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Performance analysis of PV fed single phase Z-source inverter

Kannan S. A[1], Rakesh R[2], Amal M R[3], Kamala Devi V[4], Prof.(Dr). Jayaraju M[5]

M Tech Scholar, Power Electronics, Toc H institute Of Science And Technology, Ernakulam, Kerala, India[1]

M Tech Scholar, Power Electronics, Toc H institute Of Science And Technology, Ernakulam, Kerala, India[2]

M Tech Scholar, Power Electronics, Toc H institute Of Science And Technology, Ernakulam, Kerala, India[3]

Scientist, Agency for Non-Conventional Energy and Rural Technology, Trivandrum, Kerala, India[4]

Director, Agency for Non-conventional Energy and Rural Technology (ANERT), Trivandrum, Kerala, India[5]

Abstract: This paper deals with performance analysis of PV fed single phase Z-source inverter connected to Grid. The PV systems are interfaced to the grid invariably by a power electronic inverter. Many of the important characteristics of the PV generation are influenced by the design and performance of the inverter. Hence suitable models of the inverter are needed to analyze the PV systems. The Z source inverter has an ability to perform DC to AC conversion and buck boost operation in a single stage s. Generally, IEC-61730, 61215, 61701 standards are followed in India for interfacing PV generator to Grid. The PV Inverter should operate in stable mode within the standards specified by IEC. In this paper voltage fluctuations occur in PV system are studied in the z-source inverter model and THD analysis of each case is compared. The paper also consists of two different shoot through pulse generation techniques and an efficient control strategy is proposed to the single phase grid connected z-source inverter.

Index Terms: Photovoltaic (PV) cell, Z-source inverter, Boost Factor, Irradiance, Maximum Boost Z-source Inverter, Maximum Power Point Tracking (MPPT), Total Harmonic Distortion (THD)

I. INTRODUCTION

Grid-connected PV power system designs focus on converting as much irradiant power as possible into real power (current flowing into the grid in phase with the utility-defined voltage). The solar inverter is a critical component in a solar energy system. It performs the conversion of the variable DC output of the solar panel module(s) into a clean sinusoidal 50- or 60 Hz AC current that is then applied directly to the commercial electrical grid or to a local, off grid electrical network. The different families of power converters have been designed to interface the renewable resources for different applications. The traditional power electronic inverters are VSI and Current Source Inverter (CSI). In VSI two switches of the same leg can never be gated ON at same time because it causes a short circuit, which would destroy the inverter. The maximum output voltage is obtained by interfacing boost converter system with inverter system which leads to additional task to the controller circuits and this voltage can never exceed the bus voltage. These limitations can be overcome by the proposed maximum boost ZSI system.

Grid-connected PV power systems avoid the capital costs and roundtrip inefficiency of electric power storage in favor of dependence on conventional power sources as the backup power supply, because there are no incentives or regulations directing them to do otherwise.
Power electronic converter system plays an important role in the integration of photovoltaic (PV) sources into the load. Today, a distribution configuration of single-phase grid connected PV inverters with high efficiency, high reliability, and reasonable cost is possible [1]. A PV cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. The output dc voltage is converted into ac by inverters. The z-source inverter was introduced by F.Z.Peng. This Z-source inverter overcomes the difficulties of conventional voltage and current source inverters. It performs both buck and boost operation. It can be used for both voltage and current source inverter without changing the circuit design also improves the efficiency of the system because of power conversion stage in this circuit is reduced.

The boost operation of the inverter is achieved using the concept of shoot-through time period. This paper is organized as follows. Section I shows the introduction of proposed maximum boost ZSI. Modeling of photovoltaic array is addressed in Section II. Section III shows the analysis of maximum power point tracking Control scheme, MPPT and PCC control scheme is addressed in Section IV. In section V Simulation of solar panel is explained in detail. A complete review of simulation results of ZSI is presented in Section VI-IX. This paper also makes a study on voltage fluctuations due to PV generation which is explained in section X and finally, conclusion is presented in Section XI. The general block diagram of solar powered maximum boost ZSI system is shown in Fig. 1

