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IMPROVING POWER QUALITY OF THE DISTRIBUTION GRID BASED ON A MULTI LEVEL INVERTER INTEGRATED DYNAMIC VOLTAGE RESTORER-ULTRACAPACITOR DESIGN

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Abstract-. The novel contribution of this paper lies in the integration of rechargeable UCAP-based energy storage into the DVR topology. Faults on the grid and industrial loads degrade the power quality. In order to improve the quality of power, custom power devices like dynamic voltage restorer (DVR) has been used for compensating voltage sag and swell and also by using the five level diode clamped inverter based DVR ,THD levels has been reduced. Complexities involved in t he design and control of both the d c–ac inverter and t he dc–dc converter are discussed. And also multi level inverter its types and modulation technique and the Simulink model of the proposed system is represented and the results are shown.

Index Terms — DC–DC converter, d–q control, DSP, dynamic voltage restorer (DVR), energy storage integration, phase locked loop (PLL), sag/swell, Ultracapacitor (UCAP).

I. INTRODUCTION

The concept of using inverter-based dynamic voltagerestorers (DVRs) for preventing customers from momentary voltage disturbances on the utility side was demonstrated for the first time by Woodley et al. [1]. The concept of using the DVR as a power quality product has gained significant popularity since its first use. In [1], the authors propose the usage of the DVR with rechargeable energy storage at the dc-terminal to meet the active power requirements of the grid during voltage disturbances. In order to avoid and minimize the active power injection into the grid, the authors also mention an alternative solution which is to compensate for the voltage sag by inserting a lagging voltage in quadrature with the line current. Due to the high cost of rechargeable energy storage, various other types of control strategies have also been developed in the literature [2]–[8] to minimize the active power injection from the DVR. The high cost of the rechargeable energy storage prevents the penetration of the DVR as a power quality product. However, the cost of rechargeable energy storage has been decreasing drastically in the recent past due to various technological developments and due to higher penetration in the market in the form of auxiliary energy storage for distributed energy resources (DERs) such as wind, solar, hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicle (PHEVs). Therefore, there has been renewed interest in the literature [10]–[17] to integrate rechargeable energy storage again at the dc-terminal of power quality products such as static compensator (STATCOM) and DVR. Various types of rechargeable energy storage technologies based on superconducting magnets (SMES), flywheels (FESS), batteries (BESS), and ultracapacitors (UCAPs) are compared in [10] for integration into advanced power applications such as DVR. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The majority of these systems rely upon three-phase

AC power the standard for large-scale power transmission and distribution across the modern world. Specialized power systems that do not always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners and automobiles UCAPs are ideally suited for applications which need active power support in the milliseconds to seconds timescale [10], [13], [14]. Therefore, UCAP-based integration into the DVR system is ideal, as the normal duration of momentary voltage sags and swells is in the milliseconds to seconds range [15]. UCAPs have low-energy density and high-power density ideal characteristics for compensating voltage sags and voltage swells, which are both events that require high amount of power for short spans of time. UCAPs also have higher number of charge/discharge cycles when compared to batteries and for the same module size, UCAPs have higher terminal voltage when compared to batteries, which makes the integration easier. With the prevalence of renewable energy sources on the distribution grid and the corresponding increase in power quality problems, the need for DVRs on the distribution grid is increasing.

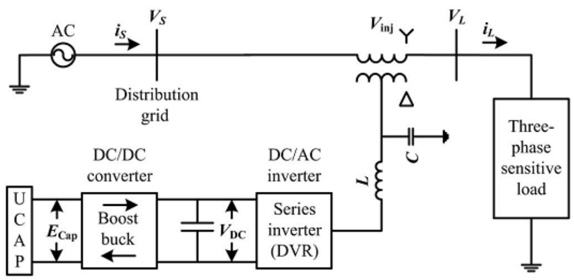

Fig. 1. One-line d iagram o f DVR with UCAP energy storage.

II . THREE-PHASE SERIES INVERTER

A. Power Stage

The one-line chart of the framework is appeared in Fig.1. The force stage is a three-stage voltage source inverter, which is related in arrangement to the lattice and is in control for remunerating the voltage lists and swells; the model of the arrangement DVR and its controller is appeared in Fig. 2.

