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Voltage Quality Enhancement in Microgrid through Customized Synchronous Reference Frame Theory Based Upgraded Dynamic Voltage Restorer

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Abstract- **Microgrid (MG) offers an elaborate list of solutions to solve the common problems associated with local distribution systems. These problems are mainly reliability issues. Researchers are trying to develop improvements in its properties and features to overcome these problems as well as the ones regarding power quality (PQ). The standard microgrid structure does not support power quality compensation strategies, which is why there are distribution system issues related to it. Implementations of the DVR have been proposed at both a low voltage (LV) level, as well as a medium voltage (MV) level; and allow protecting high power sensitive loads from voltage sags, because it is very efficient. We have proposed in this paper about the Upgraded Dynamic Voltage Restorer (UDVR) and mentioned that it would provide a convenient solution to the voltage sag and swell in grid-connected microgrid problems. A microgrid structure provides a reliable distribution system for local loads on the other side; UDVR allows a sag/swell free power supply for loads. This control via UDVR comes from a fuzzy technique system and an Upgraded Synchronous Reference Frame (USRF) concept. The dynamic compensation characteristics of UDVR are applied to voltage transient disturbance analysis under various run conditions. The proposed control system's stability is also analyzed. The entire system is manufactured by utilizing the MATLAB/Simulink environment. The results of the simulation confirmed the performance of UDVR under the proposed control approach. Simulation results prove that the proposed method is correct and has better real-time and compensation flexibility.**

Index Terms-- **Micro grid, Power Quality, Upgraded Dynamic Voltage Restorer, Upgraded Synchronous Reference Frame**

I. INTRODUCTION

Electrical power distribution systems are facing major power reliability issues in different parts of the world. The cause of this is an increased demand for electricity due to its low generation in power stations, as well as the limited resources and natural fuels (such as coal and gas, which are essential to run power stations). Other reasons include a complete blackout (power failure), and the lack of ability to collect renewable energy resources (RES), such as solar photovoltaic (PV) and wind energy [1].

The structure of microgrid contains distributed generation units that consist of renewable energy sources as well as nonrenewable resource. The essential elements of a microgrid are the energy storage system (ESS) and the necessary power electronic interface PEI. There are two modes of operation for the microgrid: grid-connected mode (GCM) and islanded mode (IM) [2]. The islanded mode has a complex PEI mechanism compared to the former because the overall task strength is higher in the Islanded way and is more capable of resolving online working challenges [3, 4].

Most concerning problem is the quality of power that is being delivered to loads. In simple words, it is called the power quality of electrical supply [5]. This feature is a measurement of the standardized waveforms of voltage and current that are being delivered to electrical loads.

Distorted power quality results in several problems in the local distribution system. The common issues that disrupt electrical loads include voltage sag and voltage swell, voltage transients, voltage unbalance, current harmonics, and current imbalance [6]. Out of all the most important problem are voltage sag and swell, usually sensitive loads are severely affected. These effects include damage to essential electrical equipment and loads, malfunctioning of electrical equipment, loss of production data and corruption of data, the underperformance of electrical systems, etc. [7]. Thus, microgrid is a need of the hour. The reliability pattern of the local distribution system will improve if it links with microgrid structure. The microgrid will not only act as a backup supply but also save its surplus power inside the energy storage unit. The literature survey has further discussed different concepts in which the microgrid and power quality compensation technique combine to improve the distribution system's performance.

The Hybrid AC / DC microgrid approach is now popular and commonly used to merge the properties of both AC and DC microgrids. Therefore, inertia control techniques are put forward to control the power quality of individual DG units effectively [8-10]. For interfacing converter (IC), a two-level control is suggested to solve the problems related to DG level and system-level power quality. The primary level is responsible for the compensation of power quality problems that are based on DG units. In contrast, the secondary level is accountable for the compensation of power quality problems in hybrid microgrid systems [11-15]. The deployment of distributed generation units improves the power quality of the microgrid system [10]. Rather than the typical design of microgrid, a more elaborate and improved battery energy storage system is proposed and successfully installed with the distribution system. It reduced the overall power quality issues in the microgrid performance [11].

