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DESIGN AND IMPLEMENTATION OF TRANSIENT CONTROL PI BASED BOOST CONVERTER

Miss. Meera Uikey*[1] & Asst. Prof. Mr. Sudeep Mohaney[2]
*[1]ME (High voltage power system,) Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur, MP, India.
[2]Asst. Professor, Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur, MP, India

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ABSTRACT
This paper proposes a new boost DC-DC with PV connected system converter with a high voltage conversion ratio for the renewable energy source. To get a high voltage gain, the proposed converter consists of the new two stage cascaded structure and has two voltage conversion processes. Due to the new structure and voltage conversion process, it has the higher output voltage gain at the same duty cycle than the conventional boost converter. To verify the PI performance and effectiveness the proposed circuit was analyzed and tested by the MATLAB 2015a simulator. The calculated power steady state time of the proposed circuit was 0.02s and the proposed circuit had the 3.5 times higher conversion ratio at the half duty cycle than the conventional boost converter. Therefore, the superior voltage conversion ability of the proposed circuit is proved from the simulation results.

KEYWORDS: DC-DC converter; voltage regulation; Boost converter; overshoot; PI; Block Diagram Reduction; stability.

1. INTRODUCTION
The extensive use of DC power supplies inside most of electrical and electronic appliances leads to an increasing demand for power supplies that draw current with low harmonic content and also have power factor close to unity. DC power supplies are extensively used in computers, audio sets, televisions and others. The presence of nonlinear loads results in low power factor operation of the power system. The basic block in many power electronic converters are uncontrolled diode bridge rectifiers with capacitive filter. Due to the non-linear nature of bridge rectifiers, non-sinusoidal current is drawn from the utility and harmonics are injected into the utility lines. The bridge rectifiers contribute to high THD, low PF and low efficiency to the power system. These harmonic currents cause several problems such as voltage distortion, heating and noises which result in reduced efficiency of the power system. Due to this fact, there is a need for power supplies that draw current with low harmonic content and also have power factor close to unity.

The AC mains utility supply ideally is supposed to be free from high voltage spikes and current harmonics. Discontinuous input current that exists on the AC mains due to the non-linearity of the rectification process should be shaped to follow the sinusoidal form of the input voltage. The conventional input stage for single phase power supplies operates by rectifying the ac line voltage and filtering with large electrolytic capacitors.

This process results in a distorted input current waveform with large harmonic content. As a result, the power factor becomes very poor (around 0.6). The reduction of input current harmonics and operation at high power factor (close to unity) are important requirements for good power supplies. Power factor correction techniques are of two types: passive and active power factor correction. While, passive power factor correction techniques are the best choice for low power, cost sensitive applications, the active power factor correction techniques are used in majority of the applications due to their superior performance.

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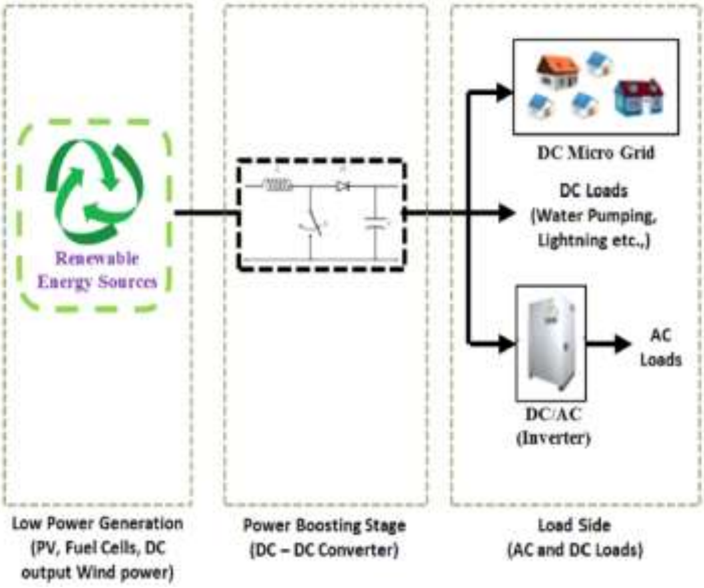

Fig (1.1) typical renewable energy system with DC–DC converter

Demand for electric power keeps on increasing nowadays; hence, the world is switching over to the field of renewable energy sources as it is pollution-free, free of cost, and easy to access in remote areas.