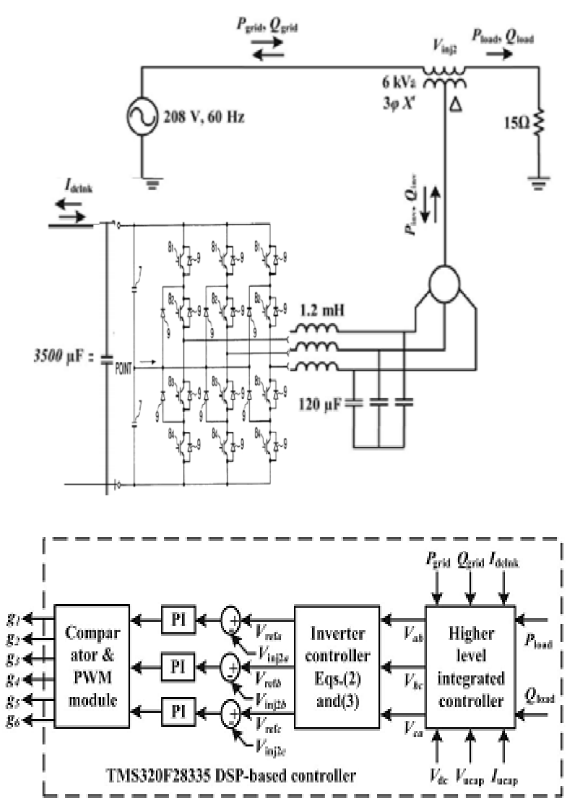

Fig. 2. Model of three-phase series inverter (DVR) and its controller with integrated higher order controller.

The inverter framework comprises of a protected entryway bipolar transistor (IGBT) module, its door driver, LC channel, and a separation transformer [2]-[3]. The dc-join voltage V dc is directed at 260 V for best execution of the converter, in view of these, the regulation record m of the inverter is given by

$$m = \frac{2\sqrt{2}}{\sqrt{3\, V_{dc*n}}} V_{ab(rms)} \qquad (1)$$

Where n is the turn’s ratio of the isolation transformer. Substituting n as 2.5 in (3.1), the necessary modulation index is considered as 0.52. Therefore, the output of the dc–dc converter should be synchronized at 260 V for providing correct voltage payment. The objective of the integrated UCAP-DVR system with active power ability is to compensate for impermanent Voltage sag and swell.

Table I
Comparison of THD level

S. No	Event	THD level when inverter based DVR is used	THD level when five level diode clamped inverter is used
1	Voltage sag	1.23	0.11
2	Voltage swell	2.14	0.10

B. Controller Implementation

There are different systems to control the arrangement inverter to bear the cost of element voltage re-foundation and the majority of them depend on infusing a voltage in quadrature with prevalent stage, so that receptive force is used in voltage reinstallation.

The ongoing oversee arrangement in light of a non-direct state variables input move toward that decouples the dynamic and receptive line mongrel rent segments permitting the self-representing oversee of dynamic and responsive supply power has been anticipated in [4].

The decoupling control has been additionally connected on rapid operation of affectation engines where its relies on upon the accuracy of the stator inductance and the spillage element In this anticipate, the present control of PWM-VSI has been executed in the turning (synchronous) d-q reference outline following the synchronous casing chief can dispose of enduring state blunder and has quick transient reaction by de-coupling be responsible for However, synchronous casing controller is more intricate then the stationary edge controller and requires changing of computed stationary edge air conditioning current to spinning outline dc segments [5], In light of the anticipated θ and the line–line source voltages, V_{ab}, V_{bc}, and V_{ca} (which are accessible for this delta-sourced framework) are adjusted into the d–q space and the line–neutral parts of the source voltage V_{sa}, V_{sb}, and V_{sc}, which are not possible, can then be unsurprising utilizing

