Optimal Control Strategy of Modular Multilevel Converter to Mitigate Solar Panel Unbalance Grid Condition

Omika Singh
Department of Electrical Engineering
College of Technology and Engineering, Udaipur, Rajasthan, India

Abstract— The usage of Multi-level inverter has become a very prominent in past years on account of the low distortion outputs, reduced dv/dt stresses and excessive switching frequency. Multi-level Inverter system are power converters frame works made by a cluster of power semiconductors sources which when appropriately associated and controlled, can create a multi-step voltage waveform with variable and controlled phase, frequency and amplitude. This study deals with a three-phase eleven level inverter system connected to grid using GTO as a switching element and for the direct current source solar photovoltaic array is used. The inverter topology considered here is the Cascaded MLI. The above-mentioned system is simulated in MATLAB Simulink with SPWM control, executed for the inverter. THD of the proposed three-phase eleven level cascaded MLI topology has been discussed with the help of FFT analysis under various grid conditions.

Keywords: Diode clamped Inverter (DCI), Cascaded Multilevel Inverter (CMI), Cascaded H-bridge Inverter (CHI), Gate Turn-on thyristor (GTO), Total harmonic distortion (THD), Flying Capacitor Inverter (FCI), Sinusoidal Pulse Width Modulation (SPWM)

I. INTRODUCTION

Demand of energy is escalating day by day. Increased access to electricity leads to rising demand for energy. For energy, we can either prefer renewable or non-renewable source of energy. Non-renewable source of energy are generally fossil fuels such as coal, petroleum and natural gas; which are going to run out of time very soon [1]. However, burning them also cause harm to the environment. Therefore, renewable energy is booming as it delivers the clean energy and also it doesn't pollute the environment. There is widespread support for using renewable energy for the electricity as they give high power quality and performance as well as standard efficiency [2]. To generate a grid-connected system, the voltage and the frequency of the grid should be synchronized to the inverter. Here, the employment of old classical inverter has become outdated because of the need of clean sinusoidal waveform with least distortion factor [3].

Power Electronics Converters, uncommonly PWM inverters have been expanding their assortment of utilization in big businesses due to the fact they give reduced power intake and pinnacle safety. For a grid which is medium in voltage, it is onerous to attach only one power semiconductor switch straightforwardly. Because of these consequences, a multilevel framework system has been generated. As a cost-productive solution, multi-level inverter not only attains exorbitant strength ratings but furthermore permits the usage of low power application in inexhaustible power sources which incorporates PV and wind which can be effortlessly interfaced to a multi-level inverter for a high-power application [4].

Multilevel power conversion, is a quickly developing technology in the vicinity of power electronics with potential capability for further development. In general, multilevel electrical converter may be taken into consideration as voltage synthesizers, within which the excessive output voltage is synthesized from several separate modest voltage levels [5].

Among numerous multilevel topologies, the greatest fundamental ones are: Diode-Clamped Multi-level Inverter and Cascaded Multilevel Inverter and Flying capacitors Multi-level Inverter. The best and the most known topology is Cascaded Multilevel Inverter framework. However, the principle hassle related to the CMI topology is the requirement for remoted DC sources which aren't commonly accessible without utilizing transformers [6]. In a few unique applications comprehensive of PV systems, separate DC sources exist and might be utilized in the CMI topology. Initially, the multilevel converters had been most commonly used in traction, which can be used in both the trains and the track-side static converters [7]. Recently, the power system converters for VAR compensation, balance enhancement, High-Voltage motor drive, High-voltage DC transmission, active filtering and most currently for medium voltage induction motor variable pace drives have been the application of multilevel converters [8]. Various multilevel inverter applications pay attention on industrial motor drives generally of medium-voltage, Flexible AC transmission system, utility interface for renewable energy systems and Traction Drive systems [9].

Multi-level Inverter topologies are widely utilized in environmentally friendly framework application because of the occurrence of higher harmonics distortion in regular bipolar inverters. Right now, the utilization of grid associated photovoltaic system is extensively favored when contrasted with the standalone photovoltaic systems. With the reduction of the installation price and other monetary supports, the limits of photovoltaic power stations are unendingly mounting [10].

