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Analysis of DC bus load transients for solar stand-alone system

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ABSTRACT

ANALYSIS OF DC BUS LOAD TRANSIENTS FOR SOLAR STAND-ALONE SYSTEM

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The objective of this thesis is to design and analyze DC bus load transients for solar stand-alone system in MATLAB/SIMULINK software. In this thesis a home is connected to a photovoltaic solar energy system instead of the conventional grid. Increased pollution and global warming caused by burning of fossil fuels and ever- increasing oil prices are motivating people to choose alternative energy sources such as this.

This energy from a photovoltaic array is distributed to several residential loads connected to DC bus. The problem arises when this energy is distributed to various loads such as major appliances, electric motors, and transformers, which when first energized lead to high starting currents. These high starting currents lead to voltage drops across other bus-connected loads. Voltage dips during starting of large motors can trip other motors operating on the same bus. Due to these voltage dips computers and other electronic devices may also be affected.

The residential system involves a solar panel, MPPT, boost converter, voltage control loop, PID controller, resistive load and transient load connected to DC bus. DC bus voltage is controlled by voltage controller loop; PID controller tuning is done for stable output.

The objective of this this is to illustrate the analysis of DC bus load transients using MATLAB/Simulink. Transient load carrying current of 10 amps leads to high start-up currents and voltage drops more than 50 % across other bus-connected loads and reaches steady state due to MPPT as shown in the thesis. Investigation for different irradiation levels is also done.

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ANALYSIS OF DC BUS LOAD TRANSIENTS FOR SOLAR STAND-ALONE SYSTEM

BY

PRATHYUSHA BOMMA

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CHAPTER-1

INTRODUCTION

In this thesis a home is connected to a photovoltaic solar energy system instead of the electrical utility power grid. Increased pollution, global warming caused by burning of fossil fuels, and ever-increasing oil prices are motivating people to choose alternative energy sources. Solar, wind, fuel cells, ocean tidal and geothermal are the most commonly used renewable energy sources. Over these, solar energy converted via photovoltaic cells is the most advantageous because it is simple to build in any place, has flexibility for built-in wide-range capacity, is pollution free, has reduced environmental impact and is economically reliable for long-term operation [5].

This energy from a photovoltaic array is distributed to several residential loads connected to bus. The problem arises when this energy is distributed to various loads as the major appliances of residential loads like refrigerators, incandescent bulbs and ceiling fans involve electrical motors and transformers. Electric motors and transformers when they are first energized draw 10 to 15 times larger current than their normal current. The electrical motors and transformer in it possess high starting currents, which results in voltage drop across other bus-connected loads. Power converters also have inrush currents much higher than their steady-state currents due to charging current of the input capacitance.

Voltage dips during starting of large motors can trip some of the motors operating on the same bus. Due to this, computers and other electronic devices may also be affected. This is the motivation to take up this thesis.

The aim of this thesis is analysis of the stand-alone solar system with DC transient load and storage and the model was designed for the same in MATLAB /Simulink software.

This thesis is comprised of four chapters including various kinds of transient loads and their effects on residential load systems. It also throws light upon various forms of renewable energy sources and photovoltaic solar energy systems. A block diagram of a solar residential load system with transient load and other various design block is developed. The second chapter includes solar power requirements, sizing of the system, transient load and mathematical calculations. The third chapter elaborates on a Simulink model of the entire system for the analysis of DC Bus transients for solar stand-alone system. This model includes all its Simulink blocks like PV array, maximum power-point tracking technique (MPPT), boost converter, storage, transient load and other loads, voltage controller loop and PID controller tuning. An overview about each and every block and its applications is discussed. The fourth chapter includes simulation results and analysis of DC Bus load transients for solar stand-alone system, and investigation of the system for various solar irradiation levels is performed.The last chapter includes the conclusion of the thesis.

CHAPTER -2

DESIGN REQUIREMENTS

Figure 2.1 shows the block diagram of the residential system to be modelled in MATLAB/Simulink. Here solar energy is used as the source of energy due to the following advantages. All other blocks are discussed in brief in this chapter.