Even though DVR is the most versatile FACTS device to resolve the voltage sag/swell problems, the efficiency of DVR is entirely dependent on its coupling topology with the power line and control unit. The literature survey in [12, 13, 14] shows the design of a complex filter combination for DVR. The performance of the DVR is primarily affected by the compound structure of a microgrid [15, 16]. Furthermore, the control algorithms in [17,18-25] are shaped explicitly for those DVR structures that are working under harsh conditions. However, they are showing slow progress and an imprecise compensation voltage injection.

In this paper, Upgraded Dynamic Voltage Restorer (UDVR) is proposed to compensate for voltage sag and swell in a grid-connected microgrid scheme. The latest control strategy includes two sub-control units, an Upgraded synchronous reference frame (USRF) control unit, a fuzzy technique control system. The USRF control unit takes care of smart regulation of voltage sag/swell, while the fuzzy technique control unit makes sure that the perception of voltage sag/swell in line voltage is fast and efficient. The stability analysis of USFR and its DC link voltage is entirely controlled and presented at the time of sag/swell compensation. The associated loads are secure regarding the complete/partial power failure as well as severe voltage sags/swell

II. METHODOLOGY

A. UDVR BASED MICROGRID SYSTEM DESCRIPTION

The power distribution system is the last part of the power supply system. It is known as the least secure part of a power supply system, and it generally gets supply through the central supplier. The sensitive and normal operating loads (medical supply loads, household loads) merge to form the associated loads.

The supply system shown in Figure 1 is not secure because the local voltage supply system is the only power source, the failure could be the result of system faults or natural disasters. So microgrid is introduced in addition to the local voltage supply in Figure 2. Here, if the local voltage supply becomes faulty or is unable to provide power to loads, the microgrid will act as a backup power supply and will be a reliable source to fulfil the power demand of loads.

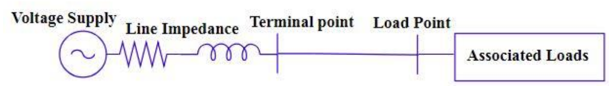


FIGURE 1. Local supply system with associated load

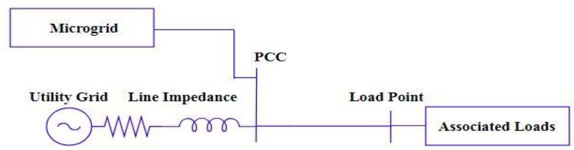


FIGURE 2. Micro grid supported power supply system

Figure 3 shows a standard microgrid's design structure. Various categories of loads can be a part of a microgrid. Figure 4 shows the modified design of power supply system in which a power quality compensation technique exists together with microgrid and local utility grid, technique is positioned at the appropriate place in power supply system for effective mitigation of voltage sag/swell.

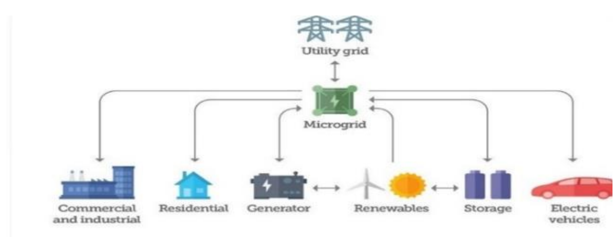


FIGURE 3. Structure of Micro grid

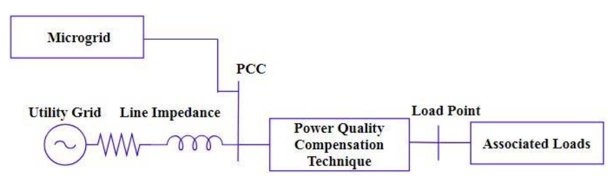


FIGURE 4. Modified design of the power supply system

The standard design and structure of UDVR are displayed in figure 5. It shows a control unit, and power electronics centred voltage source converter (VSC), necessary filter design, and series coupling transformer or injection transformer. UDVR is connected with the power line in series, and it injects the anti-sag/swell voltage to reduce these effects in the voltage. UDVR's control unit has the ultimate authority, and it runs the VSC to develop anti-sag/swell. Later, this anti-sag/swell moves through a filter combination of UDVR to remove the unwanted noise signals in injection voltage. The performance UDVR in the power supply system is dependent on the selection of its control method and combination design of its filter.