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\left(\theta - \frac{\pi}{6}\right) & \sin\left(\theta - \frac{\pi}{6}\right) \\ -\sin\left(\theta - \frac{\pi}{6}\right) & \cos\left(\theta - \frac{\pi}{6}\right) \end{bmatrix} \begin{bmatrix} \frac{V_d}{\sqrt{3}} \\ \frac{V_d}{\sqrt{3}} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} V_{refa} \\ V_{refb} \\ V_{refc} \end{bmatrix} = m * \begin{bmatrix} \left(\sin\theta - \frac{V_{sa}}{169.7}\right) \\ \left(\sin\left(\theta - \frac{2\pi}{3}\right) - \frac{V_{sb}}{169.7}\right) \\ \left(\sin\left(\theta + \frac{2\pi}{3}\right) - \frac{V_{sc}}{169.7}\right) \end{bmatrix} \quad (3)$$

$$P_{dvr} = 3V_{inj2a(rms)} I_{La(rms)} \cos\varphi$$

$$Q_{dvr} = 3V_{inj2a(rms)} I_{La(rms)} \sin\varphi \quad (4)$$

These voltages are normalized to unit sine waves using line neutral system voltage of 120Vrms as orientation and compared to unit sine waves in-phase with real system voltages V_s from 3 to find the injected voltage references V_{ref} essential to preserve a steady voltage at the load terminal, where m is 0.52 from 1. So, when there is a voltage sag or swell on the source side, an equivalent voltage V_{inj2} is injected in-phase by the DVR and UCAP system to cancel out the outcome and keep hold of a constant voltage V_l at the load end[6]-[8]. The actual active and reactive power abounding by the series inverter can be computed from the RMS values.

III. UCAP AND BIDIRECTIONAL DC–DC CONVERTER:

A. Types of DC-DC Converters:

DC-DC converter is an electrical circuit whose main application is to transform a dc voltage from one level to another level. It is similar to a transformer in AC source, it can able to step the voltage level up or down. The variable dc voltage level can be regulated by controlling the duty ratio (on-off time of a switch) of the converter. In this paper, the experimental setup consists of three 48 V, 165F UCAPs (BMOD0165P048) manufactured by Maxwell Technologies, which are connected in series. Therefore, the terminal voltage of the UCAP bank is 144 V and the dc-link voltage is programmed to 260 V. This would give the dc–dc converter a practical operating duty ratio of 0.44–0.72 in the boost mode while the UCAP is discharging and 0.27–0.55 in the buck mode while the UCAP is charging from the grid through the dc-link and the dc–dc converter. It is practical and cost-effective to use three modules in the UCAP bank. Assuming that the UCAP bank can be discharged to 50% of its initial voltage (Vu c, i n i) to final voltage (Vu c, fi n) from 144 to 72 V, which translates to depth of discharge of 75%.

B. Bidirectional DC–DC Converter and Controller

A UCAP can't be straight connected to the dc-connection of the inverter like a battery, as the voltage profile of the UCAP fluctuates as it releases vitality. In this way, there is a need to assemble .The UCAP framework from start to finish a bidirectional dc–dc converter, which keeps up a firm dc-join voltage, as the UCAP voltage diminishes while releasing and increments while charging [10]-[12]. The copy of the bidirectional DC-DC converter and its coordinator are appeared in Fig, where the info comprises of three UCAPs connected in succession and the yield comprises of an ostensible heap of 213.5 Ω to stop operation at no-heap, and the yield is connected to the dc-connection of the inverter.

The measure of Active force bolster essential by the framework in a voltage droop occasion is autonomous on the profundity and span of the voltage list, and the dc–dc converter ought to have the capacity to oppose this force all through the release mode.

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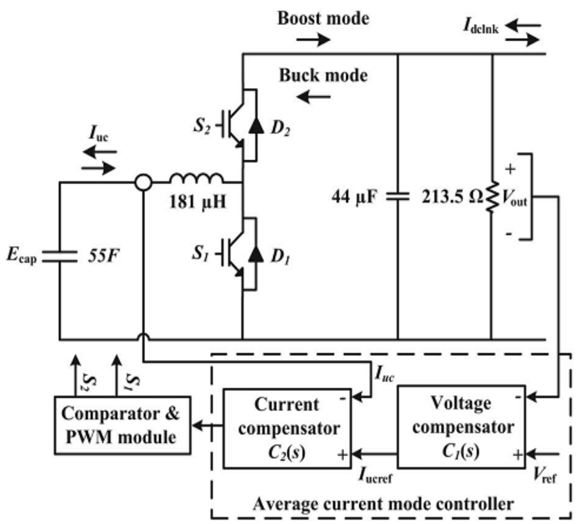

Fig. 3. Model of the bidirectional dc–dc converter and its controller.