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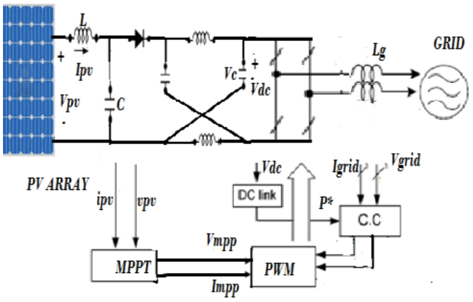

Fig 1: Block diagram of the PV- Z-Source inverter

II. MODELLING OF PHOTOVOLTAIC ARRAYS

Photovoltaic's is the direct conversion of light into electricity. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. Each individual solar energy cell produces only 1-2 watts. To increase power output, cells are combined in a weather-tight package called a solar module The basic equation from the theory of semiconductors that mathematically describes the I-V characteristics of the ideal photovoltaic cell.

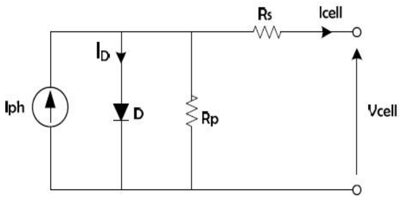

Fig2: PV Equivalent Circuit

$$I = I_{ph} - Ir\left[e^{\frac{q(V+IRs)}{akT}} - 1\right] - \frac{V + IR_s}{R_p}$$

Where, I_{ph} is the current generated by the incident light (it is directly proportional to the Sun irradiation), Ir is the reverse saturation or leakage current of the diode is the temperature of the p-n junction and '**a**' is the diode ideality constant,'q' is the electron charge [1.60217646 * 10−19C], 'k ' is the Boltzmann constant [1.3806503 *10−23J/K]. The equivalent circuit of a PV cell is as shown in Fig.. A single cell has a rated voltage of 0.51V and rated power of 0.3 W .In practical arrays, which are composed of several connected photovoltaic cells. If the array is composed of Np parallel connections of cells the photovoltaic and saturation currents may be expressed as

$$I_{pv} = (I_{pv,n} + K_I\Delta T)\frac{G}{Gn}$$

Where, $I_{pv,n}$ is the light-generated current at the nominal condition (usually 25°C and 1000W/m2), **T**= T − Tn (being T and Tn the actual and nominal temperatures [K]), **G**[W/m2] is the irradiation on the device surface and **Gn** is the nominal irradiation.

III.MPPT IN PHOTOVOLTAIC SYSTEMS

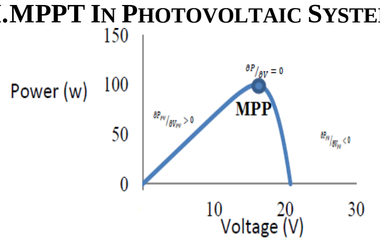

Fig 3. P-V Characteristic-Constant Irradiance

A typical solar panel converts only 28 to 40 percent of the incident solar irradiation in to electrical energy. In this Maximum power point tracking technique is used to improve the efficiency of the solar module. On the P–V characteristics, there is a point called MPP (maximum power point) which always occur on the knee of the curve, where the generated PV power is maximized as shown in Fig3. The choice of the algorithm depends on the time complexity and reliability, the algorithm takes to track the MPP, implementation cost and the ease of implementation. The commonly employed algorithms in PV maximum power point tracking systems are constant voltage, perturb and observe (P&O), open circuit voltage, short circuit current [2]-[5], and Incremental Conductance [6], [10] and [17]. In most of these algorithms, it is desired to optimize the power flow from the PV system to the load. When this is required, the operation point of the system must be maintained at the MPP. As the MPP depends on irradiation and temperature, these environmental conditions varies randomly, thus, the MPP position is constantly changed. In this paper perturb and observe (P&O) method is used to track the maximum power point voltage for the control of the Z-source inverter PWM switching.