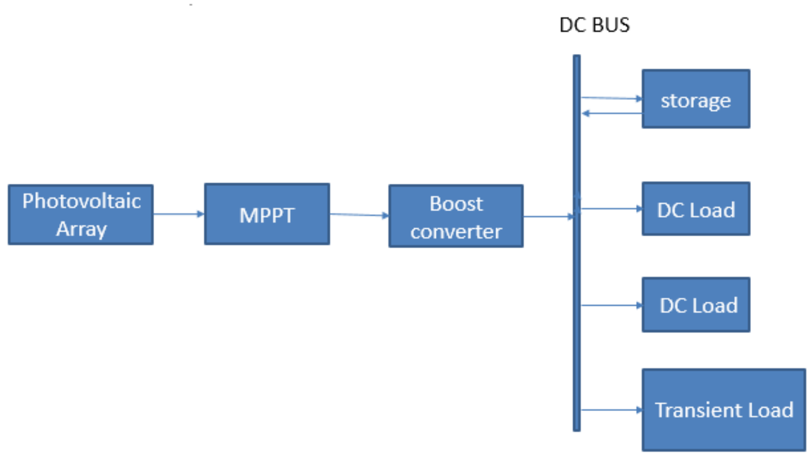


Figure: 2.1 Design block diagram of a residential load system

2.1 Why Solar Energy?

Solar energy is the best source of energy [5]. According to the current statistics earth receives 174,000 terawatts of solar radiation, approximately the amount of solar energy reaching the earth's surface is twice the amount of other renewable energy sources like wind, tidal and geothermal energy. The total amount energy of generated by solar radiation is 7,000 (human energy requirement).

Solar energy is generated by various methods like solar heat, photovoltaics, solar thermal energy and solar artificial photosynthesis [5]. Among all the methods, solar energy converted by the photovoltaics is the most promising renewable energy sources.

2.1.1 Advantages of Solar Energy

- Solar energy system is simple and flexible to build in any place in a wide range of capacity.
- Solar energy is pollution free, so it has reduced environmental effect.
- It is also economically reliable for longer term.
- It is a clean and continuous supply with unrestricted power.

2.2 Photovoltaic Effect

The solar cell is the significant component which facilitates the electrical energy in a photovoltaic (PV). A solar cell is a p-n junction fabricated in a thin layer of semiconductor. The photovoltaic effect causes the electromagnetic radiation of solar energy to be directly translated to electrical energy. This phenomenon occurs when the photons in sunlight fall on the solar cell, which have energy higher than that of the band-gap energy of the solar cell semiconductor. These photons are then absorbed leading to the formation of electron hole-pairs, whose density relies directly on the incident solar irradiation. These pairs then act as carriers that are swept apart due to the effect of the internal electric fields of the p-n junction, generating photo current. Figures 2.2 shows the photovoltaic effect [5].

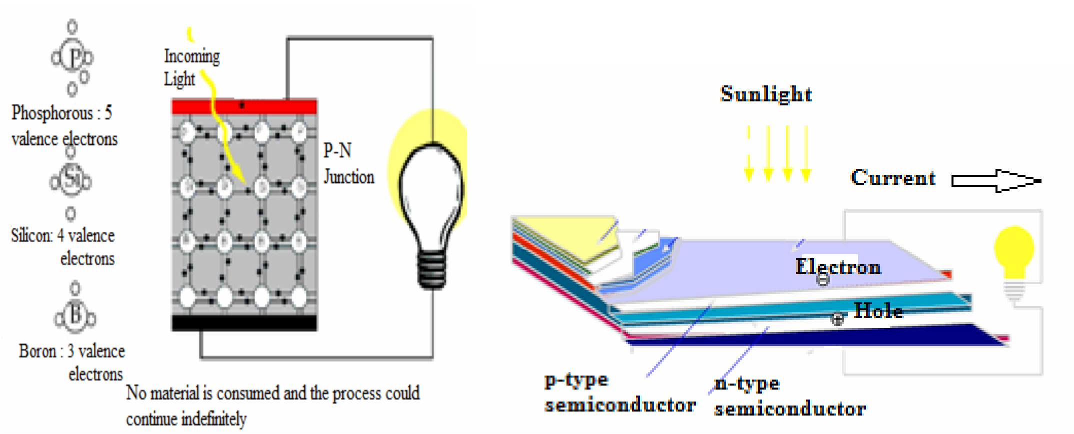


Figure 2.2 Photovoltaic effect and PV cross-sectional view [5]

2.3. Sizing of the System

2.3.1 Solar panel

In order to meet the residential load requirement the solar cells, in the panel should be connected in series and parallel, the cells arranged in parallel and series form modules and in turn these modules form PV arrays. In this thesis eight cells are connected in series and six cells are connected in parallel with 48 solar panels to overcome lower output voltage of solar cell [5].

No. of solar panels * $PV_{area}(m^2)$ * $PV_{efficiency}$*$Radiation_{kwh/m^2 day}$ = power (kwh/day) …1 [5]

The solar radiation is assumed to be 1000 $\frac{watts}{m^2}$ and solar radiation of the stand-alone solar system is assumed to be 5.5 kwh/m^2/day [5]. The daily load requirement per hour is considered to be 1.92 kw [5]. (See Table 1.)

Table: 1 Solar Panel System Specifications [5].