The DC-DC converter ought to likewise have the capacity to work in bidirectional mode to be proficient to charge or retain additional force from the matrix in voltage swell occasion. In this anticipate, the bidirectional DC-DC converter go about as a support converter while releasing force from the UCAP and goes about as a buck converter while charging the UCAP beginning the network.

A bidirectional DC-DC converter is fundamental as an intersection point associating the UCAP and the dc-join following the UCAP voltage fluctuate with the amount of vitality released while the dc-join voltage must be unbending. In this way, the bidirectional DC-DC converter is wanted to work in support mode when the UCAP bank voltage is somewhere around 72 and 144 V and the yield voltage are controlled at 260 V. At the point when the UCAP bank voltage is underneath 72 V, the bidirectional DC-DC converter is worked in buck mode and draws vitality from the lattice to charge the UCAPs and the yield voltage is again directed at 260V Average current mode control, which is lengthily investigated in content is utilized to control the yield voltage of the bidirectional DC-DC converter in both buck and help modes while charging and releasing the UCAP bank.

This strategy will have a tendency to be all the more relentless when contrasted with different techniques, for example, voltage mode control and crest current mode control. Normal current mode controller is appeared in Fig.3.7 where the dc-join and real yield voltage V_{out} is contrasted and the reference voltage V_{ref} and the blunder is concurred through the voltage compensator C1(s), which create the normal reference current.

At the point when the inverter is releasing force into the network for the time of voltage droop occasion, the dc-join voltage V_{out} has a tendency to go underneath the reference V ref and the blunder is certain; is sure and the dc–dc converter works in support way. At the point when the inverter is holding power from the matrix amid voltage swell occasion or charging the UCAP, V out tends to help over the reference V_{ref} and the blunder is negative; I_{ucref} is negative and the dc–dc converter works in buck mode. In this way, the indication of the mistake among V_{out} and V ref decide the indication of and therefore the way of procedure of the bidirectional DC-DC converter [13]-[15]. The reference current s then contrasted with the genuine UCAP current (which is additionally the inductor current) and the blunder is then affirmed through the current compensator

C2(s). The compensator transfer functions, which provide a stable response, are given by

$$C1(s) = 3.15 + \frac{1000}{s} \quad (5)$$

$$C_2(s) = 1.67 + \frac{231.81}{8} \quad (6)$$

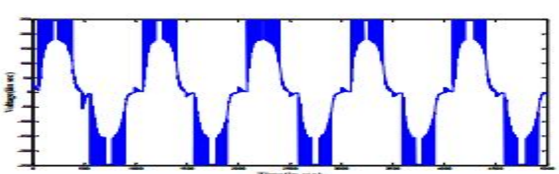

Fig.4. Output voltage of five level inverter

IV. SIMULATION RESULTS

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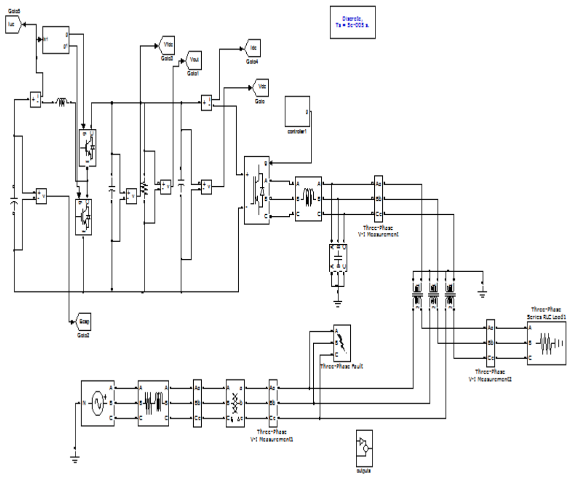