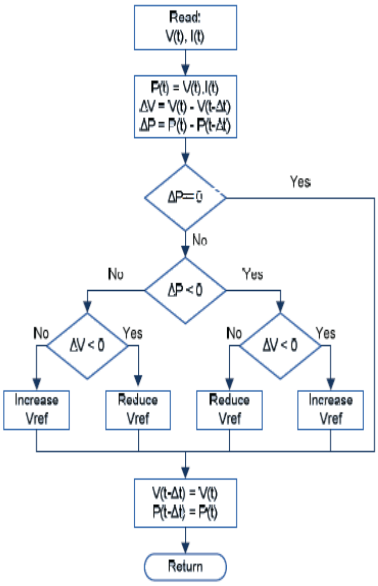

Fig 4 P&O algorithm flow chart

A. *SHOOT-THROUGH EFFECT ON THE PV SYSTEM*

During the shoot-through state, the input current of the ZSI is zero due to the blocking diode as shown in Fig. The output current of PV array should be continuous for MPPT control. Therefore, an LC filter network was inserted in front of the Z-source impedance network.

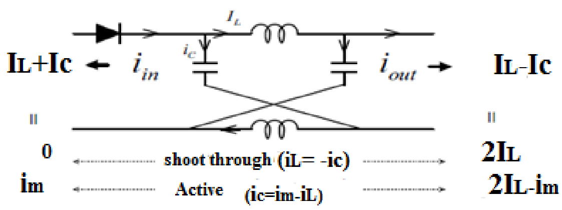

Fig 5. Current characteristic of impedance network

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The output voltage of ZSI is zero during the shoot through time interval, as shown in the Fig5,6. If the shoot through time interval is in the active state, the output voltage is affected. Thus the shoot-through time interval should be located within the zero state in order not to affect the output voltage.

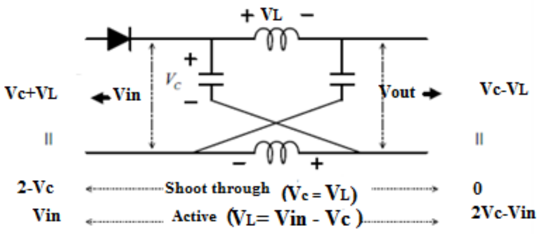

Fig 6. Voltage Characteristic of impedance network

IV. MPPT AND PCC CURRENT CONTROL

In this paper, the shoot-through state is adjusted by controlling the MPPT voltage, using MPPT algorithm the system continuously tracks the maximum power point voltage from the input Ipv and Vpv and the PCC current is controlled by Constant-Voltage regulation. The Constant voltage of capacitor in the impedance network is measured continuously and these voltages Vp and Vn are used to adjust the shoot through pulses of the impedance source converter.

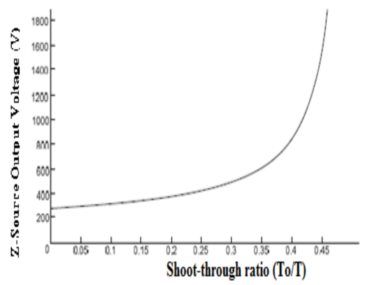

Fig.7. The boosted voltage by shoot-through time of the ZSI

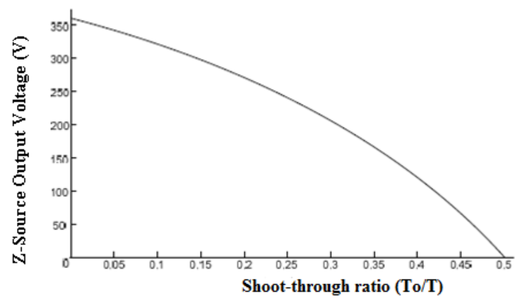

Fig.8. The reduced input voltage of PV-array by shoot-through time of the ZSI

Because the input of the ZSI is connected to the output of the PV array, the operating point can be controlled by adjusting the shoot-through time interval.