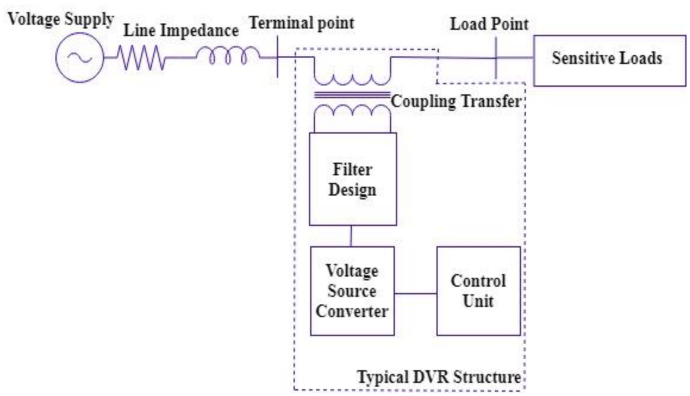


FIGURE 5. Design structure of (UDVR)

Figure 6 shows the three-line diagram with the combination of a utility grid and microgrid at PCC to give a comprehensive structure of the system with the detailed description of the proposed UDVR. The loads are attached to the load bus, and the PCC is feeding it. Here, C_T is a coupling/ injection transformer. A combination of (R_f, C_f, and L_f) is the proposed design of the filters for UDVR. R_f represents the filter's resistance, C_f is filters capacitor, and L_f is filters inductor. VSC of UDVR is a voltage source converter based on power-electronics. C_{DCL} is a DC link capacitor of VSC of UDVR. The values of L_f, C_f can be ndetermined by following equatio

$$C_f = \frac{1}{2\pi\left(\frac{f_s}{2}\right)R_f} \tag{1}$$

$$L_f = \frac{1}{(2\pi f)^2 C_f} \tag{2}$$

a) CONTROL PHILOSOPHY OF UDVR

UDVR's performance is entirely dependent on its control strategy. The strategy is built inside the control unit, which differentiates the reduction of the power quality problem approach of two DVRs, which have the same VSC design. The main purpose of using any power quality compensation device is to figure out the problem in the power line and then resolve it in a short time. To do this, an effective control methodology for UDVR is necessary. The suggested solution includes a two-stage control: a fuzzy logic-based technique system and an upgraded synchronous reference frame. The fuzzy technique detects the voltage sag/swell issues in the power line or across the load. In contrast, USRF-based control effectively diminishes these issues and protects the loads from their adverse effects.

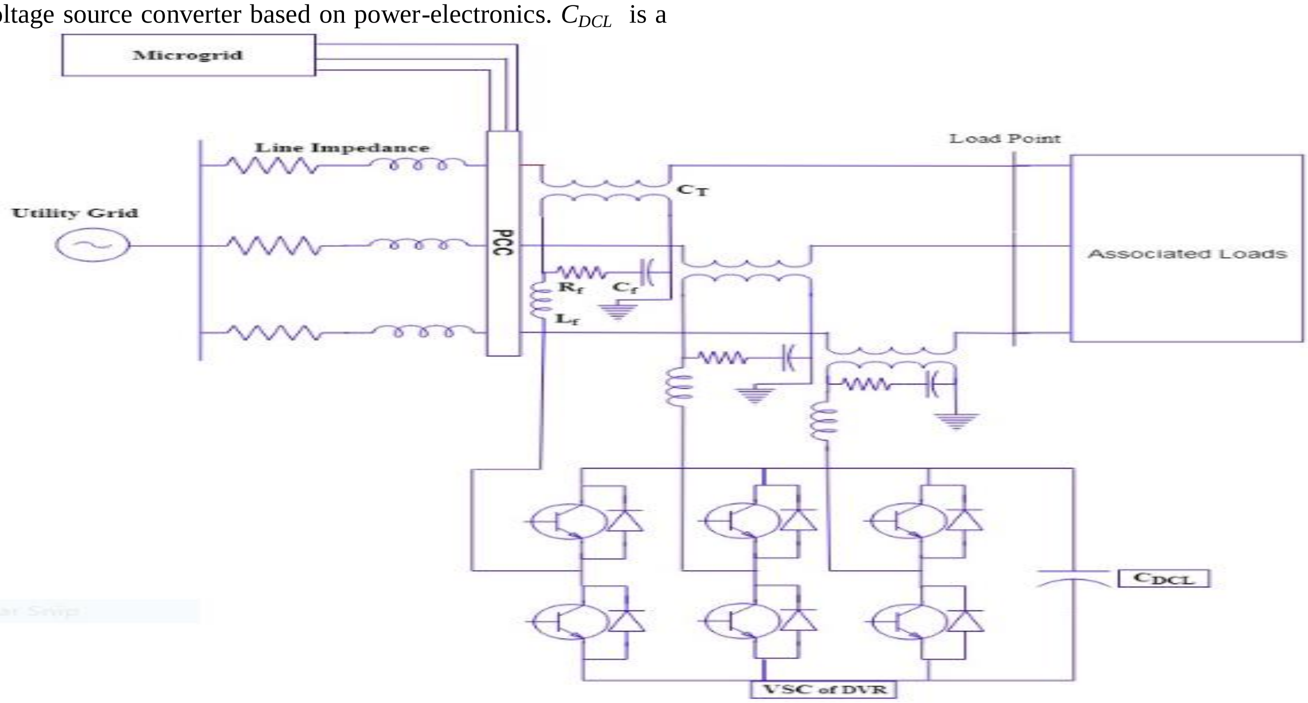
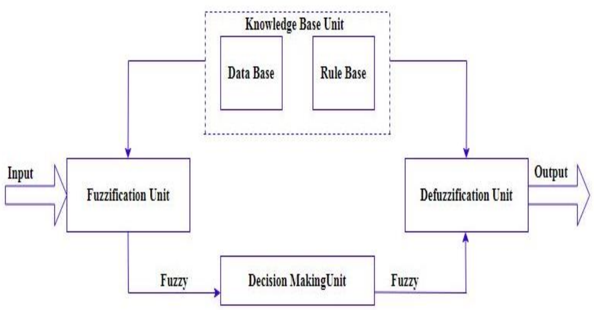