This paper presents a model of three-phase eleven level inverter using GTO as a switch and its simulation in different grid condition. The paper is divided into five sections which are organized as follows: section one gives brief about Multilevel Inverter and photovoltaic arrays and grid connected systems. Section two describes complete system configuration. Section three describes the simulation work of the system. In section four results of proposed system are discussed. At last, section five describes the conclusion of the paper.

II. MULTI-LEVEL INVERTER

A Multilevel Inverter is a device which can generate higher amount of voltage by using the devices of lower ratings. These are generally used for the industrial applications because they require high power. They have been introduced since 1975 as an alternative in high power and medium voltage situations. By increasing the number of voltage levels, it can generate a better and smoother output voltage waveform. It can also reduce the switching frequency, for the pulse width modulation application.

The most common type of inverter which is used to generate AC voltage is two-level inverter. A two-level inverter creates two different voltages for the load. If we increase the number of levels, the output voltage will have lower harmonic distortion as well as low $\frac{dv}{dt}$ ratio.

There exist various different topologies of the inverter. These variations differ with the source of input voltage given to the inverter as well as the working of the switches.

The main three multi-level inverter topologies are as follows:

A. Diode-Clamped Inverter

It is otherwise known as the Neutral Point Inverter, which was discovered by Nabae, Takahashi and Akagi in 1981. This type of inverter uses diodes and gives different voltage levels to the capacitor banks connected in series. A diode transfers a limited amount of voltage, thereby reducing the stress on the the other electrical device. A n level inverter requires $(n-1)$ input voltage sources, $(2n-2)$ switching devices and $(n-1)\times(n-2)$ operating diodes. As in Fig 1. a three phase six-level neutral clamped or diode clamped multi-inverter is shown.

B. Flying Capacitor Multi-level Inverter

In 1992, Meynard and Foch discovered the Flying Capacitor Multilevel Inverter. The main concept of this inverter is to use the capacitors, therefore also called as Capacitor clamped Multi-level Inverter. The capacitor transfers the limited amount of voltage to the electrical device. A n level capacitor clamped inverter consists of $(n-1)\times(n-2)/2$ flying capacitors to limit the voltage and $(2n-2)$ switching devices. As in Fig 2. a three phase six-level capacitor clamped MLI is shown.

