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DC offset Cancellation &Harmonic Reduction in PV Inverter

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Abstract— **Renewable sources are connecting to utility grid due to the depletion of conventional energy sources. The energy from solar power attaining more popularity among such renewable sources. Here a solar powered flyback boost converter based inverter is considered. Lot of conversion stages are there in between this DC power to utility grid AC power. They injects harmonics due to various factors to the grid. A new controller called PRI(Proportional Resonant Integral)controller is proposed for harmonic reduction. They in turn reduces the DC component in inverter output. Simulation was done in MATLAB/Simulink and the results are presented.**

Index Terms— PV Array, Flyback boost Converter, Single Phase Inverter , LC Filter , Step Up Transformer.

I. INTRODUCTION

As the global power demand is increasing and availability of power from the conventional sources is decreasing, more focus is to be given to renewable sources. The power from the PV is more attracted due to its clean mode of generation, no rotating mechanisms& less losses etc. But compared to traditional energy sources, not many PV systems have been incorporated in grid connection because of its high installation cost .Now a downward tendency on the cost of PV modules is a motivation for the massive production of PV based single phase or three phase inverters .Focus has therefore been given
to inverter solutions with cheap & innovative techniques [1]. A single phase PV powered inverter with flyback boost converter as dc-dc converter is presented. Usually a single PV cell generates very low power. So such cells arranged in series to produce maximum power output [2] . Dc-dc converters are used to reduce the no. of cells, which will generally boost up's the output from the PV array and hence the no of PV cells required at beginning can be reduced, thus initial cost can be saved. The topology of the solar system is simple. It consist of following three stages.

1. A flyback boost converter stage to perform boosting of PV array voltage.
2. Low voltage single phase H-Bridge Inverter.
3. An L-C Filter arrangement and step up transformer to interface with the load.

The advantages of this system are low voltage rated switches which reduces the overall cost and increases reliability. The best suitability for this type of inverters is coming for rating less than a kilowatt. But topologies with high frequency link transformers are much better than these types with bulky interface transformers [3]. Some applications other than dc lighting loads & dc motors requires converters to process the PV generated power [4]. Also the voltage and current may regulated by these converters. However a dc-dc boost converter is necessary to produce a regulated dc output voltage. A voltage source inverter, interfacing the PV module can provide an ac output voltage. But power quality issues generates at the inverter side due to the generation of harmonics which originates from high dv/dt and di/dt semiconductor switching transients , inverter dead time etc. Passive filter's are used to remove harmonics, even though it exhibits drawbacks such as tuning problems, series and parallel resonance etc.

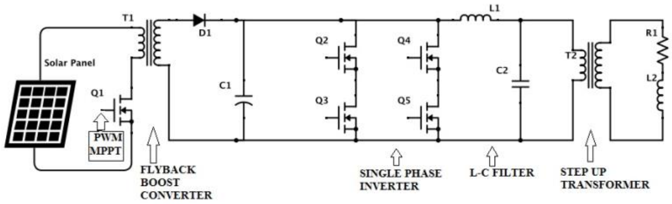

Fig 1: Power circuit topology

Usually the converter-inverter sections used in PV inverter are rich sources for the production of harmonics in the system. Also fast varying power from the MPPT block used in input section will produces DC offsets in inverter output which contributes for lower order harmonic generation, directly affects the power quality. For the system with R-L load, amount of current injected is much distorted than the voltage, so proper current compensation is given to the system to produce output with fewer harmonic so that the load side get protected from the severity of harmonics. New power quality standards for distributed generation impose very stringent limits for the current harmonics. Typically PI controllers are used to control the current of grid connected converters. But such controllers fails in removing the stationary error in stationary frame controllers for single-phase systems ,fails to remove the low current harmonics due to the bandwidth limitation. This drawbacks can be overcome by use of a controller with second order generalized integrator (GI), named as PR(Proportional Resonant) controller. Generalized integrator achieves infinite gain at certain frequency called as resonant frequency, and almost no attenuation exists outside this frequency. Thus, it can be used as a notch filter in order to compensate the harmonics in a very selective way. Also the integral controller added additionally compensates the Dc components in the inverter output.

