Grid Integration of PV System using Thyristor based Single Phase Inverter

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Abstract-In any grid tied solar PV based system, inverter is a critical component responsible for the control of electricity flow between dc source, and loads or grid. This paper presents a solar PV generation system integrated to grid. The proposed model used to mitigate the power quality issues in grid tied inverter which is simulated using MATLAB/SIMULINK in power system block set. A solar PV based grid tied inverters are used for dc-ac conversion. The conventional dc-ac inverters have square shaped line current which contain higher order harmonics. The proposed control strategy of inverter reduces total harmonic distortions in line current significantly.

Index Terms— Grid Tie Inverter, Total Harmonic Distortion, Line current, Simulink, ac-to-dc converters, Harmonic current, Renewable energy, Total Harmonic Distortion (THD)n.

1. Introduction

IN recent years the power demand is increasing regularly and it can be fulfilled by the use of conventional or non-conventional energy power plants. The benefits of power generation from these sources are widely accepted. They are essentially inexhaustible and environmentally friendly. Among the different renewable-energy sources, solar energy has been one of the most active research areas in the past decades, both for grid-connected and stand-alone applications [1]. The exponential rate of growth in the worldwide cumulative PV capacity is mainly due to enhancement in grid-connected inverter topologies. The solar photovoltaic (PV) array and the battery are connected to the AC grid via a common DC/AC inverter. AC output voltage is generated by switching the full bridge. Normally pulse-width modulation (PWM) technique is used. However, for a grid tied inverter synchronization of the incoming generated voltage to the grid is a big issue. The inverter topologies can be divided with two types that are single and multi-stage inverter. The single-stage inverter has advantage such as low cost, high efficiency, robust performance, high reliability and simple structure. Thus, renewable energy sources like PV panels are used today in many applications. Solar PV based systems are being seen as a major contributor to the present power generation technology. One of the important applications of the solar PV based power generation is to feed the generated power (dc) into grid (ac). For this purpose, normally, PWM inverters are used which use gate commutated devices (IGBT, MOSFET, GTO etc.). However, apart from higher switching losses, the power handling capability and reliability of these devices are quite low in comparison to thyristors/SCR [2]. Moreover, the conventional line commutated acto-dc inverters have square-shaped line current which contains higher-order harmonics. The line current with the high harmonic contents generates EMI and moreover it causes more heating of the core of distribution power transformers. It has become imperative to develop an efficient grid interfacing instrumentation suitable for PV systems. Therefore, A conventional thyristor based ac-to-dc converter is used, with a dc source and an inductor or highly inductive load, operates in the inversion mode with specific condition. The performance of the converter depends upon the switching angle, dc voltage and impedance angle. The instantaneous value of voltage may be positive or negative but the average value of output voltage will be only negative for RLE load. However, the converter may operate in fourth quadrant of voltagecurrent plane and power become negative. The load current may be discontinuous, just continuous (or sinusoidal) or continuous. Which depends upon switching angle and impedance angle of RL loads [3]. Thus to transfer power from solar PV module or battery

(dc) to (ac) grid a midpoint converter circuit is used. The performance of the proposed circuit is simulated using MATLAB/SIMULINK power system block set.To reduce the THD in the line current and for optimum power transfer to the grid.

2. GRID-TIED SYSTEM CIRCUIT

A full wave center-tapped controlled converter circuit with RLE load works as inverter mode when the switching angle of each of the converter is greater than 90˚ and RLE negative load.

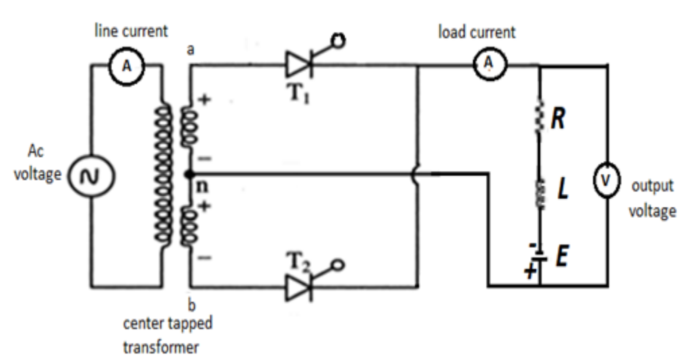

Fig.1 Single phase full wave center-tapped converter circuit

When the circuit works in inversion mode the dc source transfer power to the ac source[4]. Ideally, there should be a lossless inductor but practical inductor are not lossless. Therefore, a series resistance is also incorporated in the circuit. The dc load side has been isolated from the grid via center-point transformer.