A DC/DC converter is class of power supply that converts a source of direct current (DC) from one voltage level to another. There are two types of DC/DC converters: linear and switched. A linear DC/DC converter uses a resistive voltage drop to create and regulate a given output voltage, a switched-mode DC/DC converts by storing the input energy periodically and then releasing that energy to the output at a different voltage. The storage can be in either a magnetic field component like an inductor or a transformer, or in an electric field component such as a capacitor. Transformer-based converters provide isolation between the input and the output[1-5].

Switch mode converters offer three main advantages:

- The power conversion efficiency is much higher.
- Because the switching frequency is higher, the passive components are smaller and lower losses simplify thermal management.
- The energy stored by an inductor in a switching regulator can be transformed to output voltages that can be smaller than the input (step-down or buck), greater than the input (boost), or buck-boost with reverse polarity (inverter).
- Unlike a switching converter, a linear converter can only generate a voltage that is lower than the input voltage. While there are many advantages, there are also some disadvantages with switching DC/DC converters. They are noisy as compared to a linear circuit and require energy management in the form of a control loop. Fortunately, modern switching-mode controller chips make the control task easy.

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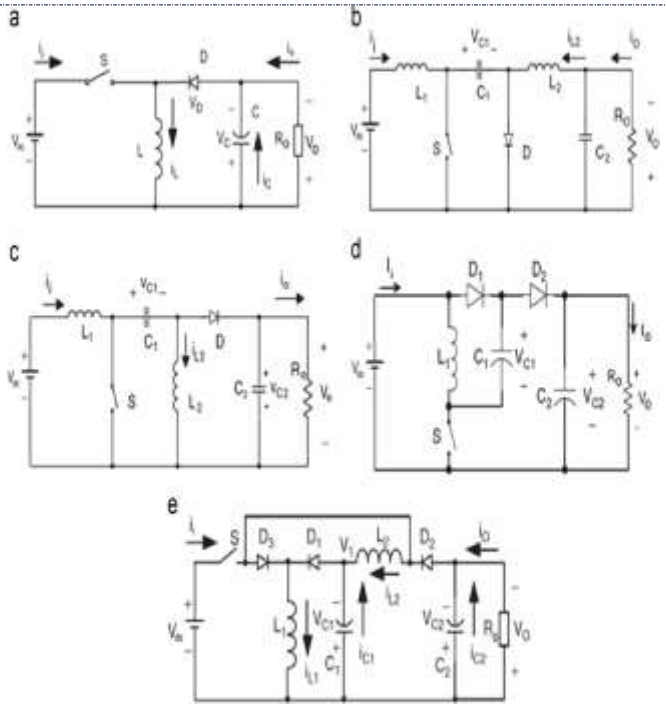

Fig (1.2.a) DC-DC converters

The isolated DC-DC converters convert a DC input power source to a DC output power while maintaining isolation between the input and the output, generally allowing differences in the input-output ground potentials in the range of hundreds or thousands of volts. They can be an exception to the definition of DC-DC converters, in that; their output voltage is often (but not always) the same as the input voltage. The various topologies of the DC to DC converter can generate voltages higher, lower, higher and lower or negative of the input voltage namely:

- Buck
- Boost
- Buck boost
- Cuk
- Sepic

2. CONVENTIONAL PFC BOOST CONVERTER

Among the different topologies, the conventional boost converter is the most widely used topology for power factor correction applications. It consists of a front-end full-bridge diode rectifier followed by the boost converter as shown in Figure 2.1. The diode bridge rectifier is used to rectify the AC input voltage to DC, which is then given to the boost section. During ON-time of the switch, the current flows through two rectifier diodes (D1 and D3) and the power switch (QB). Similarly during OFF-time of the switch, the current flows through the other two rectifier diodes (D2 and D4) and the output diode DB. Thus it results in significant conduction losses in three semiconductor devices which reduce the converter efficiency. This approach is good for a low to medium power range applications. For higher power levels, the diode bridge becomes an important part of the application and it is necessary to deal with the problem of heat dissipation in limited surface area[5-10].

