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Design and Comparison of PI and Back-Stepping Control for Single Phase Two-Stage Grid Connected PV System

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Abstract

In grid connected two stage PV system some Control technique are applied to get maximum power point, voltage adjustment of boost converter , inverter voltage , DC link voltage control, grid current control, power factor improvement and reduction in total harmonics distortions. In this paper the two control techniques like back-stepping control and PI control are designed and their results are compared. The output behavior of the PV array is non-linear, there is a continuous change in output power, due to change in the temperature and change in irradiations. Due to this nonlinear behavior of PV the maximum power point is affected. To achieve maximum power point a special type of tracking system is used. In this paper the main objective like dc-link voltage control, grid current control, power factor improvement and reduction in total harmonics distortion is achieved. MATLAB/SIMULINK is used for simulation and studies.

Keywords: Maximum power Point tracking (MPPT), Photovoltaic (PV), Back-stepping Control (BSC), Total Harmonics Distortion (THD).

I. Introduction

There is a rapid increase in the population and industrialization of the world and due to this increase there is a huge demand in the energy. Conventional energy sources like coal, oil, gas etc are depleting day by day and there cost is escalating too. Because of this, the current ongoing research around the world has been based on renewable energy resources such as wind, solar, tidal etc. Among these renewable resources, PV is gaining more popularity because of its abundant availability, pollution free and cheap energy

However, efficient utilization of the solar energy is a very big problem in grid connected PV system [I]. Since the behavior of the PV system is nonlinear in nature, the output of the PV is continuously changing due to change in temperature and irradiations, and for that which the maximum power point of the PV system also changes, and hence the efficiency of the PV system is decreased.

To overcome this problem different MPPT technique like incremental inductance method, fixed voltage method fractional open circuit voltage method and perturb and observe method have been proposed by many other researches [II].In this paper perturbation and observation method is used for maximum Power point tracking.

Grid connected PV system is used for high power applications. The grid connected system is further divided into two type's single stage and two stage grid connected PV system. In single stage grid connected PV system there is direct connection between the PV array and grid, but in case of two stage grid connected PV system the voltage from the PV array is step-up through boost converter and then the voltage is sent to the inverter and utility grid [III]. Conventionally, maximum power point tracking (MPPT) is achieved by the DC/DC converter stage while the second inverter stage in habits two control loops to deliver power to the grid [IV-V]. The first is an outer voltage control loop at the inverter DC-link and the second is an inner current control loop which forces the inverter to produce a sinusoidal grid current at low THD and almost unity power factor. The grid current ripples can be filtered out using L type filter before the grid.

II. System Representation and Model

Below figure show the Equilent circuit model of the Single phase two stage Grid connected PV system, this system consists of PV panel, DC to DC converter which is used to step-up the Dc voltage from the PV panel, this Dc voltage is feed into the H-bridge type inverter and the L type filter is used to reduce the harmonics distortions of grid current and voltage

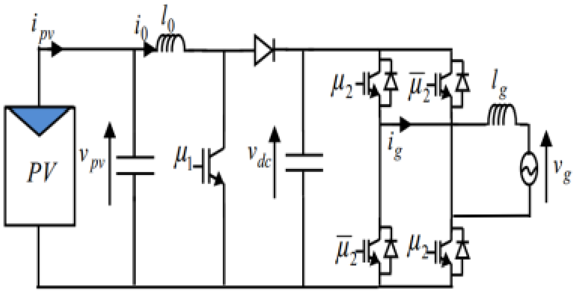

Figure 1.Single phase two stage Grid Connected PV system

$$C_{pv}\frac{dVpv}{dt}=i_{pv}-i_o \quad (1)$$

$$Lo\frac{dio}{dt}=V_{pv}-(1-\mu_1)\,Vdc \quad (2)$$

$$L_g \frac{di_g}{dt} = \mu_2 V_{dc} - V_g \quad (3)$$

$$C_{dc} \frac{V_{dc}}{dt} = (1- \mu_1)\, i_o - \mu_2 i_g \quad (4)$$

Where V_{pv} and I_{pv} are the voltage and current generated by the PV array, V_{dc} is the dc link voltage , V_g and I_g are voltage and current of the grid. i_o is the input current chopper and μ_1 and μ_2 are the switching functions given by

μ_1= {1 if s_o is ON
μ_1= {0 if s_o if OFF
u_2= {1 if (s_1,s_2) is ON and (s_3,s_4) is OFF
u_2= {-1 if (s_1,s_2) is OFF and (s_3,s_4) is ON

II.aSolar PV System Modeling

A photovoltaic cell is a device which converts the energy from the sun directly into electricity Photovoltaic cell consists of cell which is connected in series or in parallel combination. These combination of the of cell form a PV module [VI] .The Equilent model of the PV module is shown in the figure below. Solar cell consists of a current source a diode connected in parallel. The current source represents light generated current, I_{ph}, in addition to thisthere are two resistors one is shunt resistor R_{sh} and the other one is series resistors R_s, these resistors represent the losses in the PV cell. And the output of the cell is given by V and I.