Daily load requirement per hour	1.92kw
Average radiation	5.5 kwh/m^2/day
Number of modules	48 from equation 1
PV_{area}	67.4 (1.4 $m^2/module$* no of modules)
Efficiency	12.9%

The design specifications of the PV array is taken from a previous thesis [5].The solar power alone is not sufficient to meet the requirements of the load as the average radiation is 5.5 kwh/$\mathrm{m}^2/\mathrm{day}$. To ensure that there is enough energy for the system there should be battery which can supply energy during hours of no sun.

In this thesis current-controlled source is used as energy storage system which stores energy during day time (or sun hours) and supplies energy during night time. Here current-controlled source instead of battery is used to overcome design complications.

2.4 DC Voltage Control Loop

The standard AC voltage to be maintained at the load bus is 120V.

In order to reduce the complexity in the model DC bus, transients are shown and the DC voltage to be maintained is calculated.

$$V_{dc} = 2V_{max}/\pi = 2\sqrt{2}V_{rms}/\pi = 0.9\ V_{rms}$$

$$V_{dc} = 0.9 * 120$$

$$V_{dc} = 108\text{V}$$

108 V is used as a reference voltage to maintain the constant voltage at the DC load bus.

2.5 Design of Load

In this thesis two types of loads are connected to the same DC bus, resistive load and transient load.

2.5.1 Resistive Load:

It is designed to draw 2000 watts as the maximum hourly power consumption is 1.92kw [5].

$$R = \frac{V^2}{P}$$

$$R = (108)*(108) / 2000$$

$$R = 5.8 \text{ ohms}$$

2.5.2 Transient Load

DC transient load is designed to carry current of 10 amps with a step time of 15 seconds; it is connected in parallel with resistive load to the same DC bus. Residential loads like bulbs, inductions motors and transformers draw high power among other loads.

CHAPTER 3

SYSTEM TOPOLOGY

The system topology consists of a solar panel which is connected to a boost converter (DC/DC converter), as seen in Figure 3.1.The output of a boost converter is connected to a DC link of 108V; DC voltage is controlled by varying reference voltage. The load here used is a transient load in parallel with a resistive load [5].

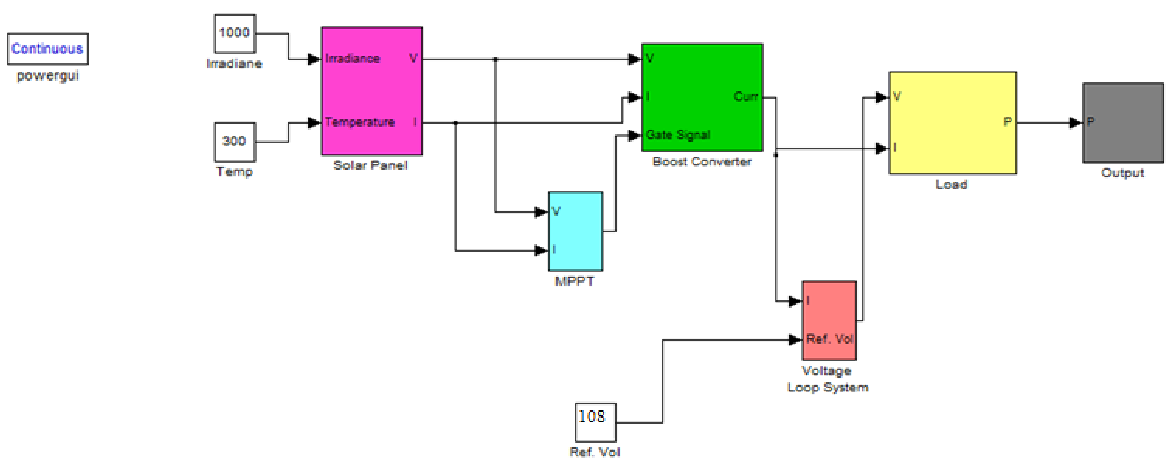


Figure: 3.1 Block diagram of the solar stand-alone system with transient load.

3.1 Solar Panel

Solar panel consists of PV array, boost converter and MPPT which is connected to DC bus that delivers DC power to residential load.

3.1.1 Mathematical modelling of PV array

An ideal solar cell is modelled by current source in parallel with a diode, the shunt resistance Rsh or series resistance Rs is added to the model. The resulting equivalent model of solar cell is shown in the Figure 3.2 [4].