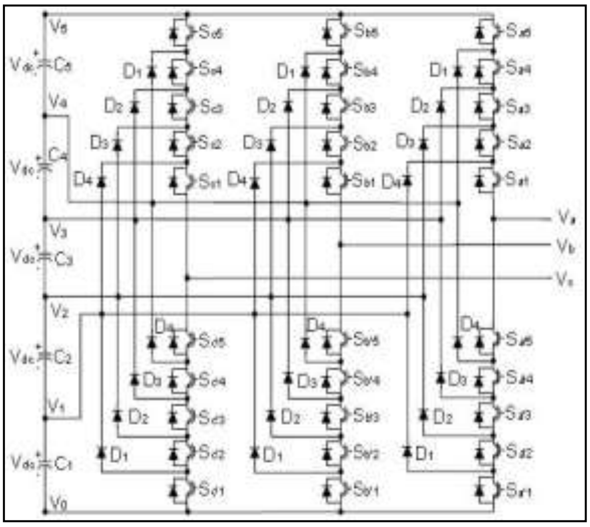

Fig. 1: Three phase Six-level Diode clamped Multi-level Inverter

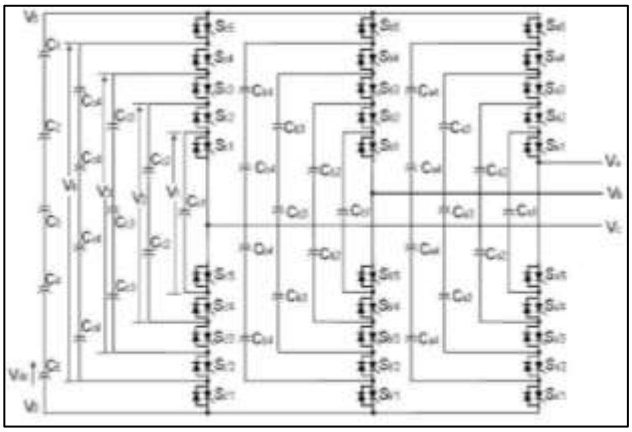

Fig. 2: Three phase six level Capacitor clamped Multilevel Inverter

C. Cascaded H-bridge Multi-level Inverter

This type of inverter consists of both the capacitors and switches. The combination of capacitors and switches is known as H- bridge, which gives the separate input DC voltage for each bridge. It requires a smaller number of components in each level as compared to the previous described types, therefore the price of this type of inverter is low as compared to previous ones. Formula for the no. of voltage level at output is given as $(2n+1)$ where n represents the no. of voltage cells. As in Fig 3. a single-phase structure of a cascaded H-bridge inverter is shown.

III. SIMULATION WORK

The simulation work is done with the help of MATLAB Simulink. We have modelled the three-phase eleven level inverter in MOSFET by using the GTO as a switching device and solar photovoltaic array is used as a DC source. The Eleven level three phase inverter consists of three arms. Each arm consists of total of five cascaded bridges, so total of twenty-five bridges are utilized. For a single bridge four switching devices are used. Output of the inverter is connected to the AC grid through line filters for harmonic reduction. The predetermined module of solar photovoltaic module is utilized in the study.

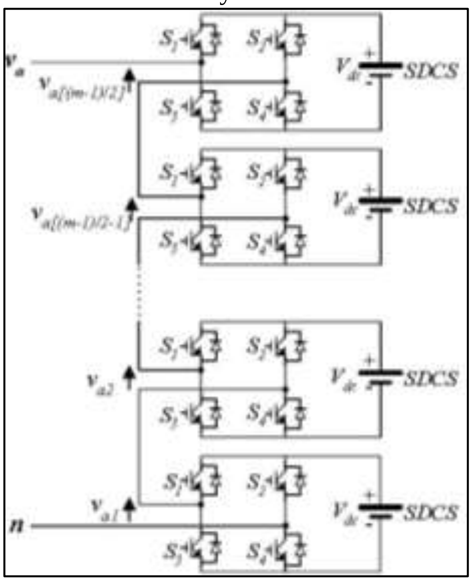

Fig. 3: Single-phase cascaded H-bridge inverter

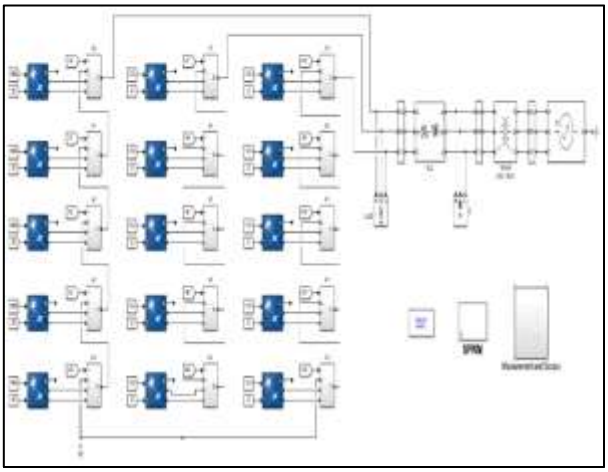

Fig. 4: Proposed system model

The sinusoidal pulse width modulation technique is used for the pulse generation that is required for switching of the power switches. For pulse generation 50Hz reference signal with carrier triangular signal of 2500Hz is used. Here the simulation step size is selected as one micro second that means simulation data will update at every one micro second. The proposed system model is shown in Fig. 4.

The solar module used in the above module works at the standard test condition of 25℃ and $1000W/m^2$. Open circuit voltage of the single module is 50.93V and short circuit current is 6.2A. Maximum power is 249.952W. and voltage at maximum power point is 42.8V. Sinusoidal Pulse width modulation technique is used for the controlling. As a reference sinusoidal signal is selected and for carrier triangular signal is selected. Reference signal is compared with the high frequency carrier signal. The amplitude levels of the carrier signal are varied. Carrier and the reference signal are shown in Fig. 5.