FIGURE 6. Design structure of proposed system

b) FUZZY TECHNIQUE SYSTEM

Fuzzy inference system (FIS) is an extraordinary logic control mechanism that allows fast and precise results as compared to the standard logic controllers. Its major components includes the fuzzification unit, defuzzification unit, knowledge base, and decision-making unit shown in figure 7. The knowledge base unit is further divided into a rule base and database. The database depends on membership functions, that are made according to our data. In contrast, rule-based depends on if-then rules that we define according to our database. The fuzzification unit switches the normal input values/quantities to fuzzy quantities to execute an operation, whereas a defuzzification unit converts the fuzzy quantities into normal values/quantities, which can then be used as the output of the fuzzy inference system.



FIGURRE 7. Block diagram of FIS system.

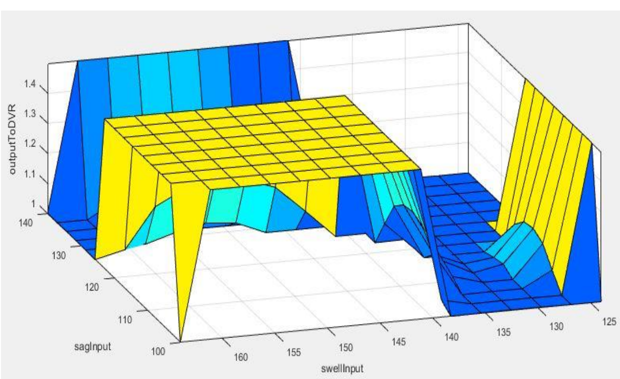


FIGURE 8. Surface viewer in FIS control

c) UPGRADED SRF BASED CONTROL

Synchronous reference frame SRF is a flexible and adaptable control technique as compared to other control techniques such as instantaneous reactive power (IRP) theory and Adaline-based control, in term of complexity, computational speed limitation, and flexibility, which are common problems in the other control techniques. An upgraded SRF based control is a proposed in this paper for an effective reduction of voltage sag/swell. First the USRF based control consists of multiple loops of error reduction and speed increment to reduce the error between the nominal voltage and line voltage during voltage sag/swell. Secondly increases the speed of the overall control during controlling operation. Figure 9 represents the fundamental flow of the USRF based control that is adopted for a UDVR to make it unique. Initially, the line voltage that is affected due to voltage sag/swell converts into park transformation. This part transformation is also known as dq0 transformation. Then, the proposed improved control methodology is applied to the components of the dq0 reference frame.