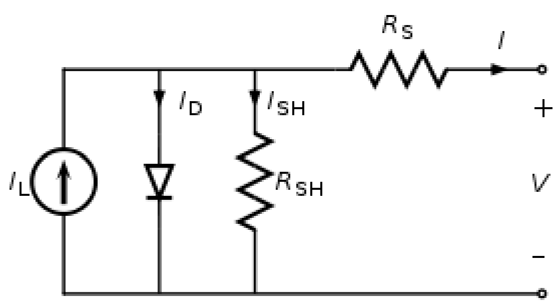


Figure: 3.2 Equivalent model of solar cell [4]

Solar cell uses photoelectric effect and converts solar energy into electrical energy. Thus electrical characteristics like current, voltage and resistance vary when light is incident upon it. This results in generation of electric current without being attached to any external voltage source. To obtain power consumption, external load is attached [4].

Solar cell construction includes the following equations:

Thermal Voltage Equation

$$V_T = \frac{K_B T_{OPT}}{q}$$

Diode Current Equation

$$I_D = Np\ I_S\ [e\ (V/Ns) + (IRs/Ns)/N\ V_T\ C\ -1]$$

Load Current Equation

$$I_L = I_{PH}\ Np - \mathbf{I_D} - I$$

Photocurrent Equation

$$I_{PH} = [ki\ (T_{OPT} - T_{REF}) + I_{SC}]\ I_{RR}$$

Shunt Current Equation

$$I_{SH} = (IRs+V)/R_{SH}$$

Reverse Saturation Current

$$I_S = [I_{RS}\ (T_{OPT}/T_{OPT})3 * q^2 Eg/Nk_B * e\ (1/T_{OPT} - 1/T_{REF})$$

Reverse Current Equation

$$I_{RS} = I_{SC} / [e^{(\frac{qV_{OC}}{k_i C T_{OPT}})} - 1]$$

Output Power

$$P=VI$$

V_{OC}: Open circuit voltage (21.1V).

I_{Ph}: Photocurrent function of irradiation and junction temp (5 A).

I_S: Reverse saturation current of diode (2*10-4 A).

I_{SC}: Short circuit current (3.8A).

I: Cell output current (A).

T_{REF}: Reference operating temperature of Cell (25 °C).

T_{OPT}: Operating temperature of cell (°C).

R_{SH}: Shunt resistance of cell (360.002 Ω).

R_S: Series resistance of cell (0.18Ω).

Eg: Energy band gap (1.12 eV).

N: Ideality factor (1.36 for solar cell).

k_B: Boltzmann constant (1.38 × 10-23 J/K).

k_i: Current proportionality constant (2.2*10-3).

k_v= Voltage proportionality constant (73*10-23).

q : Electron charge (1.602 × 10^{-19}C).

Ns: No. of cells in series (8)

Np: No. of cells in parallel (1)

G: Irradiance (W/m^2).

C= No. of cells in module (72)

C_1=200uf, C_2= 3mf, L=0.01H

The ideal PV and IV characteristics of the solar panel are shown in the Figure 3.3.

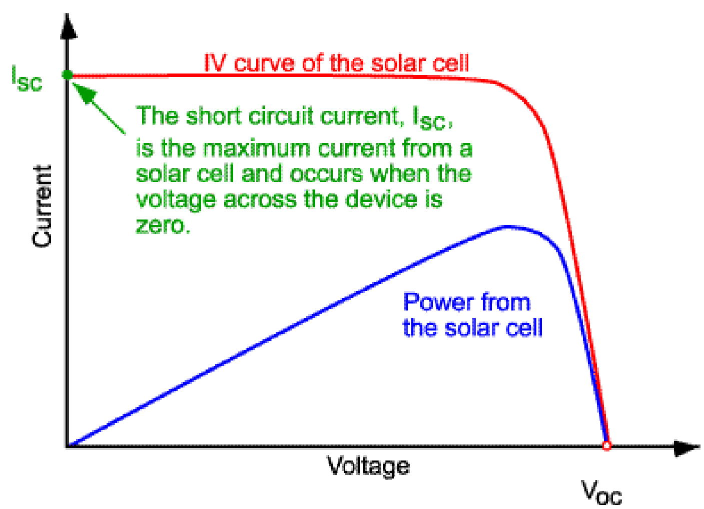


Figure: 3.3 PV and IV characteristics of solar panel [4].

The equations described above are modelled and designed to show IV and PV characteristics from a single diode solar cell in MATLAB/Simulink as shown in Figure 3.4, which is submask of solar panel from Figure 3.1.