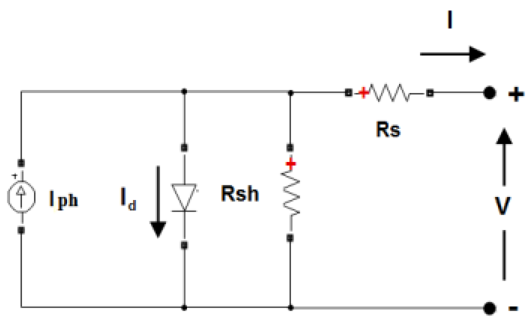

Figure 2.Equilent modal of PV Array

$$I = I_{ph,\,cell} - I_D \quad (5)$$

$$I_D = I_{O,\,Cell} * \exp\left[\left(\frac{qV}{AKTc}\right) - 1\right] \quad (6)$$

$$I = I_{ph} - I_o * \exp\left[\left(\frac{v+IRs}{AVt}\right) - 1\right] - \left[\frac{v+IRs}{Rsh}\right] \quad (7)$$

$$V_t = \frac{NsKTc}{q} \quad (8)$$

Whereas,
I=PV
Iph, Cell= Photocurrent,

$I_{D=}$Diode Current

I_{oCell}=Leakage Current

q=Electron charge (1.602 × 10-19 C).

K=Boltzmann constant (1.38×10^{-23} J/k)

V=Output Voltage of PV

$T_{c=}$ Operating Temperature of the PV

A=ideality factor of diode

$I_{ph:}$ is the Photovoltaic Current

I_o: is the Reverse Saturation Current

R_s: is the Series resistance of PV Cell

R_{sh}: is the Shunt Resistance of PV Cell

V_T: is the Terminal Voltage

N_s: Number of series Cell

N_P: Number of Parallel Cell

In this paper we use 7 modules in series to make a PV array. Each Module contains 60 cells connected in series and one in parallel. The below table represent the experimental parameter of the PV module

TABLE 1 PV array Data Sheet

PV Module Type	1Soltech 1STH-215-P
Maximum Power	213.5 w
Cell per Module	60
Open Circuit Voltage	36.3
Short Circuit Current	7.84
MPPT Voltage	29
MPPT Current	7.35
Diode Ideality Factor	0.98117
Series Resistors	0.393
Shunt Resistors	314

II.b Boost Converter Modeling

The Boost converter play a very important role in grid connected PV system, the MPPT is achieve by using boost converter , both the backstepping and PI controller is used to control the duty cycle of the boost controller .The boost converter consists of inductor, capacitor. So we will select a proper inductor and capacitor according to our input and output voltage. The following equations are used for the proper selection of boost converter.

$$V_{out} = V_{IN}/ (1\text{-}D) \tag{9}$$

Selection of Inductor

$$L=\frac{Vs\times D}{Fs\times \Delta I} \tag{10}$$

Selection of Capacitor

$$C= \frac{Io\times D}{Fs\times \Delta Vc} \tag{11}$$

Ripple Current

$$\Delta I = \frac{Vo \times D \times (1-D)}{LFs} \qquad (12)$$

Table 2 Boost Converter Data

Cpv	0.2mF
Lo	100mH
Dc link	5mF
Fsw	100Khz

II.c Boost Converter Modeling

Change in load effect the Dc link voltage directly. Due to this change in voltage harmonic distortion is produced which causing lowering the power factor .PI controller is used to maintain the Dc-link voltage.

$P_{dc}=K_{P}(V_{dc\ Ref}-V_{dc}) + K_i\int(Vdc\ ref - Vdc)dt$

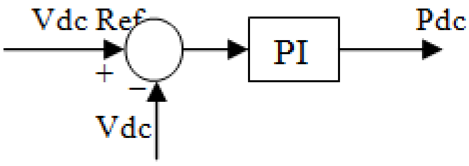

Figure 3. PI Controller

II.d L type Filter

The voltage from the inverter is full of harmonics usually of higher order harmonics, these harmonics are non-sinusoidal in nature, these non-sinusoidal voltages and current produces a lot of harmonics in the grid. And according to the IEEE rule the Grid harmonics should be less than 5% [X-XI], so to reduce these harmonics we will use L type filter, L type filter acts as a low pass filter and the harmonics are reduced by using this type of filter.

III. Perturbation and Observation

To get the maximum power point form the PV array we will use maximum power point tracker and this maximum power point tracker works on the perturbation and observation algorithm [VII]. The flow chart of the P&O method is shown in the figure below. First of all the value of voltage and current are measure from the PV array, after this the reference power is measured with change in irradiation the power of PV array is changed, hence changed in power is measured between new power and old power and if the change in power is greater than zero, and change in voltage is greater than zero than there will be increase in voltage by the system module.