II. FLYBACK CONVERTER BASED PV INVERTER

In this section an inverter powered from solar energy with flyback boost converter is described. Each section is designed for a maximum power rating of 100W.

A. PV Array

The basic equations used for the design of PV array are derived from the theory of semiconductors. PV module exhibits non linear characteristics. Hence it is necessary to model with MPPT for PV power applications. The equations are ,

$$I = I_{pv} - I_d \tag{1}$$

But for a practical PV cell the equation 1 is modified in terms of R_s& R_P

$$I = I_{pv}-I_o[\exp(V+ R_sI/V_ta)-1]-V+ R_sI/ R_P \quad (2)$$

The light generated current I_{pv} of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the equation

$$I_{pv}= (I_{pv.n}+K_I\beta_T)G/G_n \quad (3)$$

The diode saturation current I_d is given as

$$I_d = (I_{sc,n}+ K_I\beta_T)/(\exp(V_{oc.n}+ K_v\beta_T)-1) \quad (4)$$

Table I

PV Array designed parameters

Parameter	Value
V_{pv}	17.34V
I_{pv}	5.76A
p_{pv}	100W
N_s	29
N_p	1

The table above shows the output from the PV array. From the PV array the voltage obtained is around 17.34 V . This voltage is held to be constant with the help of MPP tracker. Here a simple MPP tracker called P&O MPPT is used. The implementation complexity & cost is less with this tracking technique. A subsystem model for a practical PV cell is shown below. The following figure shows the PV array output with MPPT.

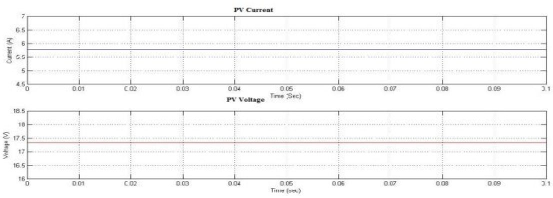

Fig 2: PV Array Output

From the PV array & MPP tracker an output of 17.34V is obtained.

B. Flyback Boost converter

Here output from the PV source is less, hence a dc-dc boost converter is needed. A flyback boost converter is proposed since it mainly creates an isolation between input and output side by the use of transformer called as flyback transformer as shown in fig 1.Also it produces less distortion in inverter output than normal boost converter. Flyback converter in turn reduces the distortion provided by PV source.

The design parameters for the flyback converter includes

1. Duty ratio (D) of converter switch
2. Primary inductance (*Lp*) of flyback transformer etc.

1. Duty ratio (D)

The equation used to calculate duty ratio(D) is

$$V_{out}/V_{in}= N\times(D/(1-D)) \quad (5)$$

Here an output of 40V is desired from the flyback boost converter, hence V_{out} =40V & input voltage is the output from the PV array,also the turns ratio N selected is 1.

Thus equation(5)becomes

D=0.70 or 70%

2. Primary inductance (*Lp*) of flyback transformer

It is one of the main parameter for the design of flyback transformer, the equation given as

$$Lp = (V_{in.min}\times D_{max})/(Ip\times f_{sw}) \quad (6)$$

Where f_{sw}= device switching frequency

On substitution we get Lp = 1.955×10^{-5}H

Table II

Designed parameters of flyback converter

Parameter	Value
V_{in}	17.34V
V_{out}	40V
Duty Cycle (D)	0.70
I_{out}	2.5A
Primary inductance (L_p)	1.955×10^{-5}H
Switching frequency (f_{sw})	40kHz

Figure below shows the output from the dc–dc flyback converter with input as 17.34 V boosted to 40V.