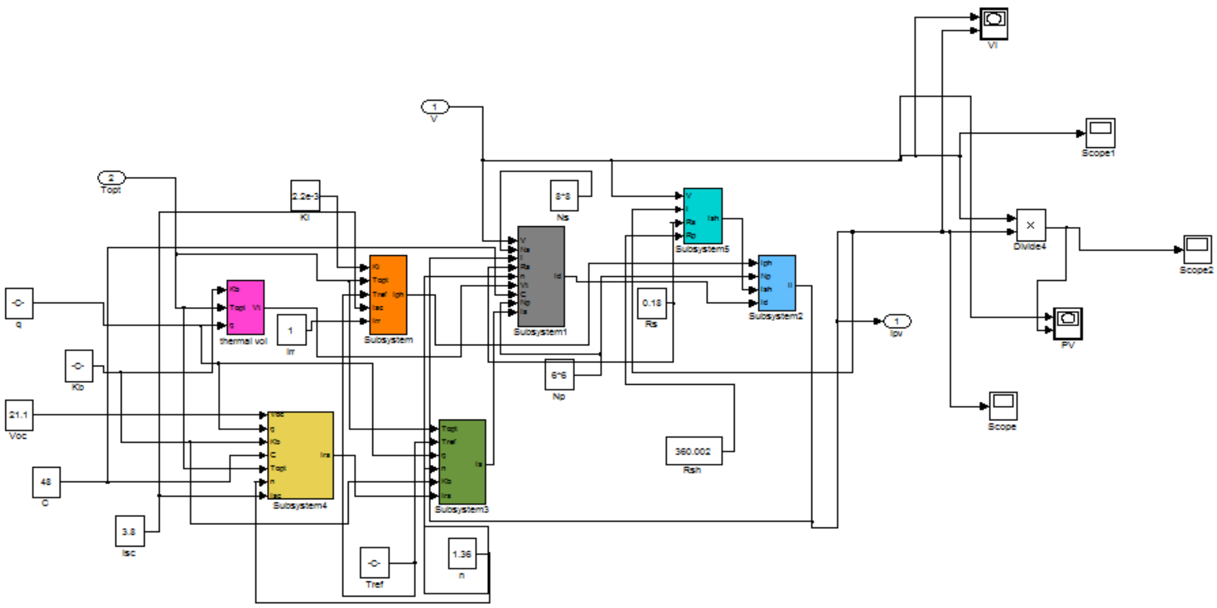


Figure: 3.4 Solar panel topology

3.1.2 Modelling of Susystem Equations

$V_T = K_B T_{OPT}/q$ is the thermal voltage equation which is used to describe average energy of electrons diffused in solar cells. Thermal voltage V_T becomes 25.85mV and operating temperature T_{OPT} is set to 300K.Figure 3.5 below shows the submask of thermal voltage from Figure 3.4.

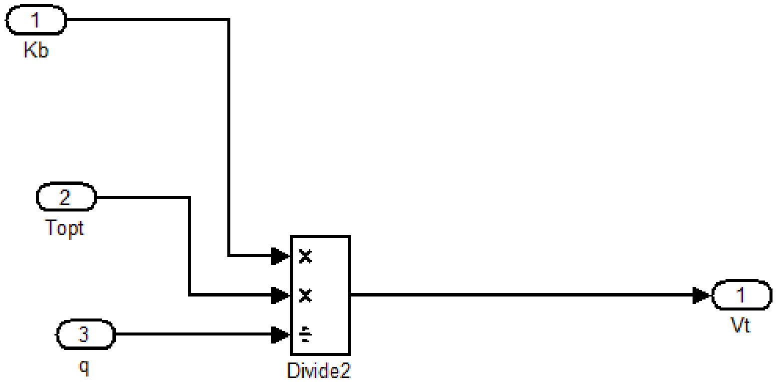


Figure: 3.5 Thermal voltage equation [4].

I_D= Np I_S [e (V/Ns) + (IRs/Ns)/N V_T C -1] is the diode equation for the current through the diode as a function of voltage [2].Figure 3.6 below shows the diode current equation model which is a sub mask of subsytem1 from the Figure 3.4.