And if the change in voltage is not less than zero the system module algorithm will decrease the voltage. If difference in power is not greater than zero and change in voltage is also non zero then there will be increase in module voltage on the other hand if the change in voltage is greater than zero then there will be decrees in module voltage.[IX] This perturbation and observation algorithm will continue till the change in power is equal to zero or the new power measured is equal to the old power, hence the maximum power point is achieved at this stage when the change in power is equal to zero

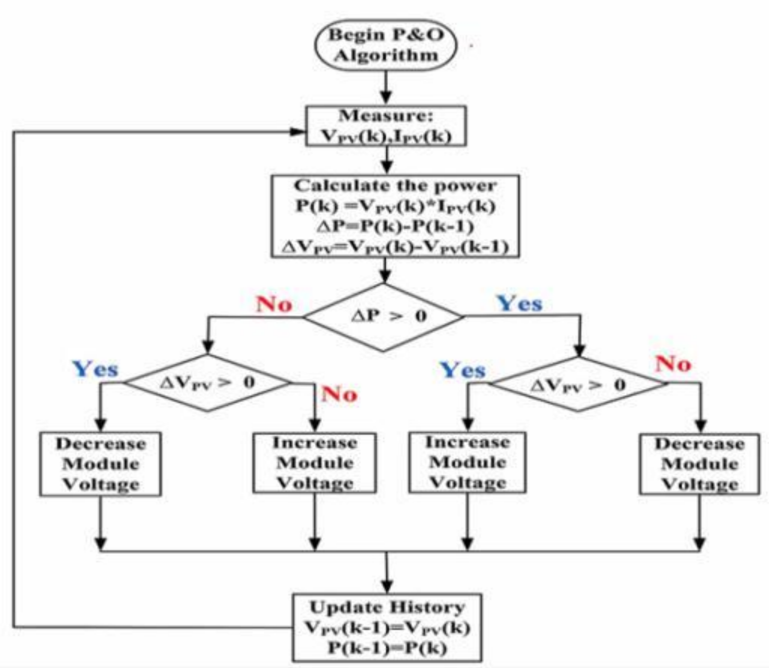

Figure4. Flow Chart of Perturb and Observe Method

As shown from the figure below the maximum power point is achieved after 4 to 5 petrubutation.

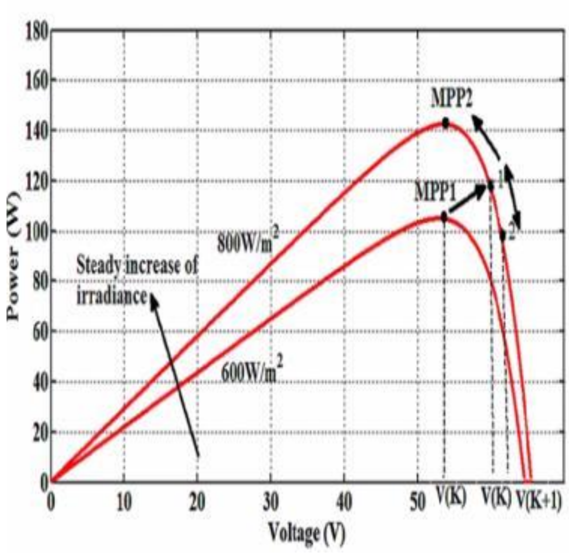

Figure5. Maximum Power Point

III.a Back Stepping Control

Back-Stepping Control is a nonlinear control technique, which works on Lyapunov stability [VIII]. Back-stepping control technique is applied to the grid connected PV system the flow chart of the Back-stepping control is shown in the figure below

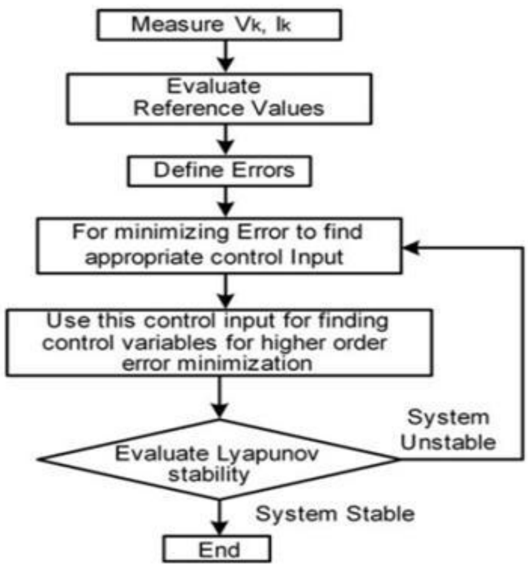

Figure6. Flow Chart of Back-Stepping Control

According to the flow chart of the back-stepping control first of all current and voltage is measured, this current and voltage values are compared with the reference values of current and voltage .After this the next step will be to define error, the error is minimized by finding the control variables, theses control variables are use for the

minimization of the error .After this a control stability equation is applied i.e. Lyapunov Stability Theorem[X].
By applying Back stepping control and measure all the design parameter of the PV system the duty cycle of the boost converter and inverter will be controlled and hence all the controlled objective will be achieved [XI].The control operation of the back stepping is shown in the figure below.