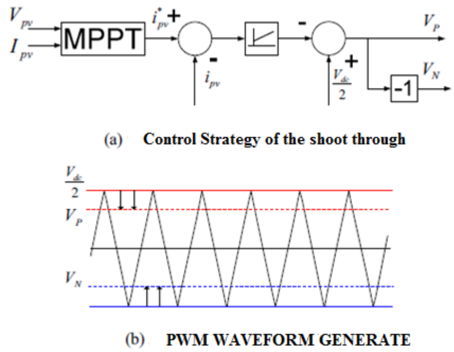

Fig 9. MPPT control by shoot-through reference

If the current reference is larger than the real current, the shoot pulse goes down. So the shoot-through time increases. This causes the increase in the PV array current (Ipv) because of the decrease in the PV array voltage(Vpv). Therefore, the shoot-through time interval can be adjusted by the P&O method with sensing the PV array output current and voltage. The shoot Pulses so obtained is combined with the sinusoidal pwm pulses from the PLL control method.

1) PCC current control

The capacitor voltage *Vc* of the impedance network is equal to the average value of the input voltage of the inverter, the capacitor voltage is used for voltage control. If the *Vc* is higher than the reference voltage, the reference value of the active power increases resulting in lowering the capacitor voltage. The output current of inverter increases and the capacitor voltage decreases. Consequently, the capacitor voltage is controlled constant.

V. SIMULATION OF SOLAR PV MODULE

The SIMULINK model of the solar panel is shown in Fig.10. This model generates the output voltage of 28V and output current of 5A at the irradiance of 1000W/m2 and at the panel temperature of 25°C.

PV-CELL MODEL

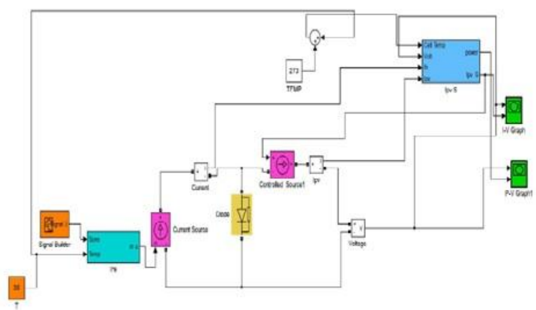

Fig 10. SIMULINK model of the PV module.

At 25°C of panel temperature, for different irradiance conditions the output voltage and current are shown in the Fig11 The Characteristics are obtained by the modelling of the solar panel using SIMULINK. The maximum voltage and current is obtained when irradiance value reaches 1000W/m2.

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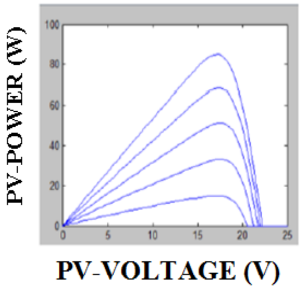
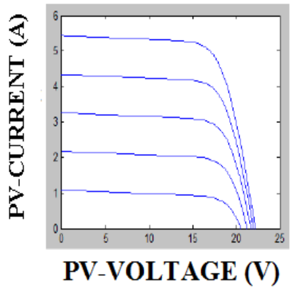


Fig 11(a) P-V characteristics of Solar Panel



(b) I-V characteristics of Solar Panel

The Fig11 (a) shows the maximum power rating of solar panel. The following characteristic performance shows the solar power induced in the solar panel for various time periods. Fig.11(b) shows the V-I characteristics of solar panel. For various solar irradiance the following characteristics is obtained. Maximum panel current is obtained at the irradiance of 1000W/m2

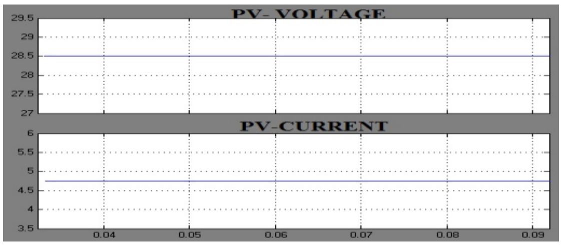


Fig 12. PV voltage and current

VI. SIMULATION OF MPPT ALGORITHM

The SIMULINK model of the MPPT P&O algorithm is shown in figure 13. It is used to detect the maximum power point voltage. Then Vmp is so adjusted to control the shoot through pulses of the Z-Source inverter.