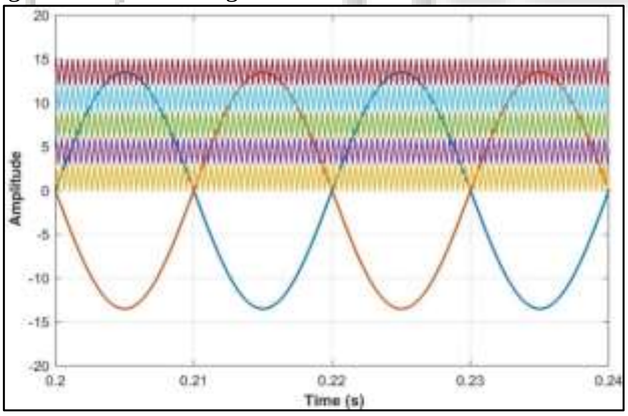

Fig. 5: Carrier and Reference Signal

The model consists of Line filters which is the combination of inductance of $12\mu H$ and resistance of $380\mu\Omega$. The load has active power of 10kW and C block provides capacitive reactive power of 2.5KVAR and has active power of 5kW. The Simulink model of the filter and the grid is shown in Fig. 6.

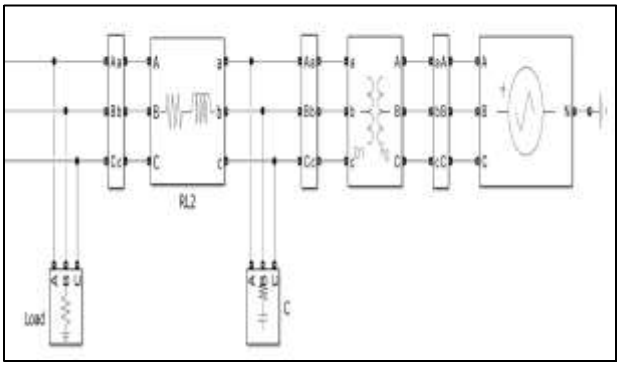

Fig. 6: Simulink Model of the filter and the grid

Here, we preferred three case studies which are carried out on the proposed system. In the first case study the grid is operating in balance condition. Second study carried out when the three-phase voltage sag occurs from grid side. In last study three-phase voltage swells occurs from grid side. For all the three cases voltage and current waveforms and THD are observed.

The different case studies are as follows:

A. Under Balance Grid

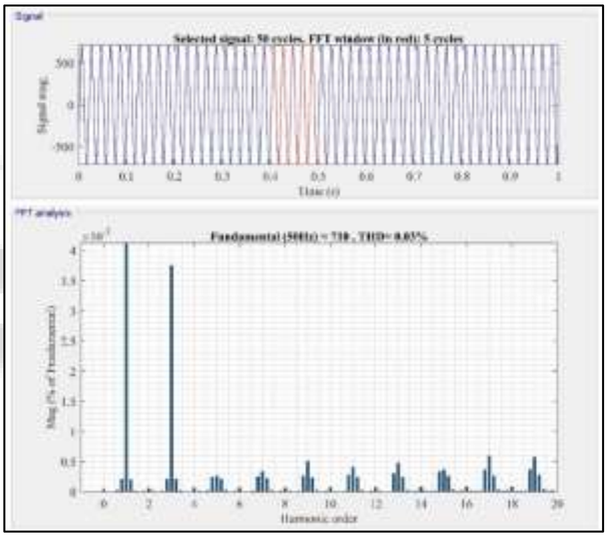

Fig. 7: FFT analysis of inverter voltage under balance condition

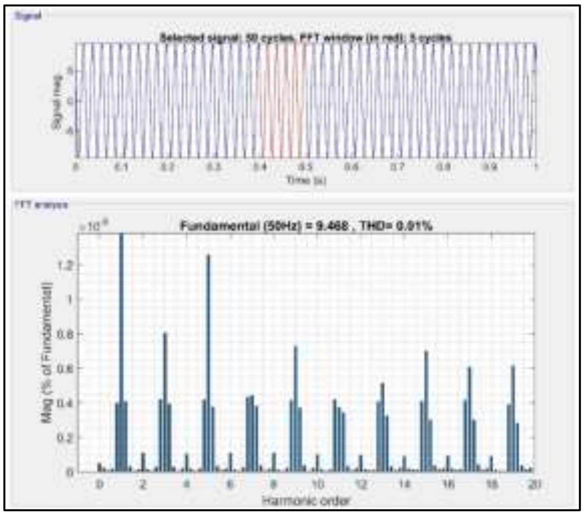

Fig. 8: FFT analysis of inverter current under balance condition

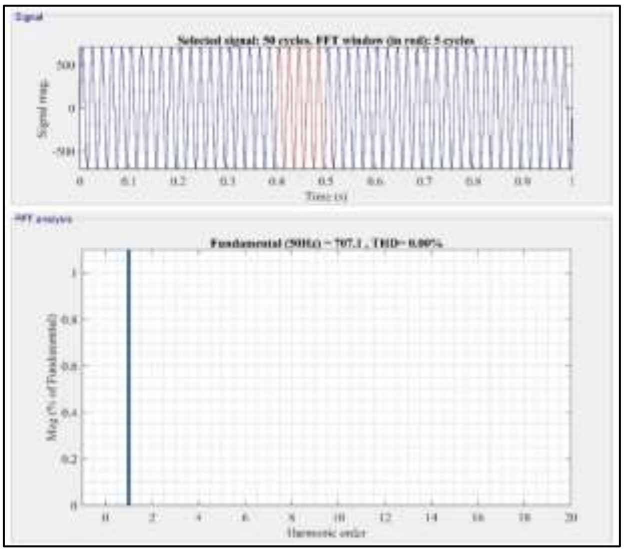

Fig. 9: FFT analysis of grid voltage under balance condition

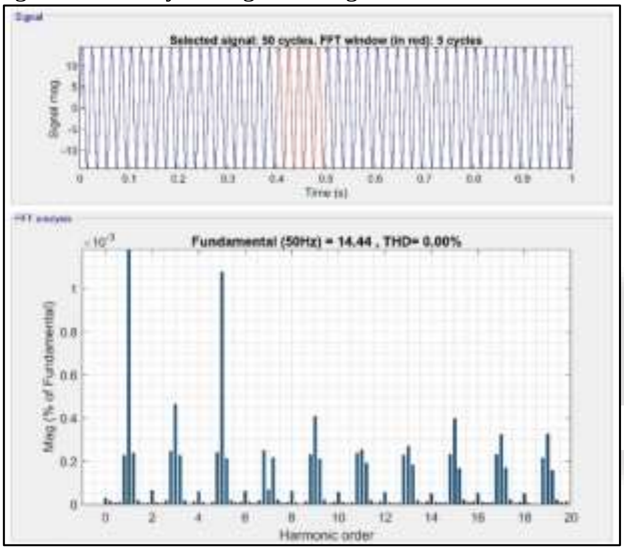

Fig. 10: FFT analysis of grid current under balance condition

B. Three-phase Voltage Sag condition from Grid Side

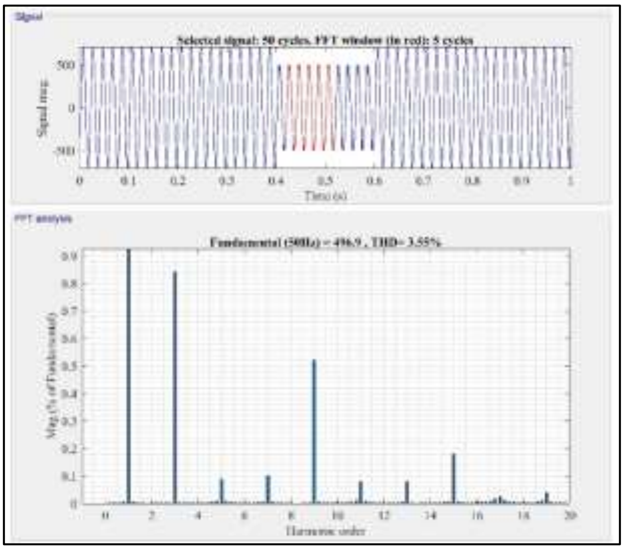

Fig. 11: FFT analysis of inverter under voltage sag condition

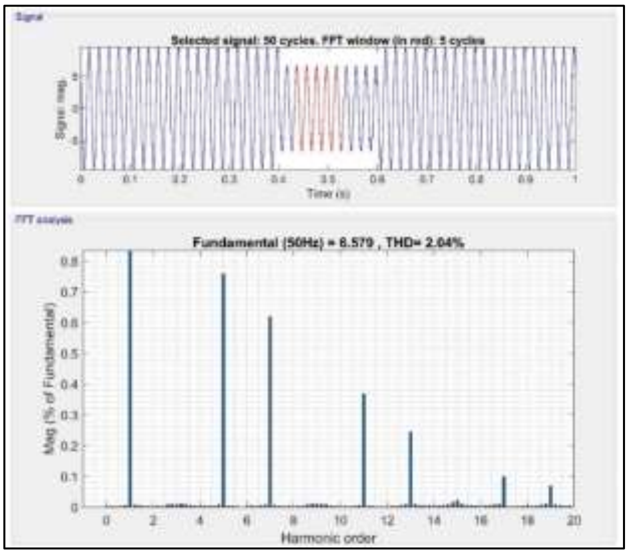

Fig. 12: FFT analysis of inverter current under voltage sag condition

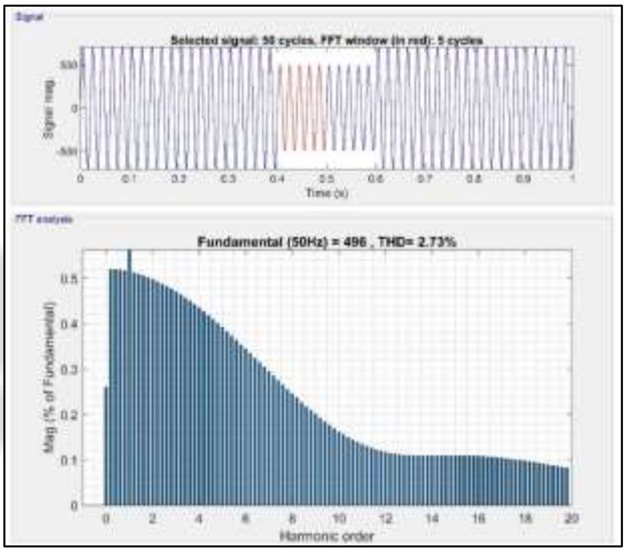

Fig. 13: FFT analysis of grid voltage under voltage sag condition

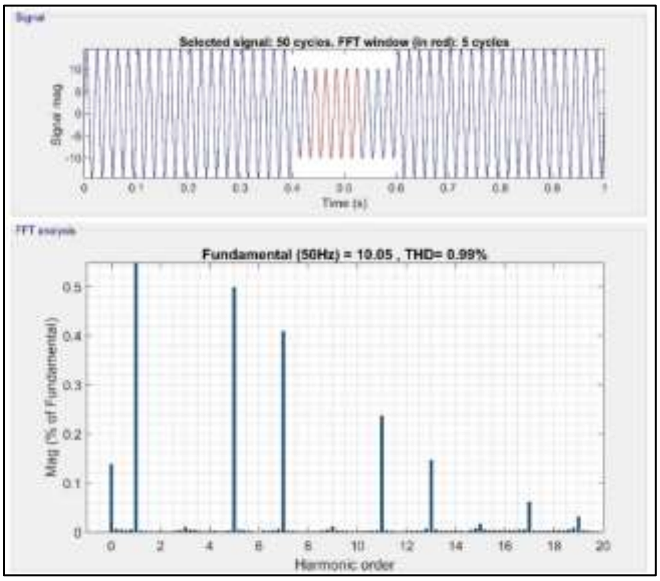

Fig. 14: FFT analysis of grid current under voltage sag condition

C. Three-phase Voltage Swell Condition from Grid Side

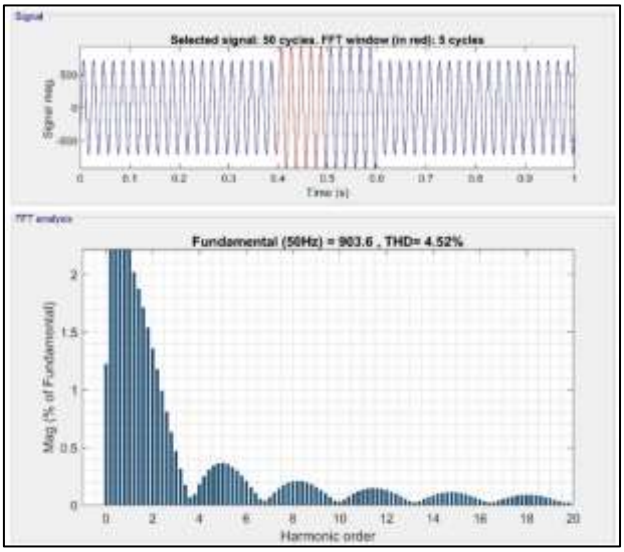

Fig. 15: FFT analysis of inverter voltage under swell condition

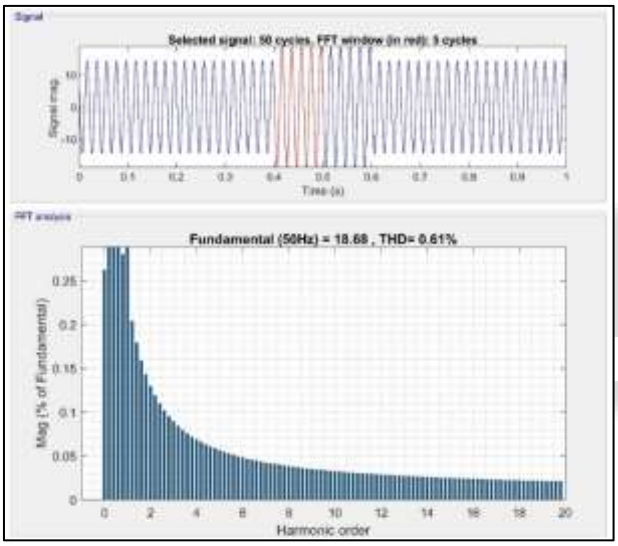

Fig. 16: FFT analysis of inverter current under voltage swell condition