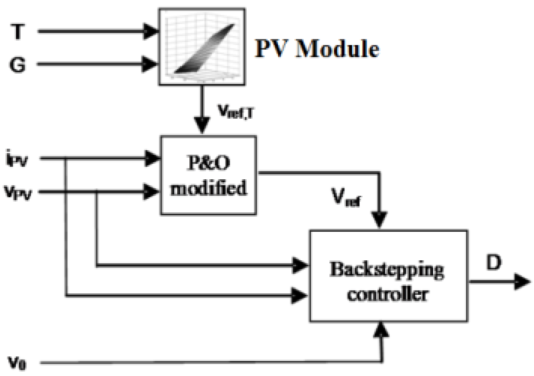

Figure 7. Back-Stepping Control Operation

III.b Simulations

All the Simulation is performed in MATLAB , the choice of the MATLAB Simulink is based on the fact that all the real time parameter of the PV system are easily available in the MATLAB and the results are very much accurate the SIMULINK blocks are shown below

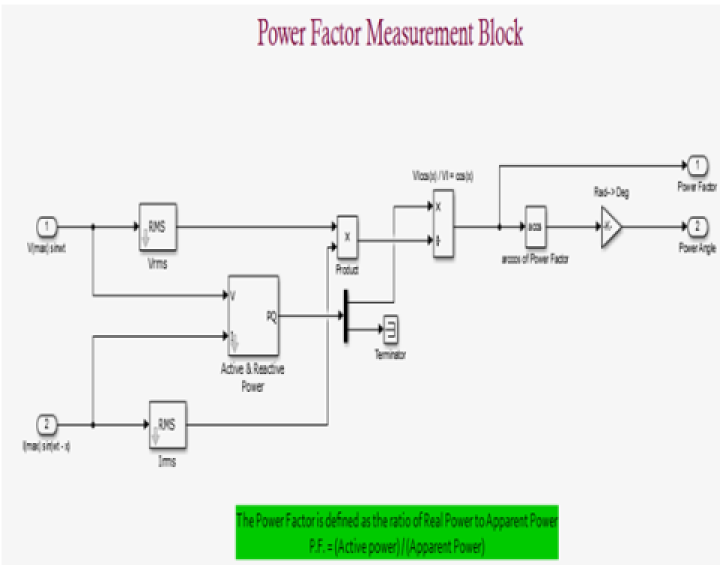

Figure 8. Power Factor Measuring Block

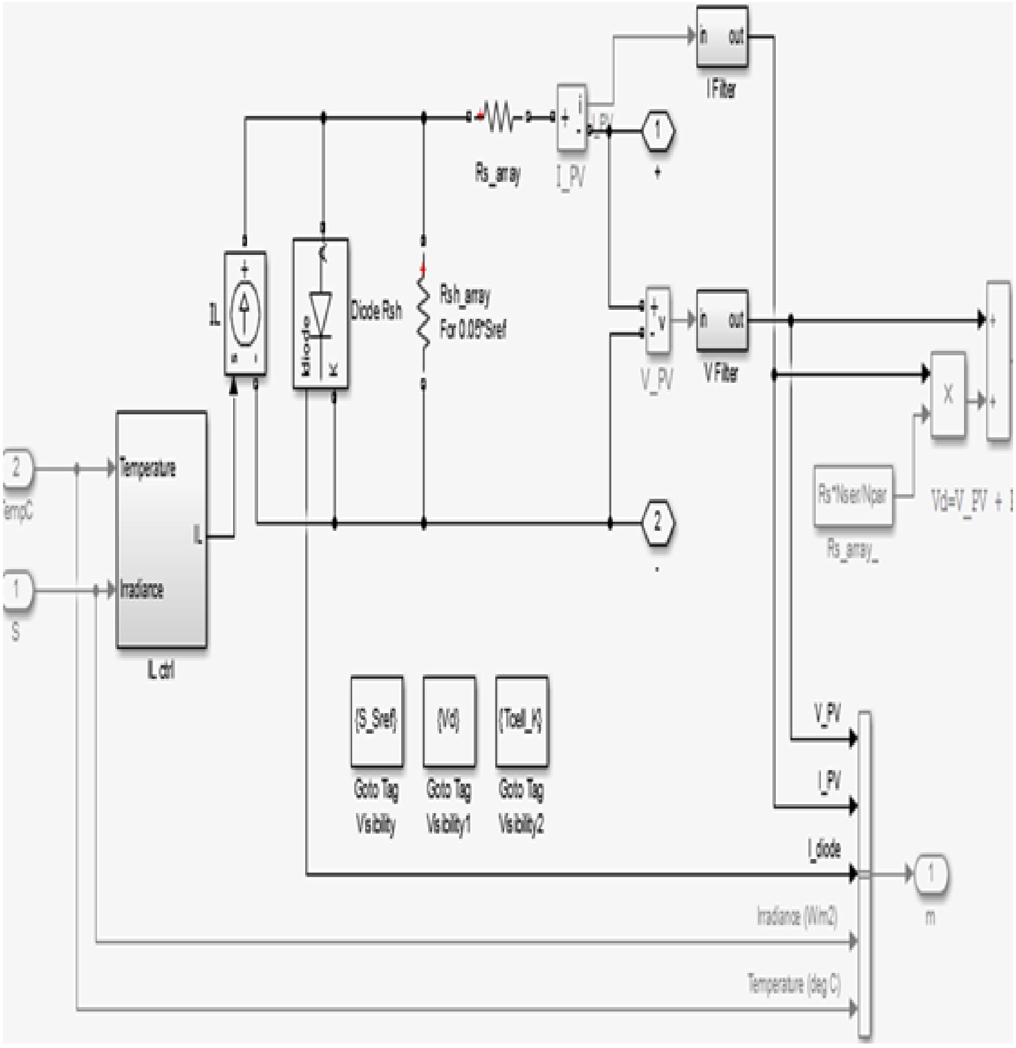

Figure9. PV array Simulation Block

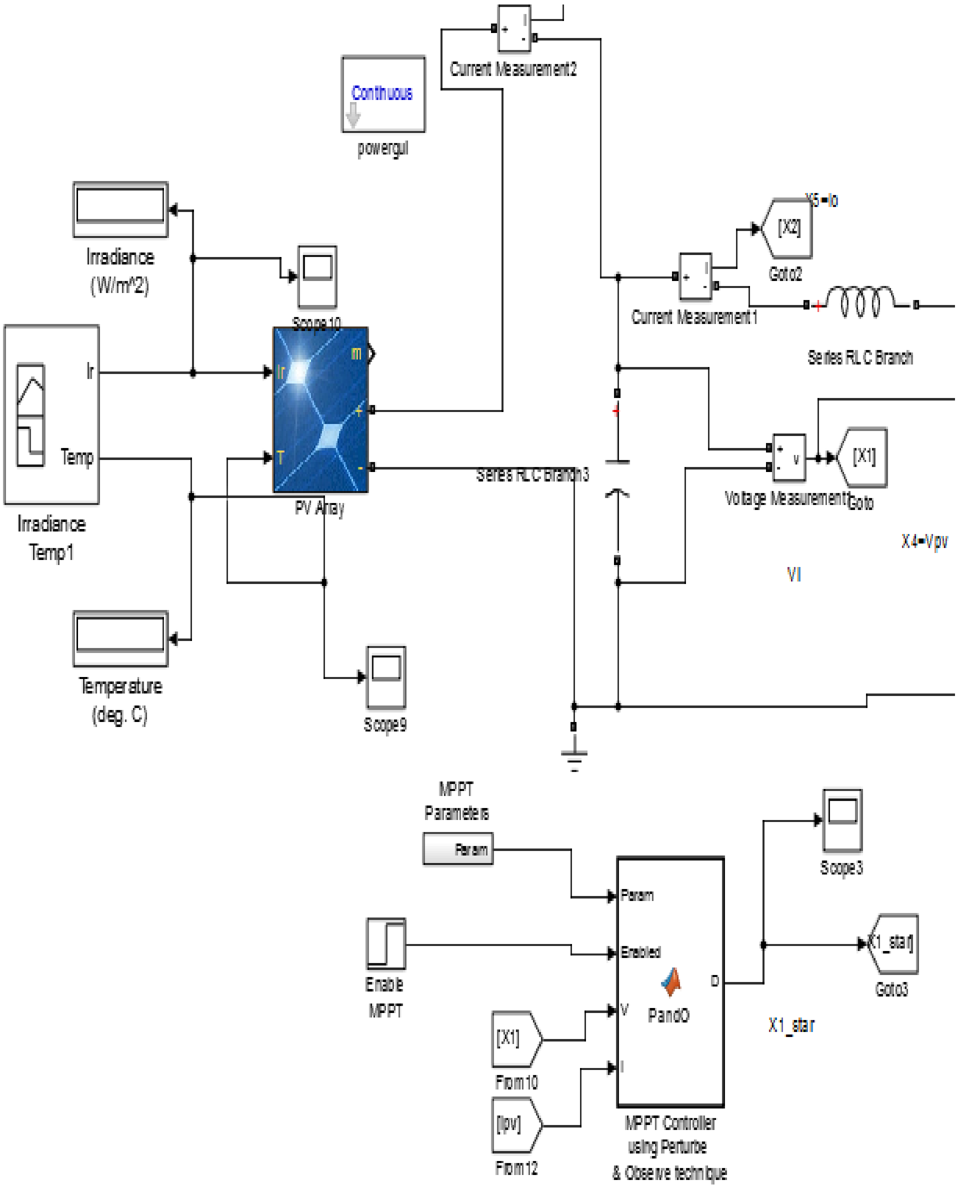

Figure10. MPPT Simulation Block

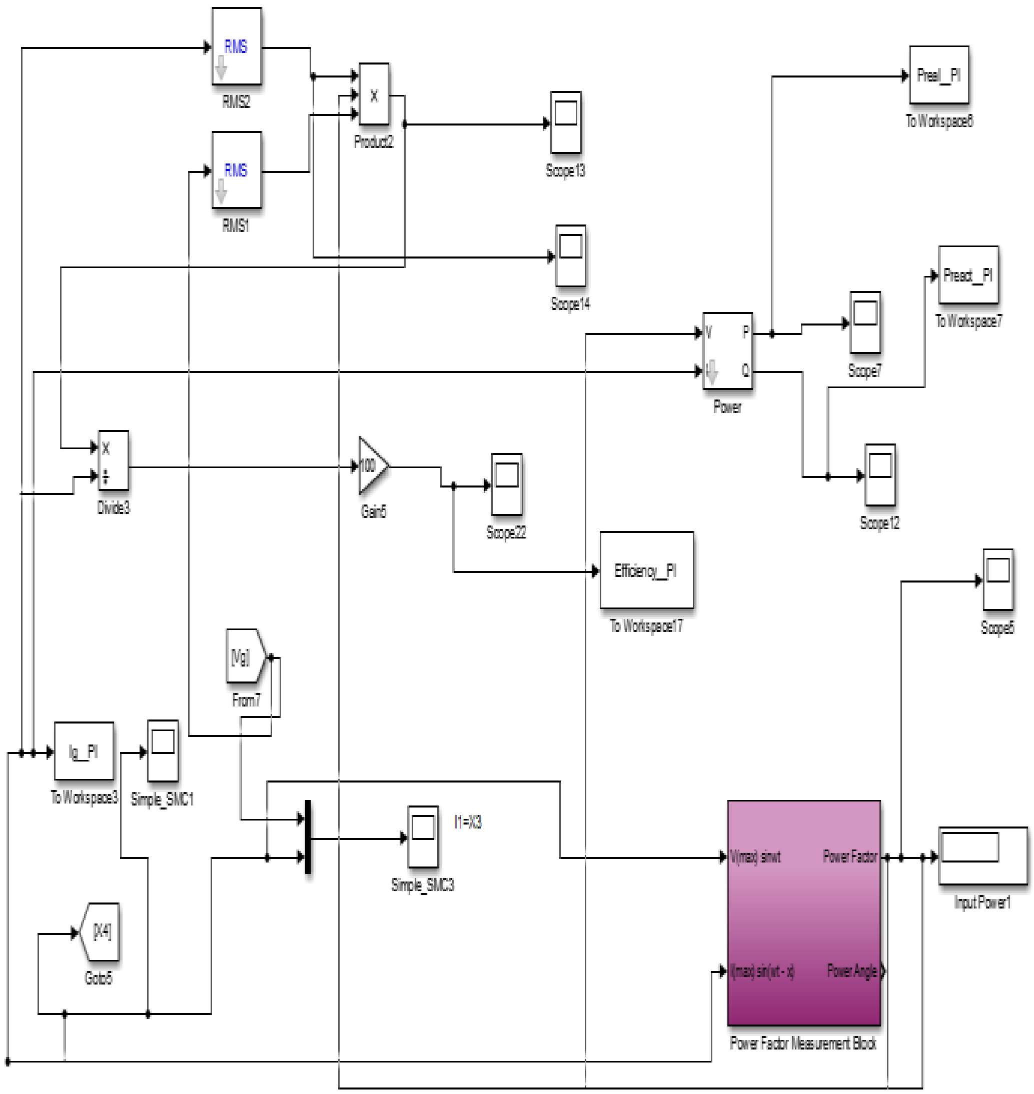

Figure 11. PI Control Simulation Blocks