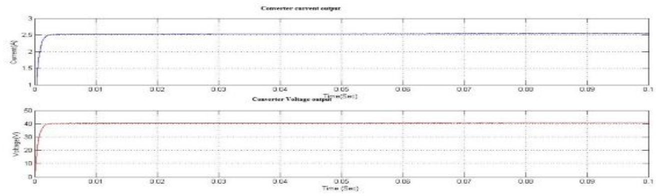

Fig 3: Flyback Converter output

C. Single Phase Inverter

The single phase H-bridge inverter is used to generate a single phase AC supply from a DC input through a set of controllable switches. The switches are controlled by Pulse width modulation technique. Fast switching of semiconductor switches with high frequency noise generation is achieved with PWM inverter.

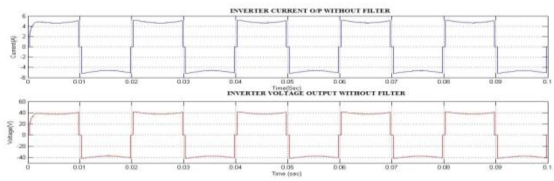

Fig 4: Single phase inverter output without filter

The above inverter output is not sufficient to feed a single phase load since it is not sinusoidal in nature. So proper filter arrangement is needed.

D. L-C Filter

L-C Filter stands for Inductor-Capacitor filter which is a second order filter. It consists of an inductor (L) connected in parallel with a capacitor (C).It is also called as resonant circuit ,tank circuit or tuned circuit.LC circuits are used either for generating signals at a particular frequency, or picking out a signal at a particular frequency from a more complex signal.

Design of L-C filter includes the both the design of inductor (L) & capacitor (C) . Following equations are used to for the design.

$$\text{Inductor (L)} = (1/8)\times(V_{in}/(\delta_r \times f_{sw})) \qquad (7)$$

Where δ_r = ripple current which is assumed to be 5% of inverter current output.

$$\text{Capacitor (C)} = (\alpha\times P) / (2\pi f \times V^2) \qquad (8)$$

Where α = reactive power factor , its value lies in the range of 1- 5 %. The resonant frequency of the filter is calculated from the equation

$$\text{Resonant frequency } (f_r) = 1/(2\pi\times\sqrt{(LC)}) \qquad (9)$$

The resonant frequency of the LC filter is kept below the switching frequency of the inverter switches. High frequency harmonics are better attenuated at a lower resonant frequency. The table below shows the values of filter.

Table III
Designed Values of L-C filter

Parameter	Value
Inductor (L)	5.007×10^{-4} H
Capacitor (C)	3.98µF
Switching Frequency (f_{sw})	40kHz
Resonant frequency (f_r)	3.565kHz

When L-C filter is included to inverter side, lower order harmonics can be reduced to minimum level and it is shown in the table below. The output from the LC filter is also shown below.

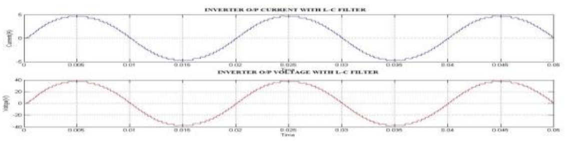

Fig 5: Inverter output with L-C filter

E. Step up transformer

Step up transformers are static devices which are used to step up the bus voltage to a required level. Here the system is connecting to a single phase grid. THD analysis on inverter without filter indicates the presence of harmonics which is injected to the system. The table below shows result of THD analysis with & without L-C filter.

Table III
THD Result With & without Filter

Parameter	Without L-C Filter	With L-C filter
DC component in current	0.001232	0.01091
DC component in voltage	0.009845	3.86
THD	45.50 %	5.98 %
3rd harmonic	35.30%	5.72%
5th harmonic	19.85%	0.40%
7th harmonic	12.83%	0.06%

The above result indicates that the presence of filter reduces the harmonic content, but it increases the dc component present in the output .. Also the harmonic content is not acceptable by power quality standards. So proper compensation is needed at the inverter side for control of DC offsets & harmonics.