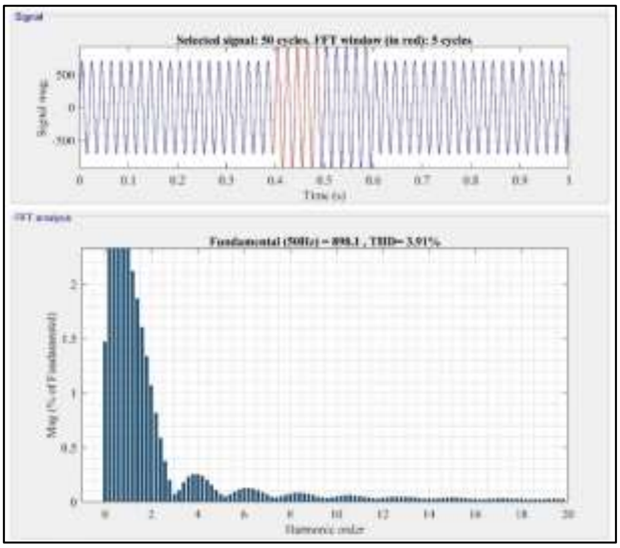

Fig. 17: FFT analysis of grid voltage under voltage swell condition

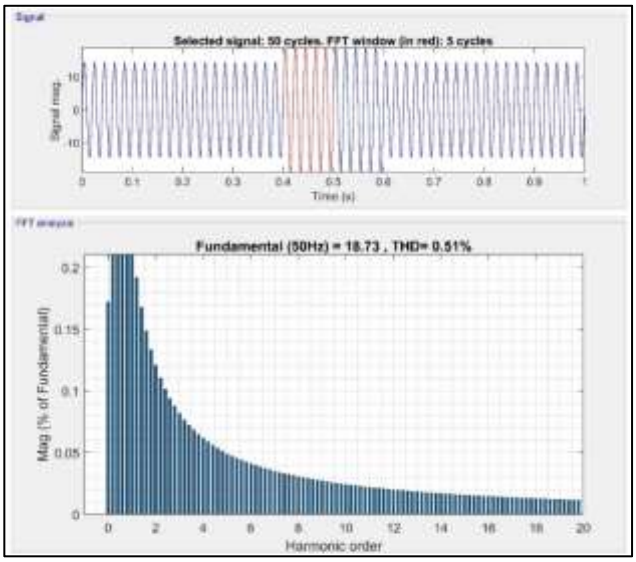

Fig. 18. FFT analysis of grid current under voltage swell condition

IV. RESULT COMPARISON

Case	Inverter voltage THD (%)	Inverter current THD (%)	Grid voltage THD (%)	Grid current THD (%)
Balance Grid Condition	0.03	0.01	0	0
Voltage Sag Condition	3.55	2.04	2.73	0.99
Voltage swell Condition	4.52	0.61	3.91	0.51

Table 1: Result Compilation

V. CONCLUSION

In this paper, we have integrated the three-phase eleven level multilevel inverter connected to the grid. For the performance analysis mainly three studies were carried out. First one was balance condition, second is voltage sag condition and the last one is voltage swell condition. Simulation results and FFT analysis shows that under balance condition THD percentage of the inverter voltage and currents are negligible but when the abrupt conditions like voltage sag and swell conditions occurs from the grid side the THD percentage overshoot are significant when the event starts and ends. In future, we can use the hybrid renewable energy sources can be integrated using multilevel inverter to deliver efficient power to the system.