Fig 5: Simulink Model of the considered system

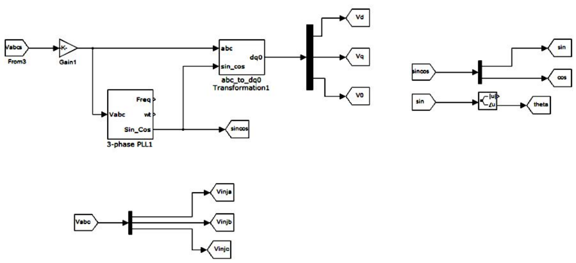
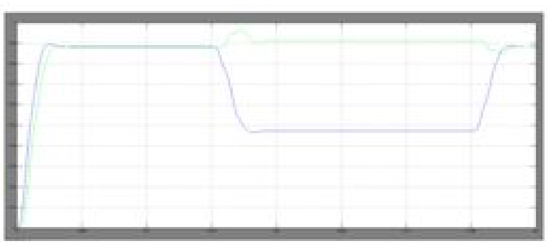
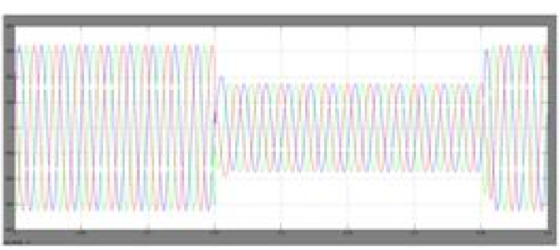
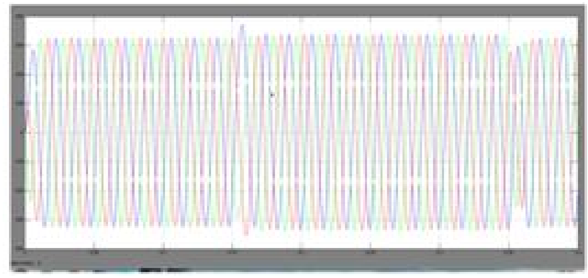
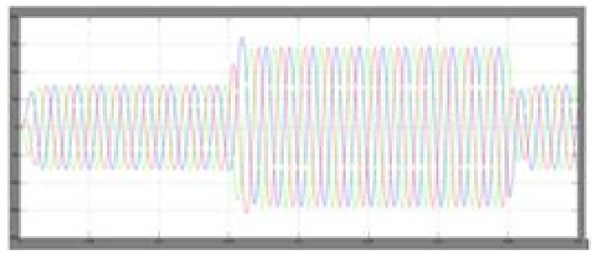


Fig .6 Controller Implementation of Dynamic Voltage Restorer









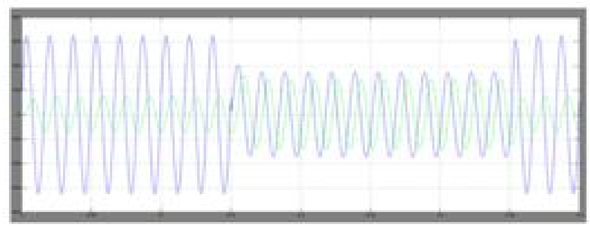
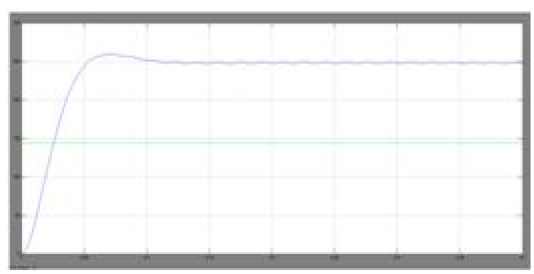


Fig. 7. (a) Source and load RMS voltages Vsrms and VLrms during sag. (b) Source voltages Vsab (blue), Vsbc (red), and Vsca (green) during sag. (c) Load voltages VLab (blue), VLbc (red), and VLca (green) during sag. (d) Injected voltages Vinj2a (blue), Vinj2b (red), and Vinj2c (green) during sag. (e) Vinj2a (green) and Vsab (blue) waveforms during sag.