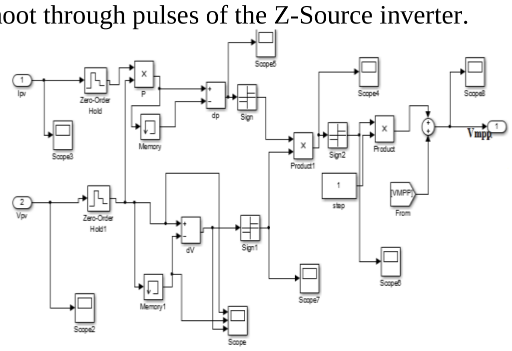


Fig 13 MPPT Tracker SIMULINK model

VII. SIMULATION OF Z-SOURCE INVERTER

The MPPT and PCC control strategy along with grid connected pwm control strategy is used to generate gate pulses for the single phase PV Z-Source inverter. The combined PWM and switching states are shown in the following fig 14

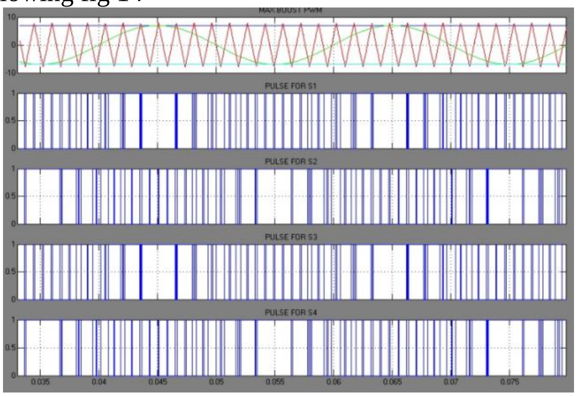


Fig14.PWM & Switching states of single phase Z-Source inverter

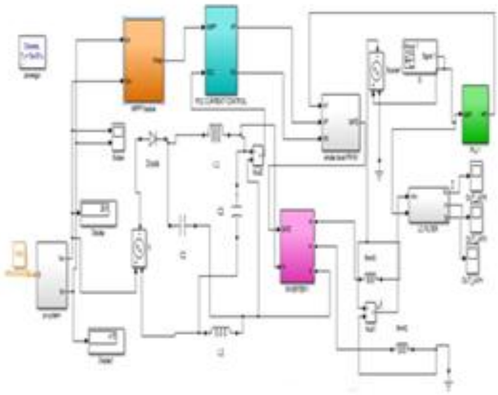


Fig15.Over all simulation of single phase Z-Source inverter

VIII. MAXIMUM BOOST CONTROL

The fig.16 shows the block diagram of the maximum boost control (MBC) technique. In Maximum boost control, the reference signal is controlled by the MPPT and PCC control and is compared with the triangular carrier signal for generating the shoot through pulses (with equal or greater than the peak of triangular signal). To obtain switching pulses, sinusoidal signals after synchronsing with single phase grid and PLL control having modulation index (M) are compared with the same triangular signal [5]. These two signals compared by using comparator. By using logic gate, the shoots through pulses are inserted into the switching waveform. These pulses are given to the power IGBT through isolation and gate drive circuit.

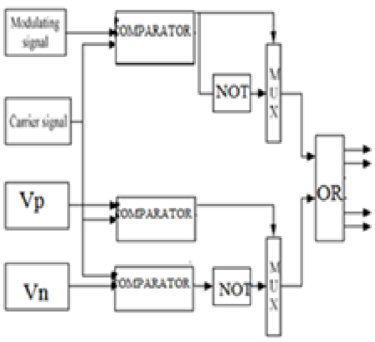


Fig 16 Block diagram of Switching Pulse Generation

The grid voltage without fluctuation is shown in the following fig.17(a) and the corresponding inverter current after LC filter is also shown in the fig17(b) .The inverter current is selected and THD analysis is carried out .The maximum boost control offers less voltage stress compared to other PWM topologies of Z- source inverter.