2.1 Full wave midpoint ac-to-dc converter as inverter

For The phase controlled ac-to-dc converter employing thyristors is extensively used for changing ac input voltage to controlled dc voltage. However, due to an RL load, the instantaneous value of voltage may be positive or negative but the average value of the output voltage is positive for RL load. However, for an active RLE load, the converter operates in fourth quadrant of voltage-current plane and voltage become negative as shown in Fig.2. However the load current (idc) may be discontinuous, just continuous or continuous. It depends on switching angle and impedance angle of RL load [5], [8]. The equation of line current (iac) is given in general as:

$$i_{ac} = \frac{\sqrt{2}.v_{ac}}{z}\left[\sin(\omega t-\varphi)-\sin(\alpha-\varphi).exp\left(\frac{\alpha-\omega t}{\tan(\varphi)}\right)\right] \quad (1)$$

$$-\frac{E}{R}\left\{1-exp\left(\frac{\alpha-\omega t}{\tan(\varphi)}\right)\right\}$$

Where:

Vac= Voltage on secondary side of center tapped transformer

α= Firing angle

ϕ= Impedance angle on DC side, and
α <wt< β

2.2 Analysis of conventional ac-dc converter with RLE (-) load

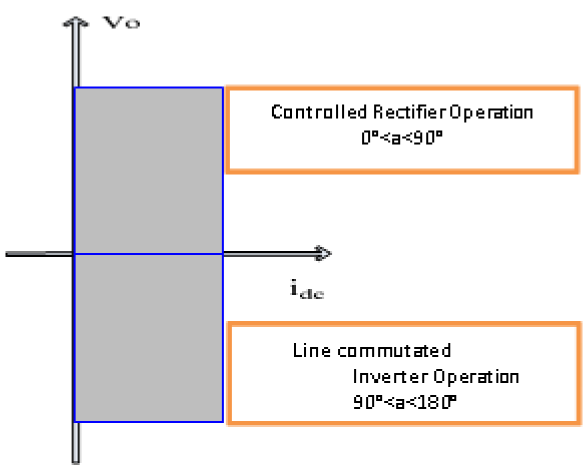

Fig.2 Modes of operation in V-I plane

Greater than 90°, it consists of one inductor and dc source at the load side.

In the positive half cycle of grid voltage, thyristor T1 is triggered at an angle 'α'. During negative half cycle thyristor T2 is triggered at an angle '180+α'.

This converter acts as a line commutated inverter with discontinuous; continuous and just continuous load current as shown in Figure below.
In discontinuous conduction mode Fig.3 line current is discontinuous and THD of the line current is high.

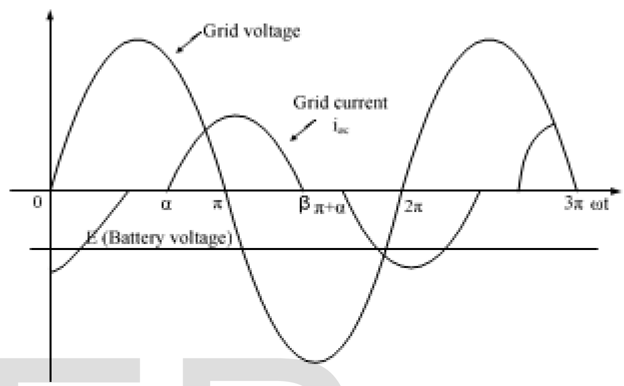

Fig.3 Discontinuous conduction mode

In continuous conduction mode line current is continuous having square shaped waveform as shown in Fig.4 having [48.84%] THD. Power transferred to grid is highest in this case.