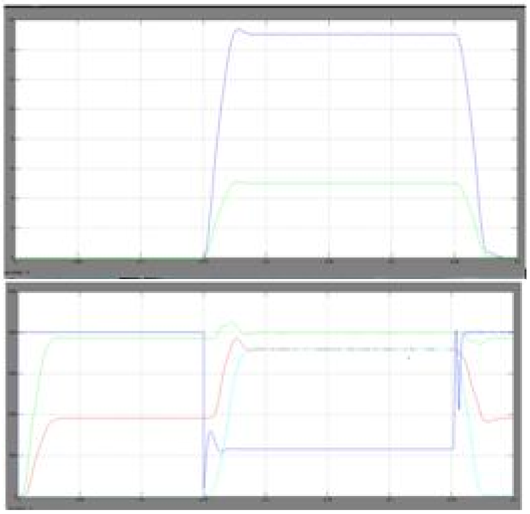
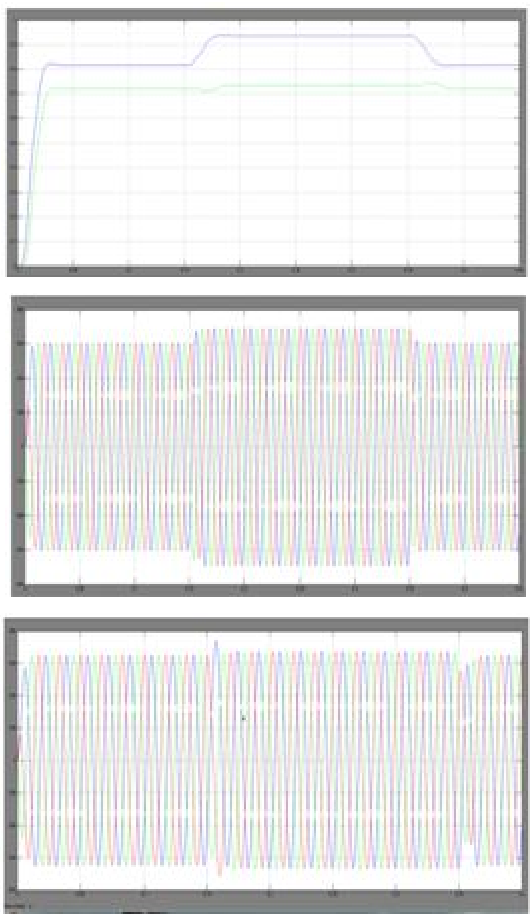


Fig. 8. (a) Currents and voltages of dc–dc converter. (b) Active power of grid, load, and inverter during voltage sag



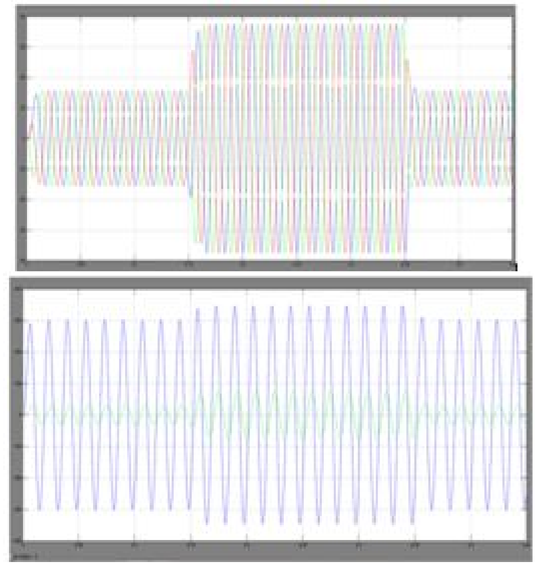
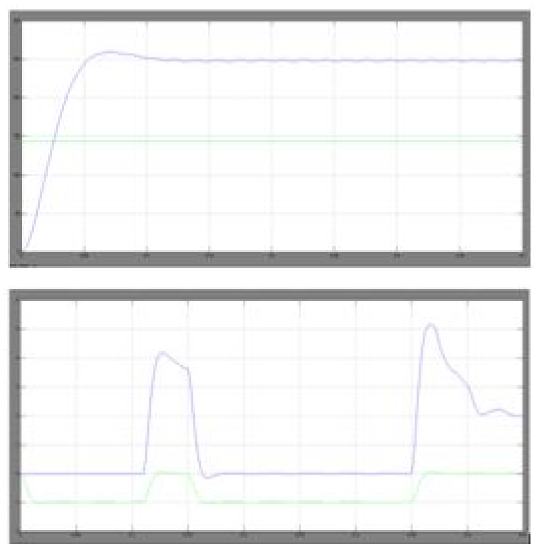


Fig. 9. (a) Source and load rms voltages Vsrms and VLrms during swell. (b) Source voltages Vsab (blue), Vsbc (red), and Vsca (green) during swell. (c) Load voltages VLab (blue), VLbc (red), and VLca (green) during swell. (d) Injected voltages Vi n j 2a (blue), Vi n j 2b (red), Vi n j 2c (green) during swell. (e) Vi n j 2a (green) and Vsab (blue) waveforms during swell.