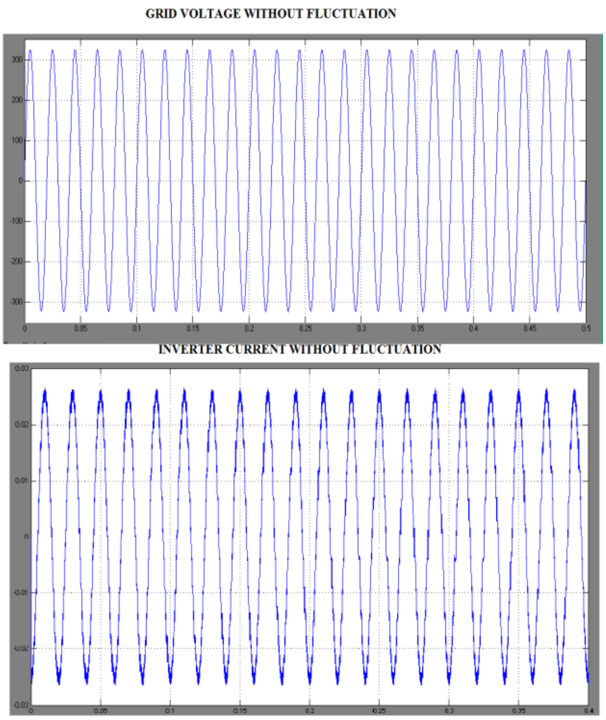


Fig 17 Grid Voltage and Inverter Current without Fluctuation

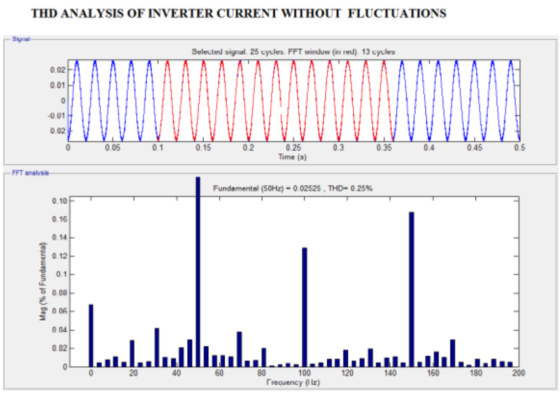
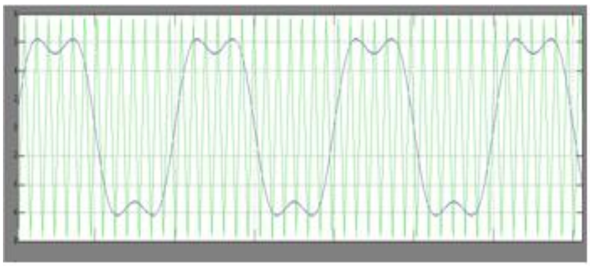


Fig 18 THD analysis of inverter current without fluctuation

Reducing the voltage stress under a desired voltage gain becomes more important to control the ZSI. The maximum boost control, [7] turns all traditional zero states into shoot-through state. In this paper Third harmonic injection method is also simulated to extend the modulation index range, as shown in Fig .Indeed, turning all zero states into shoot-through states can minimize the voltage stress of the z-source inverter. However, this method introduces a low frequency current ripple that is associated with the output frequency in the inductor current and the capacitor voltage. This will cause a higher requirement of the passive components when the output frequency becomes very low. The THD analysis of third harmonic injection method is also carried out as shown in fig.19 .The maximum boost control is suitable for applications that have a fixed or relatively high output frequency.