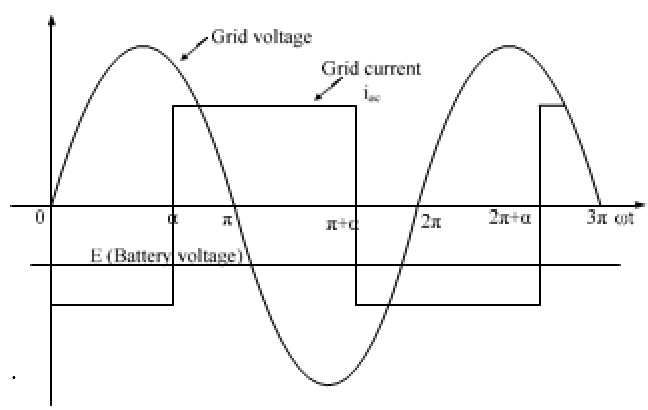

Fig.4 Continuous conduction mode

In just continuous conduction mode line current is made just continuous by firing the thyristor as soon as the other thyristor stops conducting as shown in Fig.5 In this case THD in line current is quite low [5], [6].

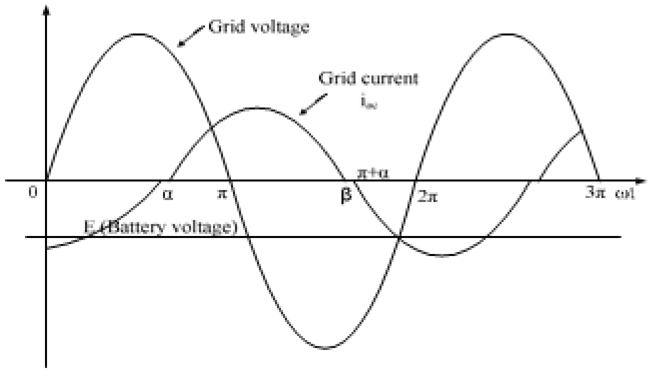

Fig .5 Just continuous conduction mode

3. SIMULATION OF CIRCUIT IN MATLAB/SIMULINK

A MATLAB/Simulink model has been simulated to simulate the working of the line commutated inverter. The model can be used to calculate instantaneous load current, THD of the waveform, various harmonic present as well as the power output. The simulation also enables to determine whether the inverter is operating in continuous conduction mode or discontinuous conduction mode. The single phase grid tied inverter has been simulated in simulink package available in MATLAB. The simulink model is shown in the Figure.6. The trigger pulses given from the pulse generator block of simulink library block set. The pulses to both the thyristors of centre-tapped windings are given at a phase difference of 180. Resister is included in series of the inductor to simulate a real inductance. The value of inductor is 84 uH. The series resistor is 0.001 ohm. The centre tapped winding transformer ratio is 230V:: 18V:0V:18V. The simulation work is basically done to study the variation of THD of the line current and average power transferred to the grid with the triggering angles [7].

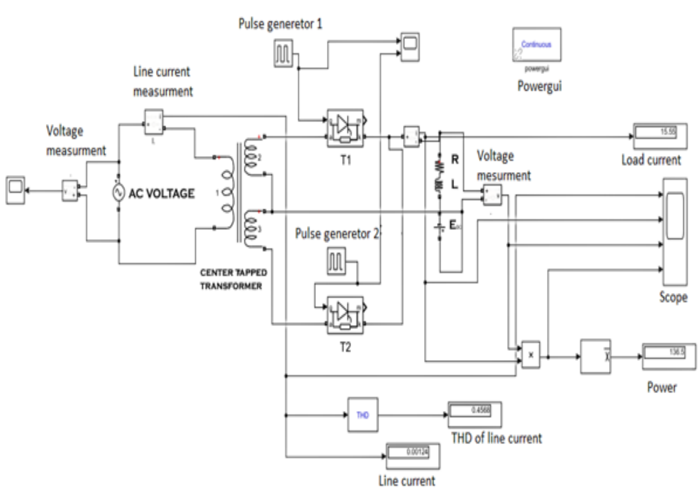

Fig.6 Simulink circuit of a grid tied inverter

4. SIMULATION OBSERVATION

The effect of variation of dc voltage on the THD and the power transfer is also analyzed. Though a battery has been considered as a dc source for simulation, the result obtained can be utilized when using solar PV panel. Since the dc voltage of a solar PV panel is not constant (vary with insolation, temperature and load), the effect of varying dc voltage on THD and power flow will help in developing a control strategy for operating the system in optimum condition i.e. changing the switching angle at different voltage level of PV panel[7].