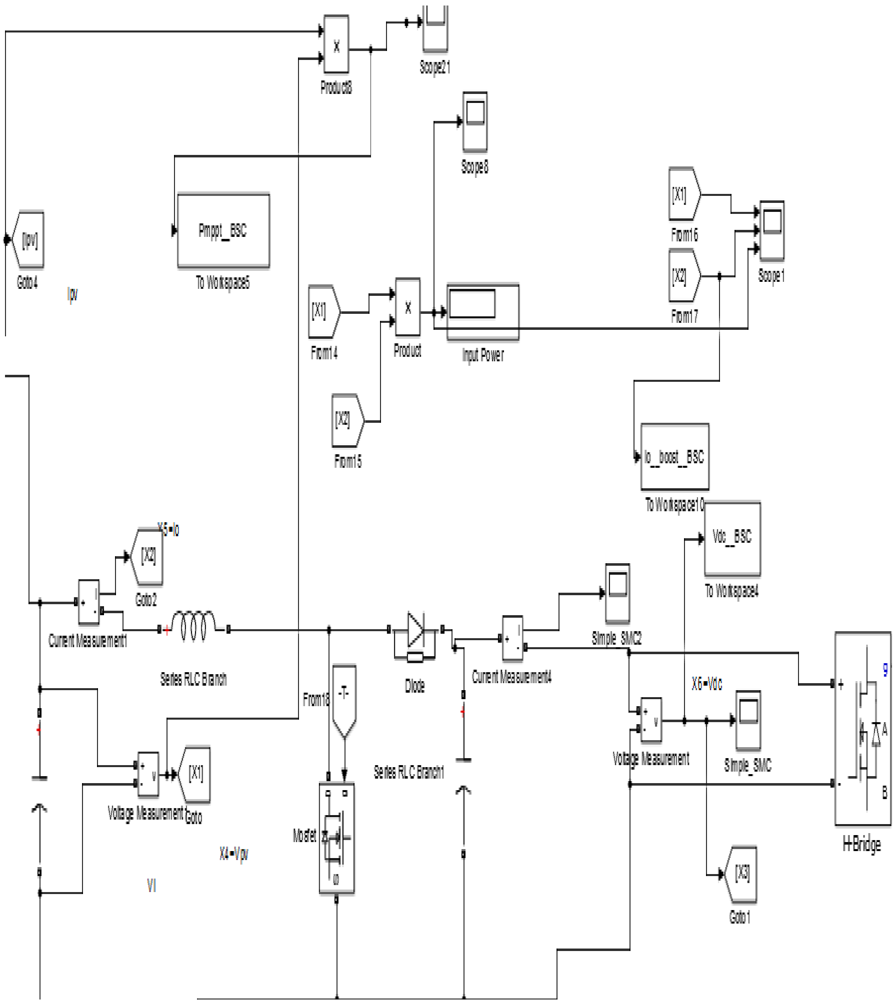

Figure12. Back-steeping Control Simulation

III.c Results

All the results from the both controller i.e. PI and back stepping Controller are compared as shown through the graph , Red line show the Back-stepping graph while the Green Line show the graph for PI controller .