(a)

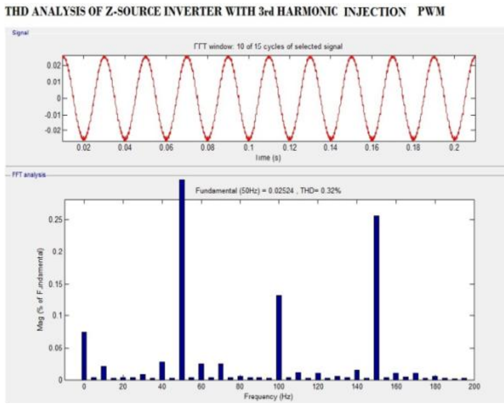


Fig 19(a) Third harmonic PWM (b)THD Analysis

IX. POWER QUALITY ANALYSIS OF THE Z-SOURCE INVERTER

Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes. IEC 61000-2-1 defines various types of voltage fluctuations. *Power frequency variations* are defined as the deviation of the power system fundamental frequency from it specified nominal value (e.g., 50or 60 Hz).Power frequency disturbances can last anywhere from one complete cycle to several seconds or even Minutes. One of the most common power frequency disturbances is voltage sag .It is a decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0,5 cycle to 1 minute. A *swell* is defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.As with sags, swells are usually associated with system fault conditions,but they are not as common as voltage sags.In this power quality analysis the grid voltage is supplied with signal builder block and using that voltage sag and swell case are drawn and by simulating the corresponding sag and swell effects in the inverter output current is verified and THD analysis of both the cases are carried out.

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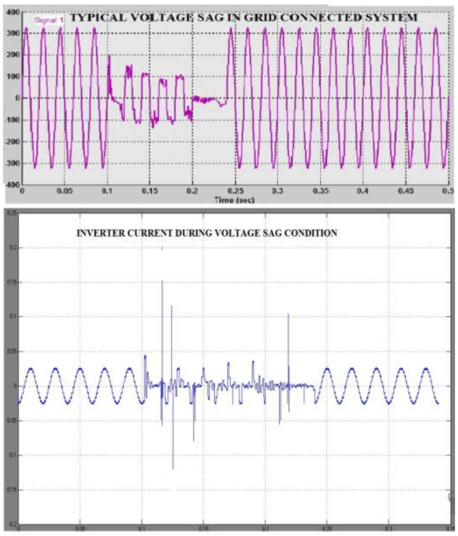


(a) & (b)

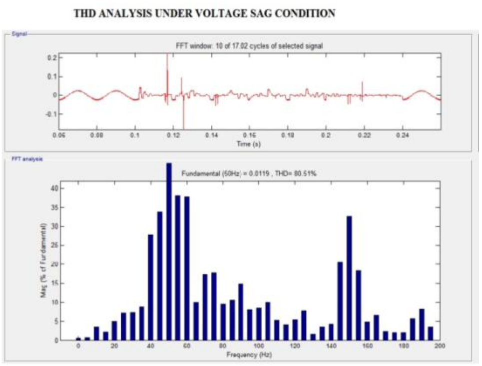
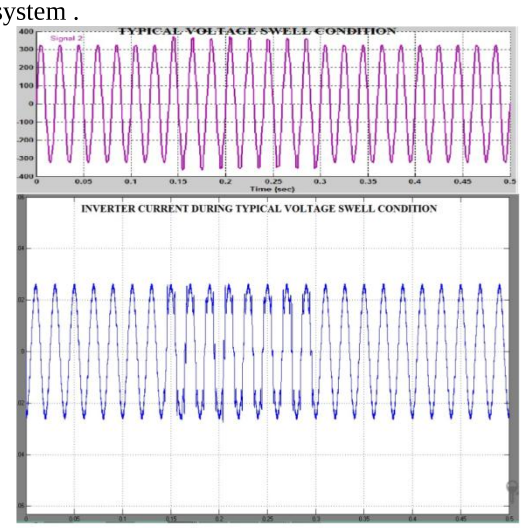


Fig 20(a) Voltage sag case grid voltage (b) inverter current (c)THD analysis of voltage sag case inverter current

The PV system suffers from nonlinear behaviour, such as faults and transients of a power system, which does not occur with a generic inverter, and this may cause the output of the PV system to become unstable. Therefore this paper analyzes the operation of the Z-Source inverter during the common power disturbances like sag and swell. It also makes a correlation between the frequency protection requirements and the stability of grid connected PV system .