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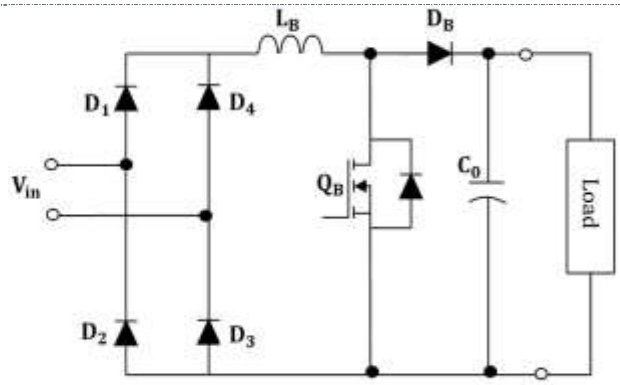

Fig (2.1) conventional boost converter

3. BUCK CONVERTER'S POWER STAGE

Inductor and capacitor forms a low-pass filter in a buck converter. The corner frequency the LC filter is always designed to at low frequency to attenuate switching ripple. As a rule of thumb, current ripple of inductor is always designed to be around 30% of average inductor current. In this design note, a theoretical derivation of ripple current to average current ratio, also called ripple factor, is introduced to get inductor size equation. By applying area-product (AP) method of inductor design, an optimal range of ripple factor can be obtained, which is helpful for capacitor design as well as the total converter design.

Buck converters are widely applied in lots of voltage step-down applications, such as on-board point-of-load converters. Basically, a power switch and a free-wheeling diode chop the dc input voltage to a rectangular waveform, then a low-pass LC filter sieves the high-frequency switching ripple and noise to get a almost pure dc voltage in the load terminal. Figure 2.2 shows a typical buck converter.

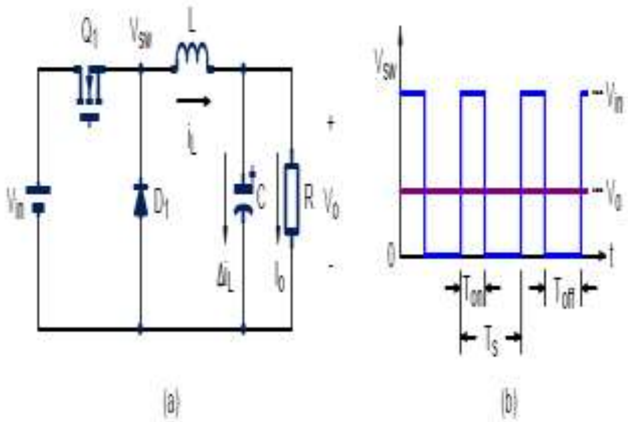

Fig (2.2) 1. (a) A typical Buck converter, (b) Switching voltage

When power switch Q1turns on, the free-wheeling diode D1is reverse bias. The input current goes through LC filter to load directly. When Q1turns off, D1is forward biased by inductor current iL. Switching voltage waveform shown as in Figure 2.2(b) is pulsating rectangular. After LC filtering, assuming corner frequency of LC is much lower than switching frequency, output voltage appears almost pure dc.

It can be understood the higher the inductance L is, the lower the capacitance C leads the same output voltage ripple. However, too big inductor causes high volume and high cost. While too low inductance causes big output capacitor. It is not purely a design trade-off problem. Let’s think about the waveforms of inductor current in steady state.

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Buck-Boost Power Stages:

A switching power supply consists of the power stage and the control circuit. The power stage performs the basic power conversion from the input voltage to the output voltage and includes switches and the output filter. This report addresses the buck-boost power stage only and does not cover control circuits. Detailed steady-state and small-signal analysis of the buck-boost power stage operating in continuous and discontinuous mode is presented. Variations in the standard buck-boost power stage and a discussion of power stage component requirements are included.

4. MOTIVATION AND THESIS OBJECTIVES

Despite the need, there is no standard bench mark model of large scale all converters systems for power System simulation studies. Thus, there is a need for developing Moreover, the components (inverter, all converters sources etc.) present in all converters system are supplied by different manufactures, who may not disclose their product dynamic properties (control structure or methodology, parameters). Therefore, the only option is to build an adequate model, which may not exactly represent the real world all converters system but provides a satisfactory tool to analyze the all converters system by expert point of view. The main objectives of this thesis are:

- To develop the model for the connected BOOST converters system.
- To build an adequate simulation model in MATLAB/SIMULINK for analysis purpose along with the PI control architecture.