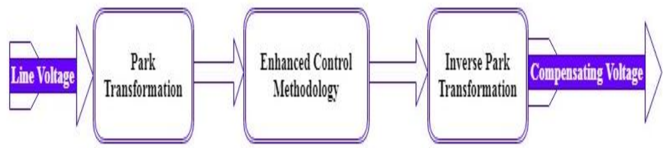


FIGURE 9. Flow of USRF control

Following the application of the control approach, the resultant components convert into abc signals using the inverse park transformation, which is also called inverse dq0 transformation. Figure 10 presents the detailed diagram of an Upgraded SRF based control, which is suggested for UDVR to reduce voltage sag/swell. First, the three-phase line voltage converts into a dq0 reference frame through park transformation. The reference angle is ɵref*. The resulted V_{Ld} and V_{Lq} move through a low pass filter to remove higher-order components, which are present in line voltage. The resulting output of LPFs then compares to respective reference signals (reference voltage) in d and q components. Error signals V_d1 and V_q1 are added to the DC link capacitor voltage feedback signal V_{DCLcon}.

To further enhance the accuracy of this control an additional accuracy loop ($V_{Ldref}^{2}+V_{d}^{22}$) added in q-axis of the control, V_d2 and V_{q2} passes through PI controller for necessary control action Error of output of PI controllers in d & q axis is taken out and passes through PI to regulate zero axis of dq0 control. Finally, V_{dq0sol} is converted to abc signals using inverse park transformation again. The output signals are then converted into sine pulse width modulation (SPWM). The output is then applied to the VSC of DVR as a switching signal. Eigenvalues stability analysis measures the stability of the enhanced SRF based controller. As a rule, if the values are mapped on the left half of the s-plane, the closed-loop system is stable.

Table 1 represents the values of the suggested controller in a closed-loop system. According to this table, it is verified both the values are in the left half of the s-plane. Hence, the closed-loop system with the proposed controller is stable. Kp and Ki proportional and integral respectively are the gain values of a PI controller used in the control system. The calculation and measurements for the park and inverse spark transformations is depict by the following equations:

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & -\sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \quad (4)$$

Transfer function of the USRF based closed-loop system is represented by equation:

$$\frac{v_{out}}{d} = \frac{a_3 s^3 + a_2 s^2 + a_1 s + a_0}{b_3 s^3 + b_2 s^2 + b_1 s + b_0} \quad (5)$$

Where,

v_{out} is the output voltage of a DVR

d is the duty cycle of VSC

$$a_3 = -L_f C_f k_p, a_2 = -(L_f C_f k_i + R_f C_f k_p), a_1 = -(R_f C_f k_i + k_p - 1), a_0 = -k_i$$
$$b3 = L_f C_f, b_2 = R_f C_f + b_1 = 1, b_0 = 0$$