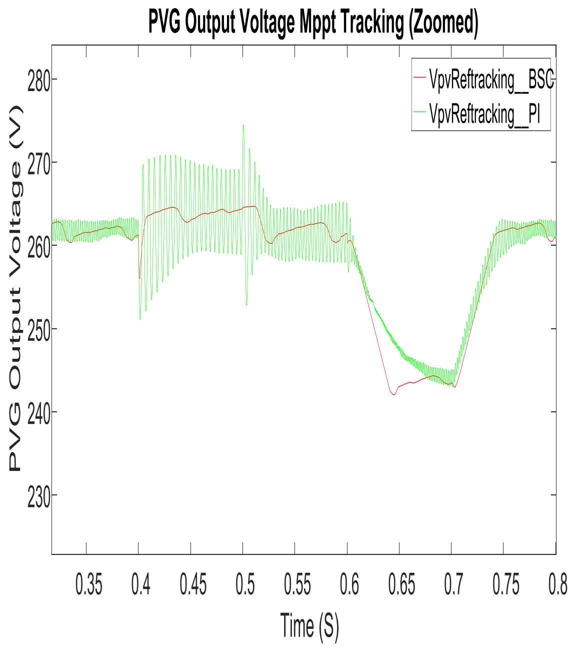

Figure 13. MPPT Tracking Voltage

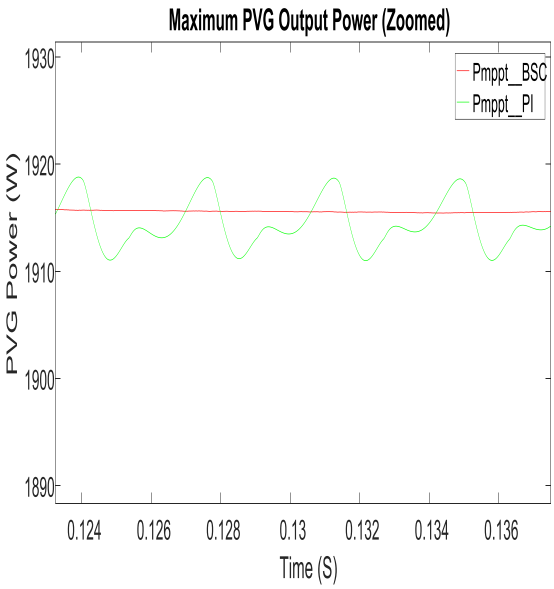

Figure 14. Maximum Power Output

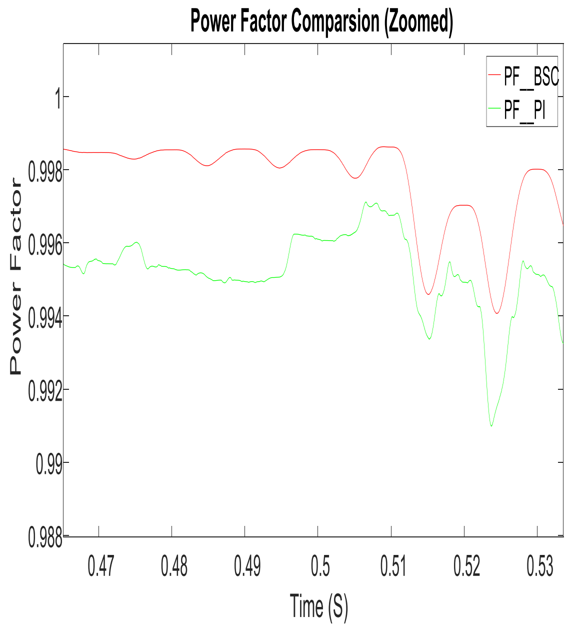

Figure15. Power Factor Compression

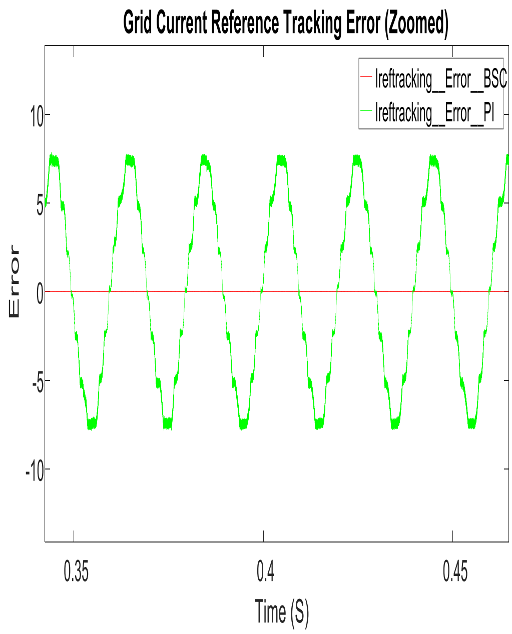

Figure 16. Grid Current Reference Tracking

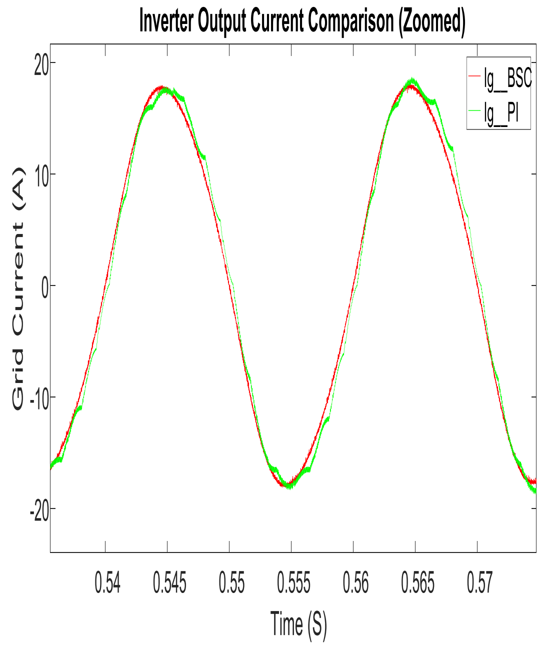

Figure 17. Inverter Output Current Comparison

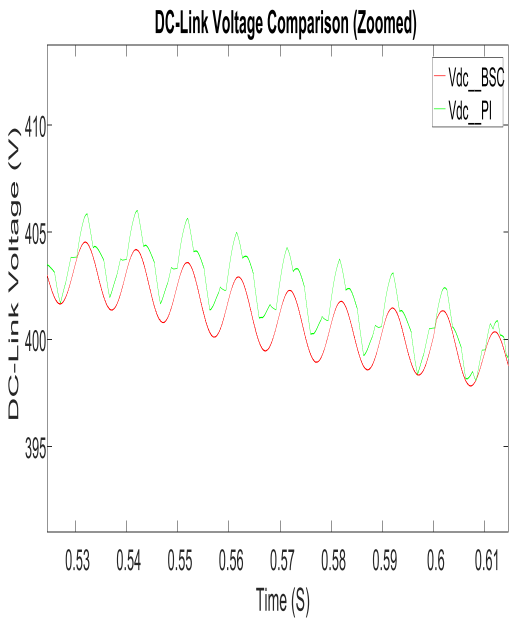

Figure 18. DC-link Voltage Comparison

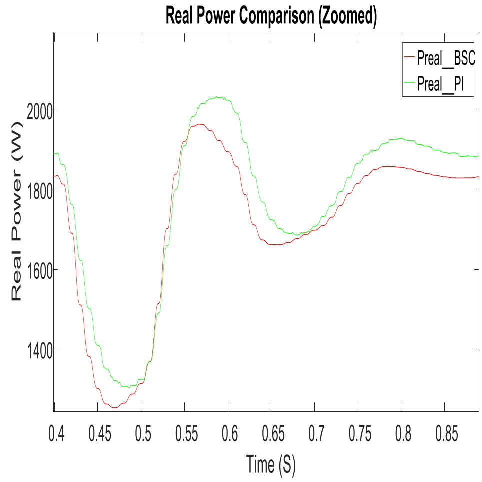

Figure19. Real Power Comparison

IV. Conclusion

The main problem in the PV system is its nonlinear behavior .this non-linear behavior of the PV system cause un balance of maximum power, change in boost converter and Dc link voltage harmonic distortion and power factor problem so to handle these problems some efficient and robust controls are used. For maximum power point tracking perturb and observe algorithm is used to get maximum power point. For Dc link voltage control PI controller is used to get accurate results. When the DC link voltage is improved the constant voltage is transfer to the inverter, due to which the inverter voltage is improved. And at the end L type filter is used to reduce total harmonics distortions. The power fact by comparing the result of PI and back-stepping controller we concluded that back-stepping control is more efficient and robust.

V. Acknowledgement

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