A or **converter** or **RES inverter**, converts the variable direct current (DC) output of a into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical balance of system (BOS)–component in a photovoltaic system, allowing the use of ordinary AC-powered equipment. Solar power inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

One of the most important parts in system architecture is the power converters. The reason is that they play an important role in transforming the different types of electricity, to make the electricity convenient to the end users. Since the solar cell produces a DC type of electricity, there's room for various types of power converters. Here, some of the most commonly used power converter types are briefly describe according to their topology, function, efficiency, and the major global manufacturers.

1. **Power optimizer:** Commonly known as a DC-DC power optimizer in solar markets, a power optimizer is a module-level power converter. It takes DC input from the solar module and gives either higher or lower DC output voltage. Such a converter is equipped with an MPPT technology to optimize the power conversion from the solar panel to the DC load or a battery or central inverter. It is also considered one of the most efficient power converters, delivering up to 99.5% efficiency. However, it needs DC cabling from the array. Some of the major players in this power converter market are Solar Edge and Tigo Energy.

2. Module inverter/micro-inverter: This is also a module-level power converter. It takes DC input from the solar module and converts it into AC electricity, which is then ready to be connected to the load or single-phase main grid or to a central inverter. It is also equipped with MPPT technology to detect the maximum power point of each module. Even though it doesn't requires any DC cabling, it is more expensive than the power optimizer due to its advanced.

3. String inverter: As an extension of a module-level power converter is the string inverter, which is suitable for a string or parallel strings of modules connected in series. Such a power converter is used for small RES systems up to 10 kW in capacity and are usually connected to the main grid. The output of such a power converter is 3 phase lines which are ready to be connected to a low voltage main grid.

5. DC-DC CONVERTERS

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than

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the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereby, the efficiency decreases. The core loss of the inductors limits the high frequency operation. Control voltage V_c is obtained by comparing the output voltage with its desired value. Then the output voltage can be compared with its desired value to obtain the control voltage V_{cr}. The PWM control signal for the dc converter is generated by comparing V_{cr} with a saw tooth voltage V_r.[8]. There are four topologies for the switching regulators: buck converter, boost converter, buck-boost converter, and converter. However my project work deals with the boost regulator and further discussions will be concentrated towards this one.

6. BOOST CONVERTER AND ITS OPERATION

The figure (6.1) below shows a step up or PWM boost converter. It consists of a dc input voltage source V_g, boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

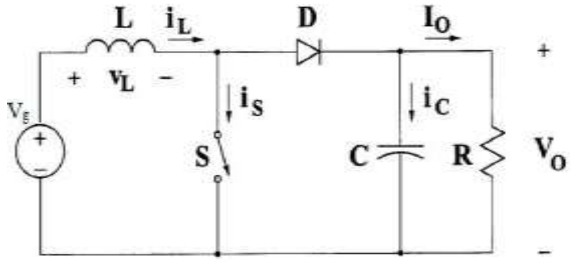


Fig (6.1) Circuit diagram of boost converter

➢ Basic Configuration of a Boost Converter

Figure 6.1shows the basic configuration of a boost converter where the switch is integrated in the used IC. Often lower power converters have the diode replaced by a second switch integrated into the converter. If this is the case, all equations in this document apply besides the power dissipation equation of the diode.

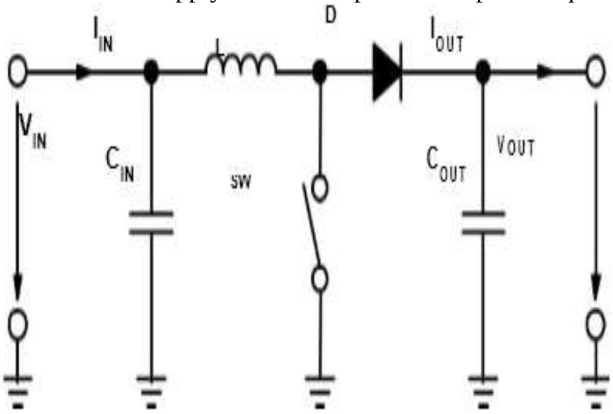


Fig (6.2) Boost Converter Power Stage

➢ Necessary Parameters of the Power Stage

The following four parameters are needed to calculate the power stage:

1.1Input Voltage Range: $V_{IN\,(min)}$ and $V_{IN\,(max)}$

1.2Nominal Output Voltage: V_{OUT}

1.3Maximum Output Current: $I_{OUT\,(max)}$

1.4Integrated Circuit used to build the boost converter. This is necessary, because some parameters for the calculations have to be taken out of the data sheet. If these parameters are known the calculation of the power stage can take place.