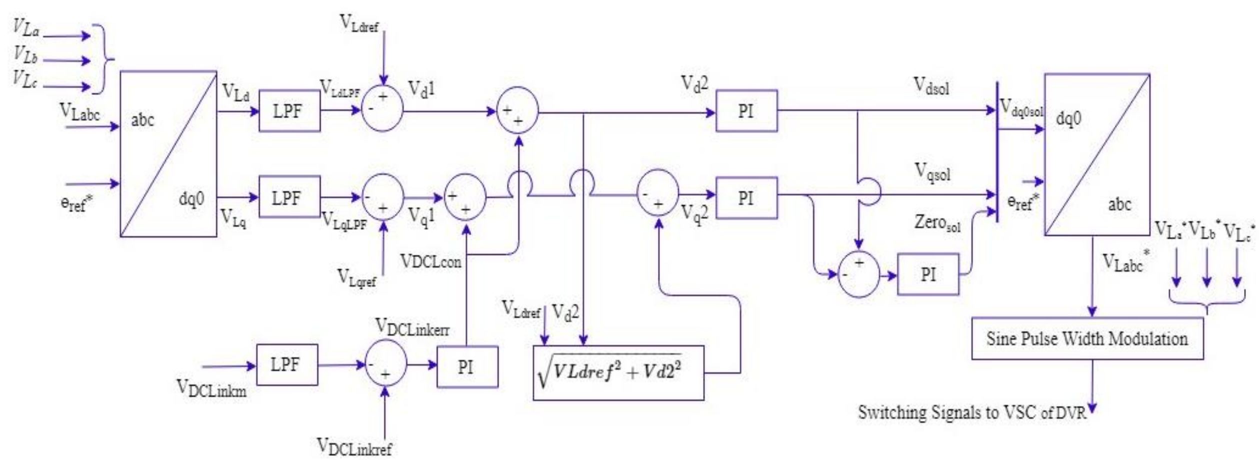


FIGURE 10. USRF control

TABLE-1: EIGEN VALUES AND CONTROLLER GAIN

Parameters	Value
Eigenvalues of Control System	-0.0011+1.0127*i* -0.0011-1.0127*i*
k_p	15
k_i	25

III. RESULTS AND DISCUSSION

For the assessment of the system's performance, the entire system with a microgrid and UDVR is simulated in MATLAB/Simulink environment. The parameters of this system are given in table 1. The primary purpose of such a microgrid design is to establish and maintain electrical power during utility grid problems. In contrast, UDVR should make sure that the power supply across loads is free of sag/swell. To ensure and verify proposed method, there are three different cases. The simulation results confirmed the performance of microgrid design and UDVR are under the proposed control methodology.

TABLE II. SYSTEM PARAMETERS

Nominal Per Phase Voltage	190V
Line Frequency	50Hz

Impedance of power line	R_l =0.23Ω L_l =2.75mH
Associated load	2.1k+j1.45k
DC link Capacitor of EDVR	6980uF
R_f	0.07Ω
C_f	3uF
L_f	3.25mH
Turn ration of C_T	1:1

A. SAG MITIGATION ANALYSIS

In this scenario, the performance of UDVR has been evaluated under voltage sag condition. The nominal voltage across the loads is 190V and fundamental frequency is 50Hz, due to sudden load change the line voltage experiences voltage sag at 0.1s. Figure 11(a) shows the case when the line voltage experiences voltage sag at 0.1s due to sudden load change, if no protection device present then this sag passes through load bus and damage electrical loads and power equipment. Figure 11(b) shows the recovery from voltage sag when UDVR detects sag at 0.1s and mitigate it in minimum time interval (approx 5ms).

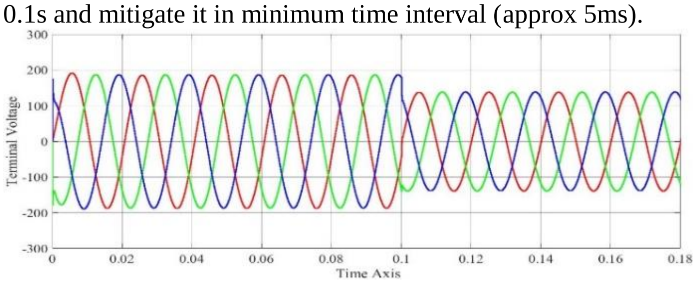


FIGURE 11(a). Sag in line voltages

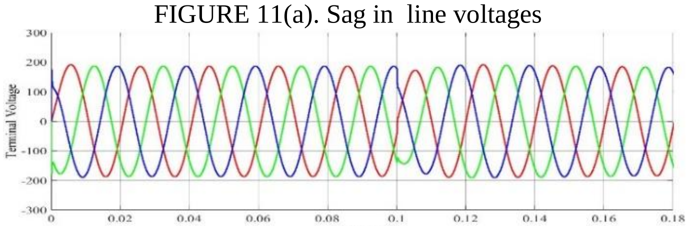


FIGURE 11(b). Sag compensation in line voltage

B. SWELL MITIGATION ANALYSIS

This is the case in which the performance of UDVR has been assessed under-voltage swell condition. The nominal voltage across the loads is 190V and the fundamental frequency is 50Hz, Figure 12(a) shows the case when the line voltage experiences voltage swell at 0.1s due to single line to ground fault if no protection device present then this swell will pass through load bus and damage electrical loads and power equipment. Figure 12(b) shows the recovery from voltage swell when EDVR detects sag at 0.1s and mitigate it in the minimum time interval (approx. 5ms).