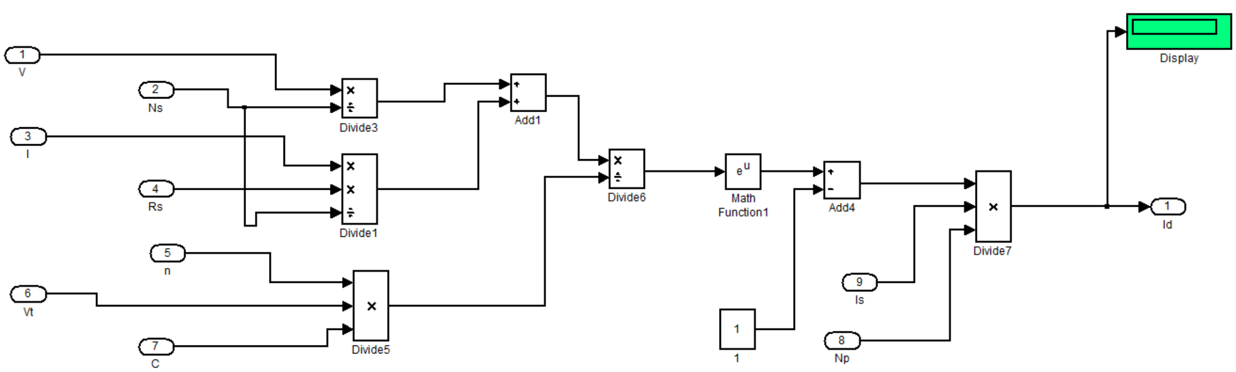


Figure: 3.6 Diode current equation model [4]

I_L = I_{PH} Np- $\mathbf{I_D} - I_{sh}$ is the load current equation which is shown below in Figure 3.7.

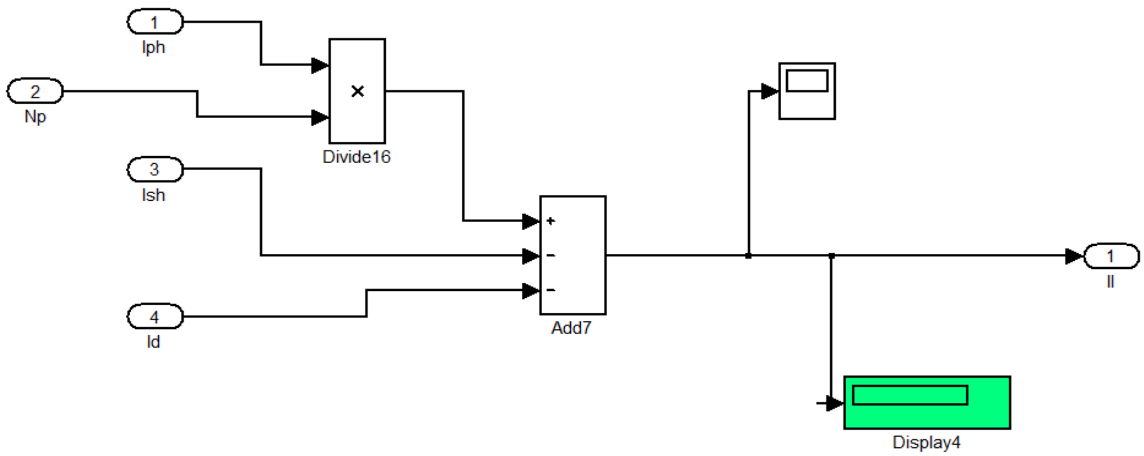


Figure: 3.7 Load current equation model [4].

I_{PH}= [ki (T_{OPT} -T_{REF}) +I_{SC}] I_{RR} is the photocurrent equation (Figure 3.8); when the light is incident on a solar cell, there is a current flow due to the thermal excitation of the minority carriers. Reverse saturation current also affects the photocurrent. Photo current is dependent both on reference cell and operating cell temperature.

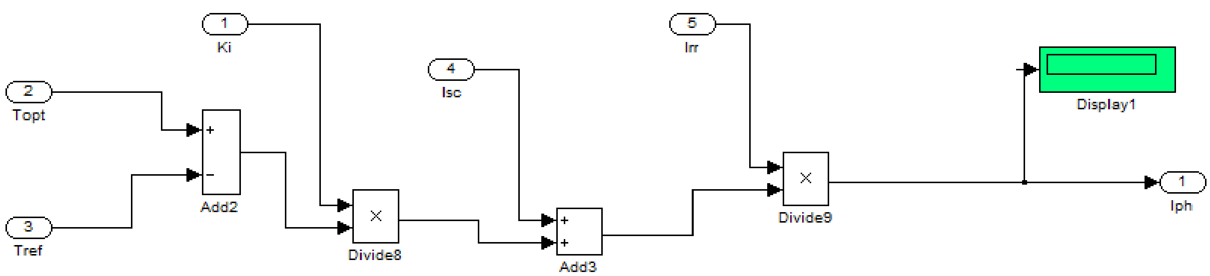


Figure: 3.8 Photocurrent equation model [1].

I_{SH} = (IRs+V)/R_{SH} is the shunt current equation (Figure 3.9). It can be shown that for a solar cell, low Rs and Is and high R_{SH} and I_{SH} alters expression of equations. Losses occurring in solar cell are due to manufacturing defects in values of series and shunt resistance. A solar cell behaves neither as current source nor as a voltage source. Since losses caused by series resistance are given by $P_{loss} = IV = I^2R_s$, they increase, quadratically with photocurrent. Similarly, current diverted through the shunt resistor increases causing the voltage-controlled portion of the IV curve to sag towards origin.