➢ **Calculate the Maximum Switch Current**

The first step to calculate the switch current is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

$$D = \frac{\mathrm{VIN(min)} \times \eta}{\mathrm{VOUT}}$$

$V_{IN(min)}$ = minimum input voltage
V_{OUT} = desired output voltage
η = efficiency of the converter, e.g. estimated 80%

The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

Either an estimated factor, e.g. 80% (which is not unrealistic for a boost converter worst case efficiency), can be used or see the *Typical Characteristics* section of the selected converter's data sheet.

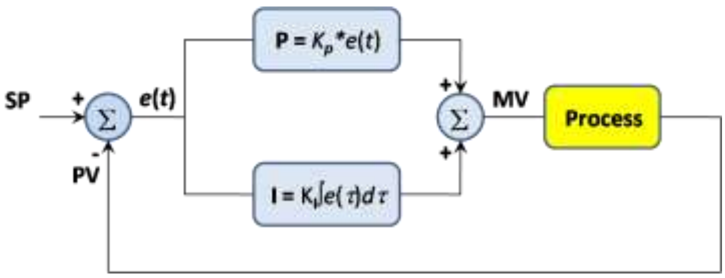
Worst-Case Component Ratings Comparisonsfor DC-DC Converters

Converter Type	Input Inductor Current (Arms)	Output Capacitor Voltage	Output Capacitor Current (Arms)	Diode and MOSFET Voltage	Diode and MOSFET Current (Arms)
Buck	$\frac{2}{\sqrt{3}} I_{out}$	$1.5V_{out}$	$\frac{1}{\sqrt{3}} I_{out}$	$2V_{in}$	$\frac{2}{\sqrt{3}} I_{out}$

7. CONVERTERS CONTROLLING TECHNIQUE PI CONTROLLER

The Proportional-Integral (PI) controller has been used and dominated the process control industries for a long time as it provides the control action in terms of compensation based on present error input (proportional control) as well as depending on past error (integral control). As the term PI suggests, it comprises of two separate constant parameters, i.e. proportional constant and integral constant which are adjusted in order to get ideal, steady and faster response and to reduce the steady state error to zero or at least to a very small tolerance limit. This paper aims to present a study of the development of a dynamic model based on theories of PI control and optimization to design voltage regulator circuit. The Controller design is demonstrated through MATLAB/Simulink in order to get an output of better dynamic and static performance. The resultant output from controller is observed using the oscilloscope.

P-I action provides the dual advantages of fast response due to P-action and the zero steady state error due to I-action. Block diagram of PI controller is shown below:



The proportional gain, by design, also changes the net integration mode gain, but the integration gain, can be independently adjusted. It is understood that the proportional offset occurred, when a load change required a new nominal controller output, and this could not be provided except by a fixed error from the set point. In the

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present mode, the integral function provides the required new controller output, thereby allowing the error to be zero after a load change. The integral feature effectively provides a 'reset' of the zero error output, after the load change occurs. At time t1 a load change occurs, that produces the error. The accommodation of the new load condition requires a new controller output. The controller output is provided through a sum of proportional plus integral action that finally leaves the error at zero. The proportional part is obviously just an image of the error.
In the same way as in integral control, we can conclude that the steady state error would be zero for P-I action. Besides, the closed loop characteristics equation for P-I action is:

$$\xi = \left(\frac{1}{2}\right)\sqrt{\frac{\tau_i}{K\tau}}$$

Characteristics of the PI mode
When the error is zero, the controller output is fixed at the value that the integral term had, when the error reduced to zero. This output is given by pt(0) simply because we choose to define the time at which observation starts, as t = 0.