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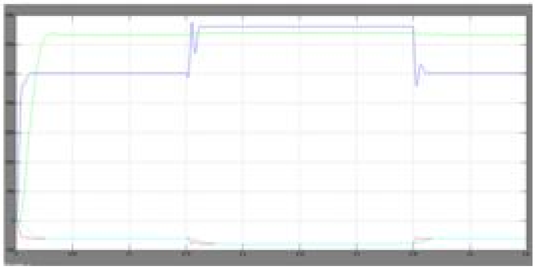

Fig. 10. (a) C urrents and vo ltages of dc–dc converter during swell. (b) Active and r eactive power o f g rid, load, and inverter during a vo ltage swell

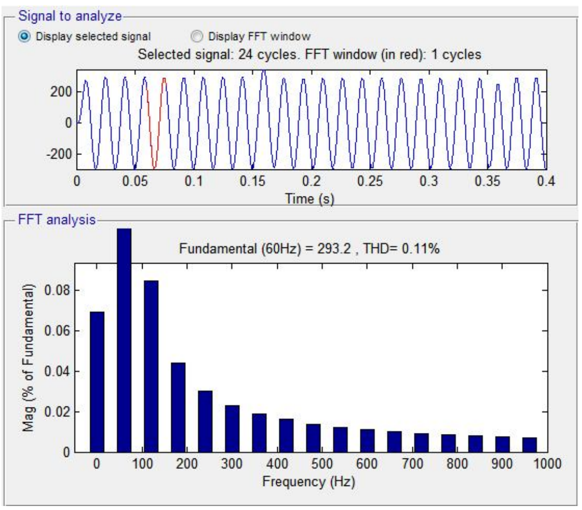

Fig11: THD Level When Five Level Diode Clamped Based Inverter is used during Voltage Sag

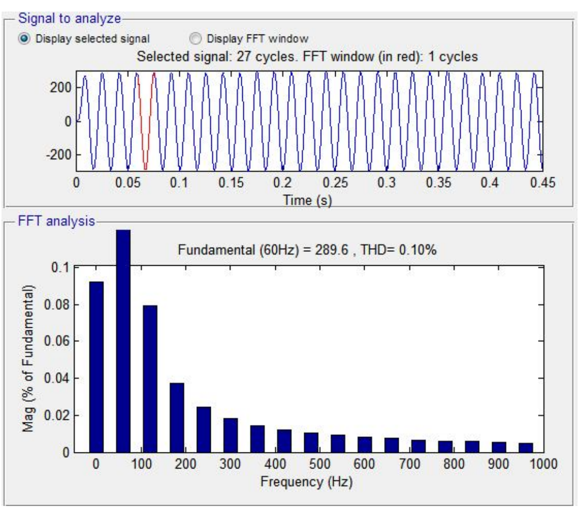

Fig 12: THD Level When Five Level Diode Clamped Inverter is used during Voltage Swell

V. CONCLUSION

This project mainly concentrates on the voltage sag and voltage swell compensation of the distribution grid and also total harmonic distortion level by using a five level diode clamped inverter. In the existing system the Ultra capacitor based rechargeable energy storage integrated to the DVR system to increase its voltage restoration capabilities is explored. DVR is able to separately compensate voltage sag and swells without relying on the grid to compensate for faults. The control approach used is simple and is based on injecting voltages in-phase with the system voltage and is easier to implement when the DVR system has the ability to supply active power. Average current mode control is used to control the output voltage of the dc–dc converter due to its naturally stable characteristics. In the existing method DVR used is a voltage source inverter based one. In the proposed system the inverter based DVR is replaced by a multi level inverter in order to decrease the THD level. Simulation of the ultra capacitor, dc-dc converter and grid joined inverter is carried out using MATLAB and FFT analysis is performed and THD level is observed for voltage sag and swell conditions. In the proposed system which consists of five level diode clamped inverter based dynamic voltage restorer and ultra capacitor is simulated and FFT analysis is performed and a reduced THD level is obtained compared to existing system.

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