From the analysis of the Simulink model for grid tied line commutated inverter, the waveforms of low THD line current, load voltage, power output and load current is shown in Fig. 7, Fig.9 and Fig.11 for 10 voltage battery. THD is measured through powergui FFT analysis tool of Simulink block and shown in Fig.8, Fig.10 and Fig.12.

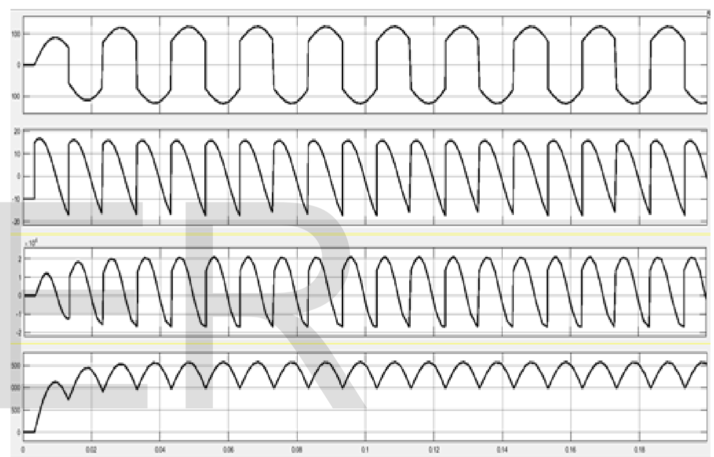

Figure.7 waveform of line current, voltage across RLE (-) load, power and load current respectively for switching angle 60 degree

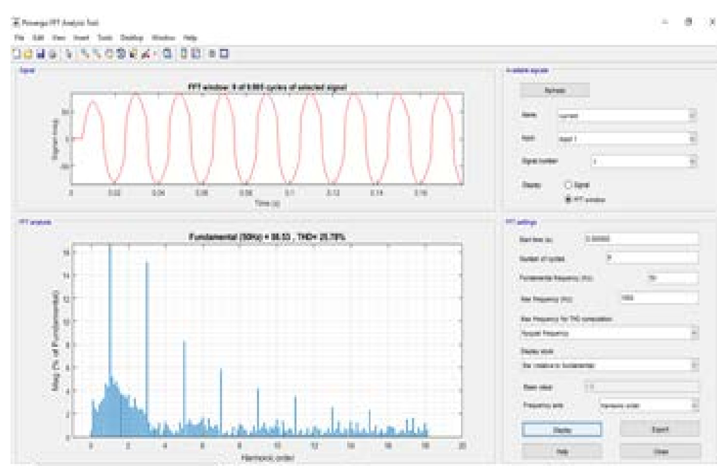

Figure.8 Harmonics analysis of line current on MATLAB/Simulink in experimental setup for swiching angle 60 degree

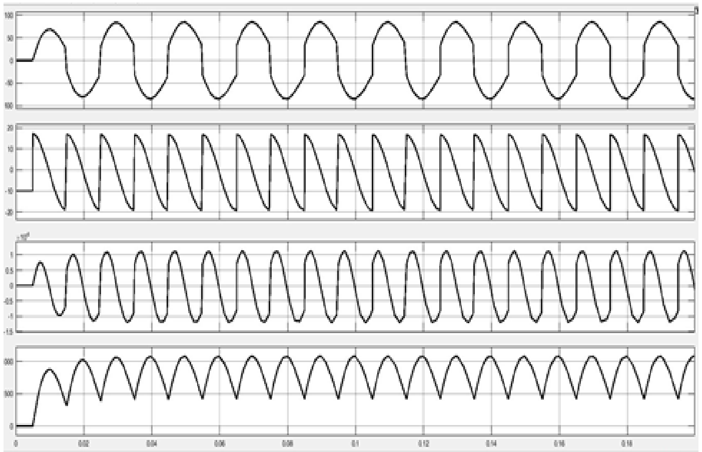

Figure.9 waveform of line current, voltage across RLE (-) load, power and load current respectively for switching angle 90 degree