If the error is not zero, the proportional term contributes a correction and the integral term begins to increase or decrease the accumulated value [initial pt(0)], depending on the sign of the error and its direct or reverse direction. The integral term cannot become negative; thus it will saturate at zero, if the error and the action try to drive the area to a net negative value.

The transfer function is given by Kp + (KI/s)
During the design of the PI controller for the buck and boost converter, a closed loop operation is performed. The open loop operation is insensitive to load and line disturbances. So this operation is ineffective. Therefore the closed loop operation is selected. The closed loop control uses a feedback signal from the process, a desired value or set point (output voltage) and a control system that compares the two and derives an error signal. The error signal is then processed and used to control the converter to try to reduce the error. The error signal processing can be very complex because of delays in the system. The error signal is usually processed using a Proportional - Integral (PI) controller whose parameters can be adjusted to optimize the performance and stability of the system. Once a system is set up and is stable, very efficient and accurate control can be achieved. Input is the voltage error (reference voltage subtracted from the actual voltage) Output is the incremental duty ratio. The controller specifications of a converter are Minimum steady state error. Less settling time.

8. RESULT AND SIMULATION
This chapter has presented the modeling of PV module and the development of the MPPT techniques. In particular, the performances of the controllers are analyzed in these four conditions with are constant irradiation and temperature, constant irradiation and variable temperature, constant temperature and variable irradiation and variable temperature and variable irradiation. The proposed system is simulated by using MATLAB-SIMULINK. Based on the simulation result, the project is successfully achieve the objective.

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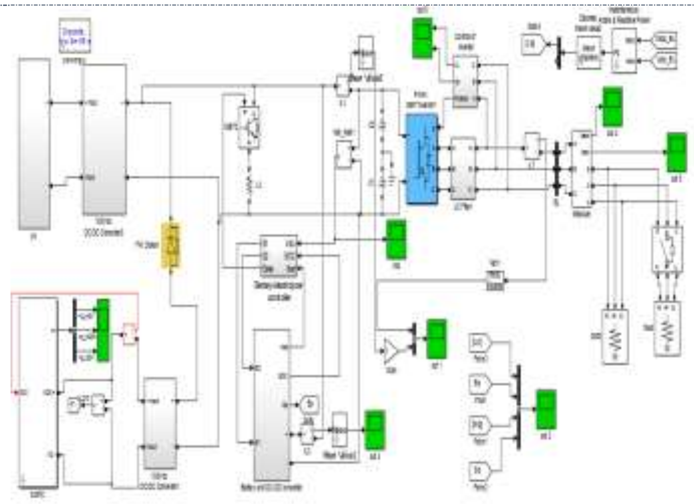

Fig (8.1) PI with MPPT system

The PV system the value of the peak power, current and peak voltage are getting increase by control to the gain of PI controller. Results are showing to the difference in between existing design and proposed design. For the improved performance the PI controller is using.

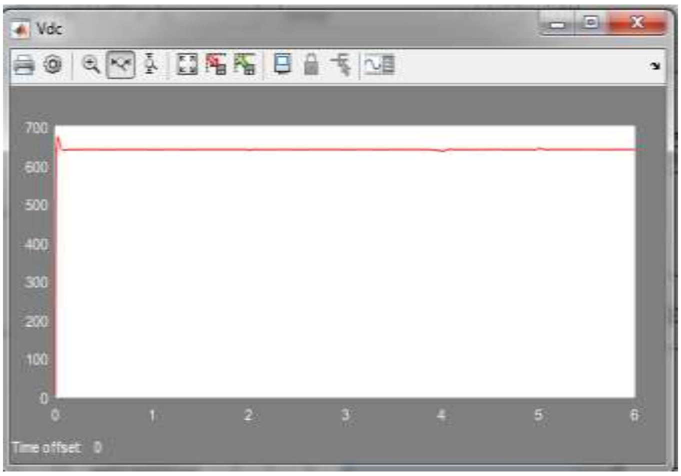

Fig (8.2) Boost converter across voltage stability

Both the output voltage and current values have been plotted against the time. From the results it is found that the voltage overshoot is 698 volts, and the settling time of voltage and current is 0.035 seconds.