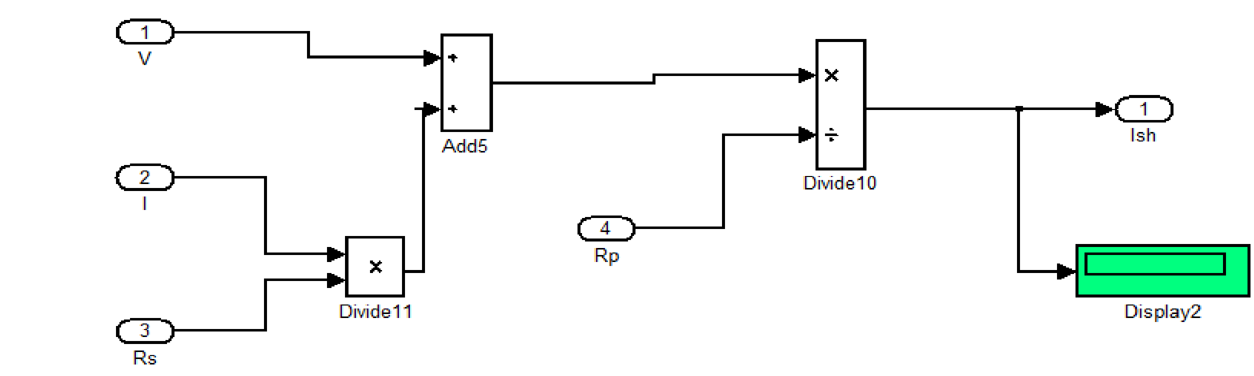


Figure: 3.9 Shunt current equation model

I_S = [I_{RS} (T_{OPT}/T_{OPT})3 *q^2Eg/Nk_B *e (1/T_{OPT}-1/T_{REF}) is the reverse saturation current equation (Figure 3.10). It is the current that flows in the reverse direction when the diode is reverse biased and it is also termed as leakage current Is. It is dependent on temperature, diffusion constant, energy band gap, ideality factor, Boltzmann constant.it is also dependent on temperature and material quality.

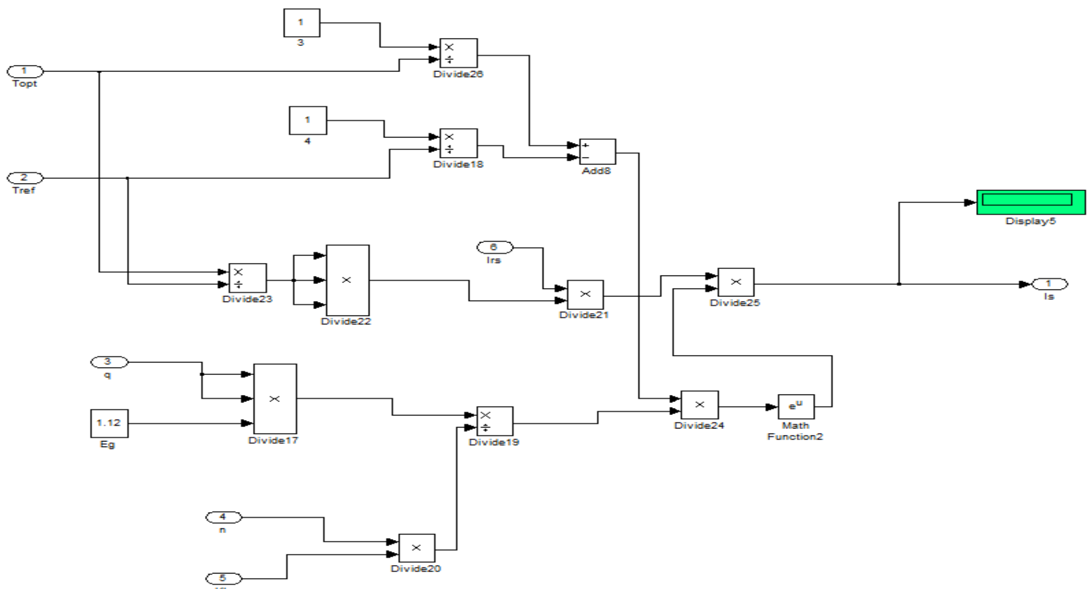


Figure: 3.10 Reverse saturation current equation model [4].

$I_{RS}= I_{SC} / [e^{(\frac{qV_{OC}}{k_i C T_{OPT}})}-1]$ is the reverse current equation which is relative to open circuit voltage and operating voltage (Figure 3.11).