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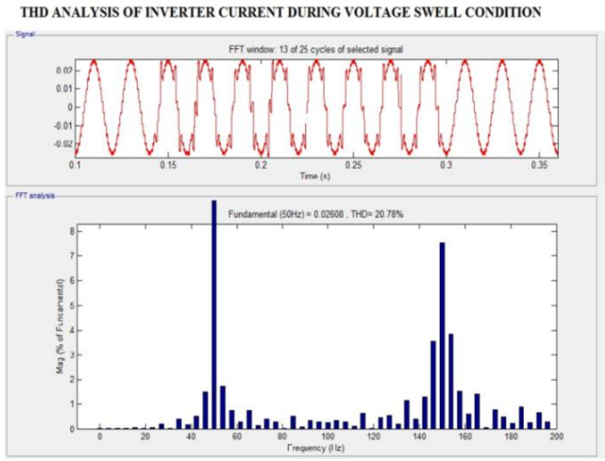

Fig 21 (a) Voltage swell case grid voltage (b) inverter current (c)THD analysis of voltage swell case inverter current

X. MITIGATING VOLTAGE FLUCTUATION DUE TO PV GENERATION

The penetration of a large amount of PV generation in to the power system could cause large voltage fluctuations when the irradiance incident on the PV is not constant. Also in most of the inverters used for PV generation are designed to operate at unity power factor.Reactivepower is neither absorbed nor produced. If PV generation is implemented on a large scale, there is a need to make better use of the PV plant to help in voltage control. we can use three voltage control technique that could help us to overcome this voltage problems caused by the penetration of PV

Generation. The techniques are, constant power factor control, automatic voltage control from the PV inverter itself and Static VAr Compensator (SVC) voltage control. By properly controlling the voltage fluctuations we can solve the PV penetration issues in the Renewable energy system. The THD analysis results are shown below.

SL No	THD ANALYSIS OF Z-SOURCE INVERTER	
	Inverter current	THD(%)
1.	Without fluctuations in grid voltage with Max Boost Control	0.25
2.	Without fluctuations in grid voltage with third harmonic injection pwm Control.	0.32
3.	During voltage sag condition	80.25
4.	During Voltage swell condition	20.70

Table 1. THD analysis of Z-Source inverter

XI. CONCLUSION

The power conversion circuit of the grid-connected PV system using a ZSI was analysed in this section. The MPPT control and PCC current control of the ZSI were suggested and its feasibility is verified through the simulation using MATLAB. The proposed system can deliver the PV power to the grid with single stage, the cost to manufacture is reduced and the efficiency is

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increased.THD level and voltage stress is reduced for maximum boost pwm control technique compared to third harmonic injection method .The power disturbances and its mitigating methods are proposed by using AVR or SVC topologies connected to the PV grid connected Z-Source inverter.

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BIOGRAPHIES

Kannan S A was born in Kerala, India in 1990. He has graduated in B-Tech in Electrical & Electronics Engineering from Kerala University during 2012. He is currently pursuing his Masters degree in Power electronics from Cochin University of science and technology, Kerala. His area of interest includes power electronics, electrical drives and control systems.

Rakesh. R was born in Kerala, India in 1991. He obtained his bachelor degree from Kerala University, Trivandrum. He is currently pursuing his Masters degree in Power electronics from Cochin University of science and technology, Kerala. His area of interest includes power electronics, electrical drives and control system.

Smt. Kamala Devi V. has graduated in B-Tech in Electrical & Electronics Engineering from Kerala University during 1992. She was ranked third in the university during the year. She did M-tech in Control Systems from Kerala University during 2003. At present she is working as Scientist in Solar division of Agency for Non-conventional Energy and Rural Technology (ANERT), Trivandrum, Kerala, India.

Prof.(Dr.).M.Jayaraju, Ph.D,FIE,FIV,MIEEE,FISLE,MISTE, (Chartered Engineer, Energy) is a Consultant, approved Valuer,approved Research Guide. Being former Professor of Dept. of EEE, TKM College of Engg, Kollam, Kerala, India, he has served as Principal of MES Institute of Technology & Management, Chathnnoor, Kollam - 691572, Kerala, India. He is at present serving as Director of Agency for Non-conventional Energy and Rural Technology (ANERT), Trivandrum, Kerala, India.