III. Closed Loop System With PRI Controller

A. PRI CONTROLLER

PRI controller stands for Proportional Resonant Integral controller, in which it is derived from conventional PI & PR controller's. PR (Proportional Resonant) controller is arrived with a second order generalized integrator (GI), which overcomes the drawbacks of conventional PI controller. Also PR controller is well known for reducing the low current harmonics, which does not performed by PI controller. Now PRI controller comes with an additional feature of reducing the DC offset present in the inverter output. The block diagram depicting PRI controller with inverter is shown below.

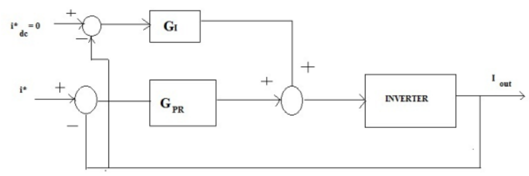

Fig 6:Block diagram for PRI controller with inverter

The transfer function of PRI controller is as follows.

$$G_{PRI}(s) = [(K_p + K_r(S)) / (S^2+\omega^2)]+ K_I/S \qquad (15)$$

B. Simulation Result

The PRI controller generates a PWM pulse by the use of PWM generator. The pulse generated given to four legs of inverter will be as follows

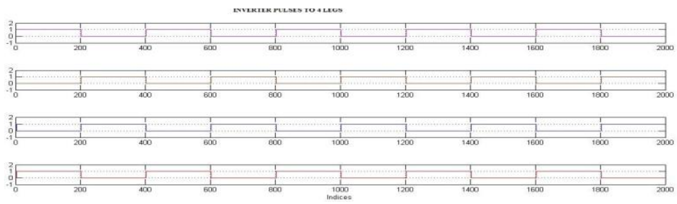

Fig 7: PRI Controller Pulses

Figure below shows the PV powered flyback converter based inverter interfaced with PRI controller for current compensation at inverter side.

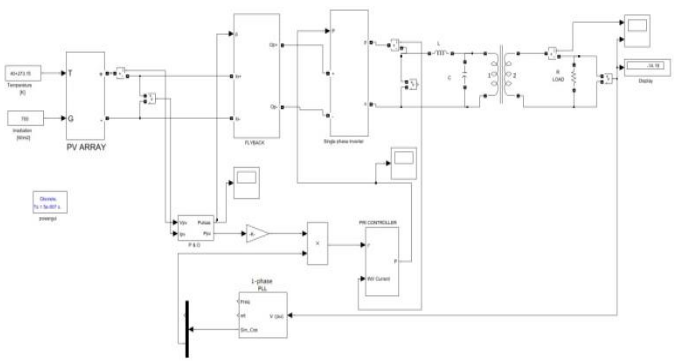

Fig 8: Simulink model of PV powered flyback based inverter with PRI

C. Comparison of THD

The table below shows the harmonic content in the inverter output with & without PRI controller.

Table VII
THD Analysis on Compensated Output

Parameter	WithoutPRI Controller	With PRI Controller
DC Component in current	0.01091	0.007008
DC Component in voltage	3.86	2.48
THD	5.98	4.87
3'rd order harmonic	5.72	4.22
5'th order harmonic	0.40	0.82
7'th order harmonic	0.06	0.83

IV. CONCLUSION

A PV powered flyback boost converter based inverter is designed. This flyback boost converter will creates less harmonic issues than conventional boost converter. The converter inverter sections used is not alone a cause for the power quality issues. The MPPT section used for regulating the PV output contributes for the quality less inverter output due to its fast changing voltage & current levels. Also a new controller called PRI (Proportional Resonant Integral) Controller is designed, which helps in reducing the low order harmonic contents & DC components in the inverter output. All results have presented in MATLAB/Simulink platform. The total THD measured in the grid current is below 5% ,which is acceptable by IEEE standards

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―outside‖! Avoid contractions; for example, write ―do not‖ instead of ―don't.‖ The serial comma is preferred: ―A, B, and C‖ instead of ―A, B and