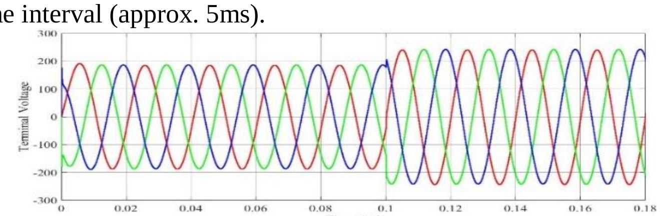


FIGURE 12 (a). Voltage swell in power line

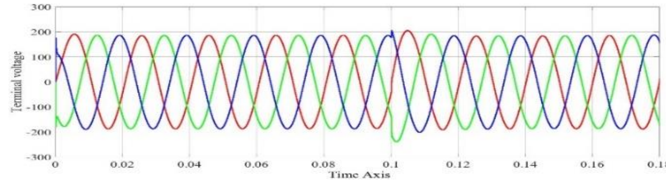


FIGURE 12 (b). Swell compensation

C. BLACK OUT ANALYSIS

In this scenario, the performance of microgrid design under the utility grid is evaluated. The nominal voltage across the loads is 190V and fundamental frequency is 50Hz. Figure 13(a) shows the case when the utility grid goes through a complete blackout at 0.1s resulting from a fault in the grid side. In this case, if no backup supply exists, loads will suffer a power outage. Figure 13(b) shows the recovery of load voltage at 0.1 s, while the utility grid that is supported with microgrid structure, instantly restores and continues power delivery to loads. Figure 13(c) show the output voltage of PV array (microgrid's DG).

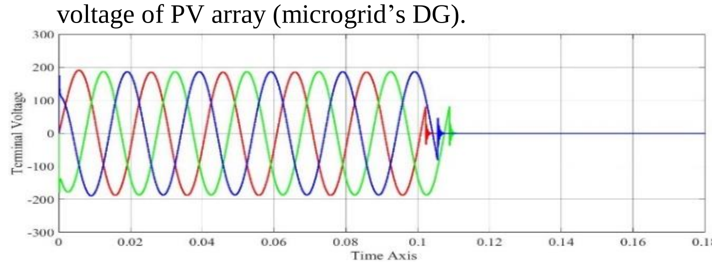


FIGURE 13(a). Utility grid voltages without MG support

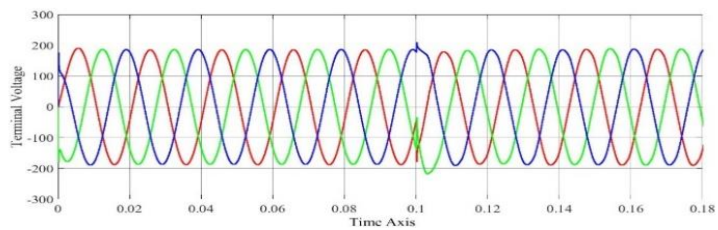


FIGURE 13(b). Utility grid voltages with MG support

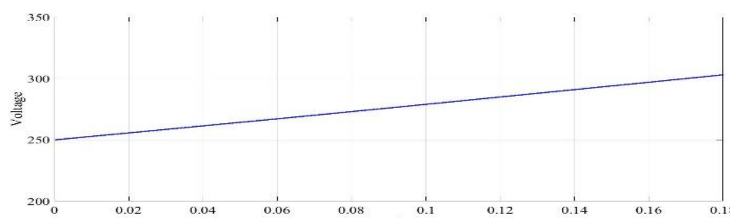


FIGURE 13(c). PV array

TABLE III. COMPARISON OF LITERATURE SURVEY

Papers #	Control Complexity	Control Processing Speed	Control Accuracy
[12]	Medium	Less	Less
[13]	High	Less	High
[17]	Medium	Less	Less
[16]	Medium	Medium	Less
This paper	Less	High	High

IV. CONCLUSION

This paper proposes a microgrid and a UDVR based power supply system to increase utility grid reliability. A comprehensive design approach is considered to improve the availability of power supply and voltage sag/swell problem. An active control technique for UDVR includes two separate control stages: a fuzzy technique system based control and upgraded synchronous reference frame UDVR based control. The fuzzy technique system based control detects the sag/swell problem in the load line, whereas the UDVR ensures a significant reduction of the sag/swell. Both subs controls enhanced the overall performance in terms of accuracy and speed. The mentioned results have verified the significance of microgrid and UDVR based power supply systems. Their presence, as a combination, completely protects against the utility grid-related faults as well as the voltage sag/swell related power quality problems.

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