REFERENCES

[1] G. Singh, V. K. Garg, "THD Analysis of Cascaded H-Bridge Multi-Level Inverter", IEEE International Conference on Signal Processing, Computing and control [ISPCC 2k17], 2017, pp 229-234
[2] S. A. Neve, V. G. Asutkar, "Lower Order Harmonic Reduction In Eleven Level Inverter With Buck

Topology", IEEE International Conference on Computer, Communication and Control [IC4-2015]
[3] C. Gupta, A. Varshney, N. Verma, S. Shukla, "THD analysis of Eleven Level Cascaded H-Bridge Multilevel Inverter with Different Types of Load Using In Drives Applications", International Conference on Advances in Computing and Communication Engineering, 2015, pp 355-359
[4] W. Christopher, R. Ramesh, M. Vishnupriya, "Modelling and Simulation of Single Phase Simplified Eleven-level Inverter", International Conference on Computation pf Power, Energy, Information and Communication [ICCPEIC-2013]
[5] K. K. Rout, A. Tripathy, O. Sahu, S. Mishra, "A Comparative Analysis of Different Topologies of an Eleven Level Inverter for Solar Power Applications", International Conference on Recent Innovation in Electrical, Electronics & Communication Engineering [ICRIEECE],2018, pp 140-146
[6] Md M. Biswas, S. Podder, Md Z. R. Khan, "Modified H-Bridge Multilevel Inverter for Photovoltaic Micro-grid Systems", 9th International Conference on Electrical and Computer Engineering, 2016, pp 377-380
[7] V. Bhargava, S. K. Sinha, M. P. Dave, "A Methodology for 11-level AC Output Voltage Generation for Stand-Alone/Grid Tied Solar PV Applications", Recent Developments in Control, Automation & Power Engineering [RDCAPE], 2017, pp 471-476
[8] N. Panda, B. Das, P. R. Kasari, A. Chakrabarty, "A Developed Eleven-Level Inverter Topology for Medium-Voltage Application", IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy [PESGRE-2020], pp 1-6
[9] B. Xiao, H. Lijun, M. Jun, R. Cameron, "Modulated Cascaded H-bridge Multilevel PV inverter with distributed MPPT for Grid-Connected Application", IEEE Transaction on Industry Applications, pp 1722-1731
[10] P. Narasimma, L. E. Mercy, S. Charles, N. Srinivasan, "Selective Harmonic Elimination Using bee Optimization technique in Hybrid Cascade Multilevel Inverter", International Journal of Emerging Researchers in Engineering Science and Technology, 2015, pp 41-46