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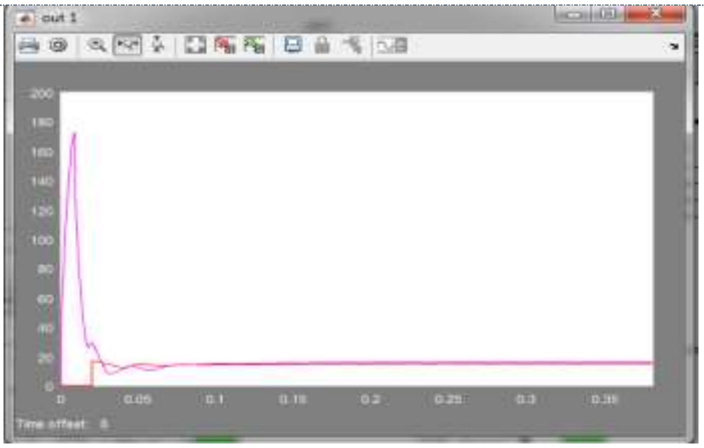

Fig (8.3) RMS current regulation at time 0.02second

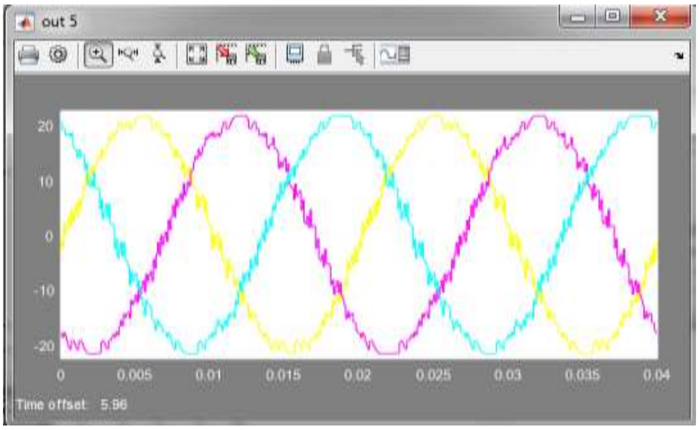

Fig (8.4) Inverter across outcomes in three phase

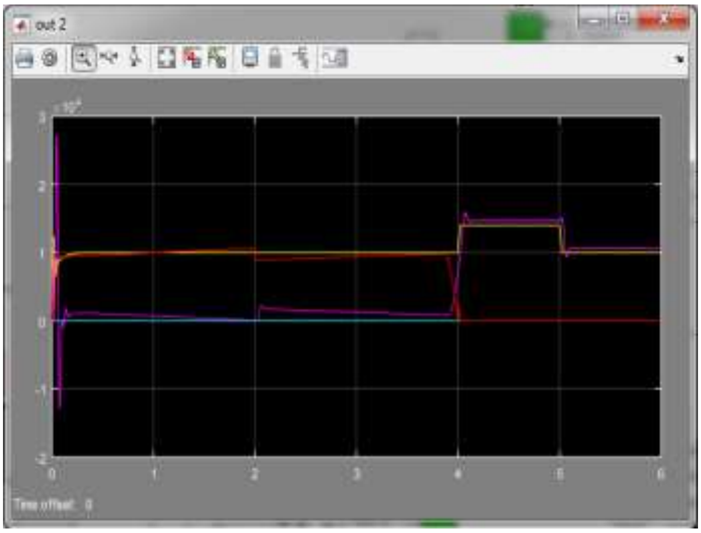

Fig (8.5) All power regulation across each Simulink block

The boost converter is fed with minimum input voltage and maximum load condition during which an input voltage of magnitude 10V is given to the converter with the load current of 2 A. The set value of the output voltage is 25V.

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9. CONCLUSION

In this, work is carried out for the implementation of the PI controller for the boost converters and the results are simulated using MATLAB2015 A. The PI controller behaves very effectively and has maintained constant output voltage subject to the input voltage and load variations. It is observed that its overshoot and settling time at the time of parameter variations are also less. The PI controller successfully controlled the process near a given set-point. Far away from the set-point, the linear PI controller efficiency will be less. To design an efficient control system, we have to combine the two kinds of available informations, the dynamic model of the linear controller and the experience of the human controller. When the first piece of information is a mathematical equation, the second one is usually expressed as linguistic rules that state in what situation which action should be taken. An efficient controller that uses both informations simultaneously and cooperatively is explained in the next chapter.

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