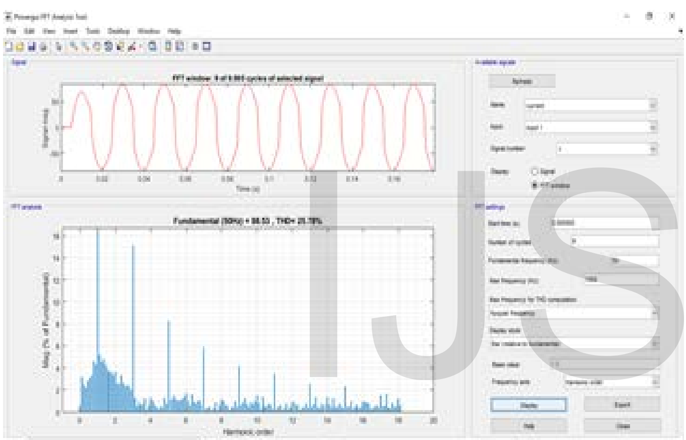

Figure.10 Harmonics analysis of line current on MAT-LAB/Simulink in experimental setup for switching angle 120 degree

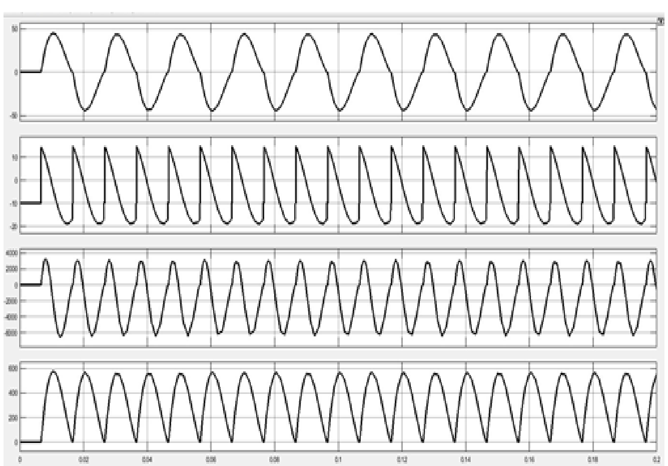

Figure.11 waveform of line current , voltage across RLE (-) load, power and load current respectively for switching angle 120 degree

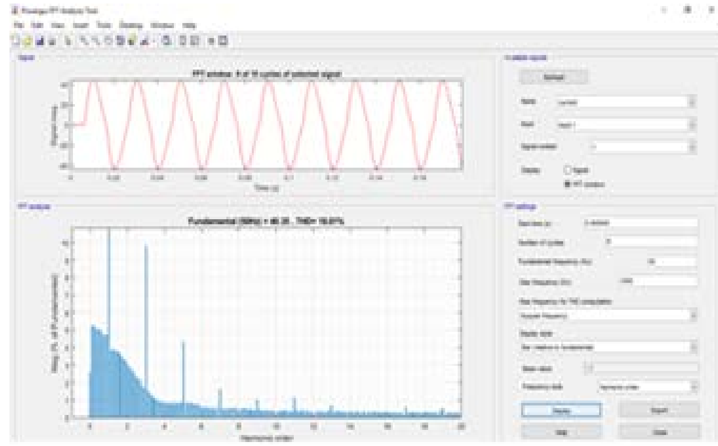

Figure.12 Harmonics analysis of line current on MAT-LAB/Simulink in experimental setup for switching angle 120 degree

S. No	Angle	Power in(watt)	Voltage across load (Volt)	Load current (amp)	THD of line Current in (%)
1	35	18.6k	-2.538	1738	39.03
2	60	5217	-2.310	1510	33.77
3	70	2116	-2.183	1383	31.70
4	90	-926.4	-1.874	1074	25.73
5	100	-1833	-1.699	899.2	21.85
6	110	-2107	-1.517	717.3	18.37
7	120	-189.7	-1.358	551.5	18.01

Table.1 Power transfer, Voltage across load, Load current and THD of line Current with different switching angle combinations

5. RESULTS

For the MATLAB/simulink model of grid tied inverter, the variation of THD and power with different dc voltage source and firing angle are studied and it is observed that the lower THD and better power transfer for battery voltage 10V and resistor R=0.01Ohm, inductor L=84uH and firing angle 120degree. The power is -189.7 watt and THD is 18.01% (low)

6. CONCLUSION

Centre tapped converter circuit which works as inverter for single phase grid tied system has successfully been implemented in simulation. A thorough study has been made to obtain optimal performance with battery as dc source and can be extended for solar PV modules. With reduced THD, it will to be a better re-placement for square wave inverter in various distributed system connected to the grid.

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