-based control method employed in this work is explained by the improvement and decrease in THD in load voltage.

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