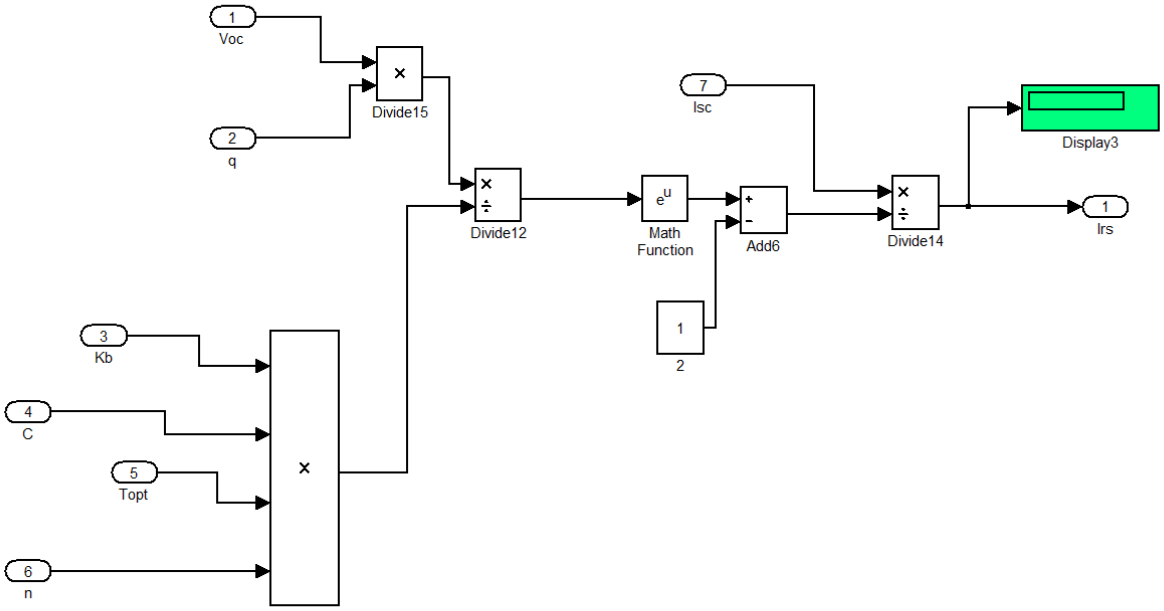


Figure 3.11 Reverse current equation model [4].

3.2 Maximum Power Point Tracking

Maximum power tracking (MPPT) helps to increase the efficiency of the solar cell as the efficiency of solar cell is very low. MPPT is the technique which is used to match the source and load to obtain maximum possible power from a varying source [3].

The PV and IV characteristics of a photovoltaic system are nonlinear making it very difficult to power a residential load system; hence, the boost converter is used for which the duty cycle is provided by the MPPT algorithm.

There are different methods used for maximum power point tracking; among them a few are listed below [3]:

- Perturb and observe method
- Incremental conductance method
- Parasitic capacitance method
- Constant voltage method
- Constant current method

3.2.1 Perturb and Observe method:

Perturb and observe algorithm is used as MPPT algorithm due to its ease of implementation and low cost, which results in increased efficiency [2]. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples the change in power to the change in voltage if $\frac{dp}{dv}$ is positive, then the algorithm increases the voltage value towards MPP until $\frac{dp}{dv}$ is negative as shown in the Figure 3.12

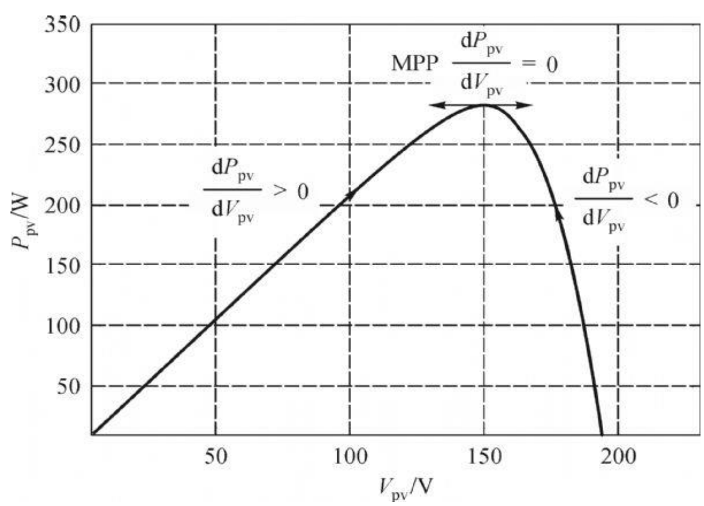


Figure: 3.12 $\frac{dp}{dv}$ changes with respect to MPP

Perturb and observe algorithm is implemented using MATLAB/SIMULINK software. See Figure 3.13.

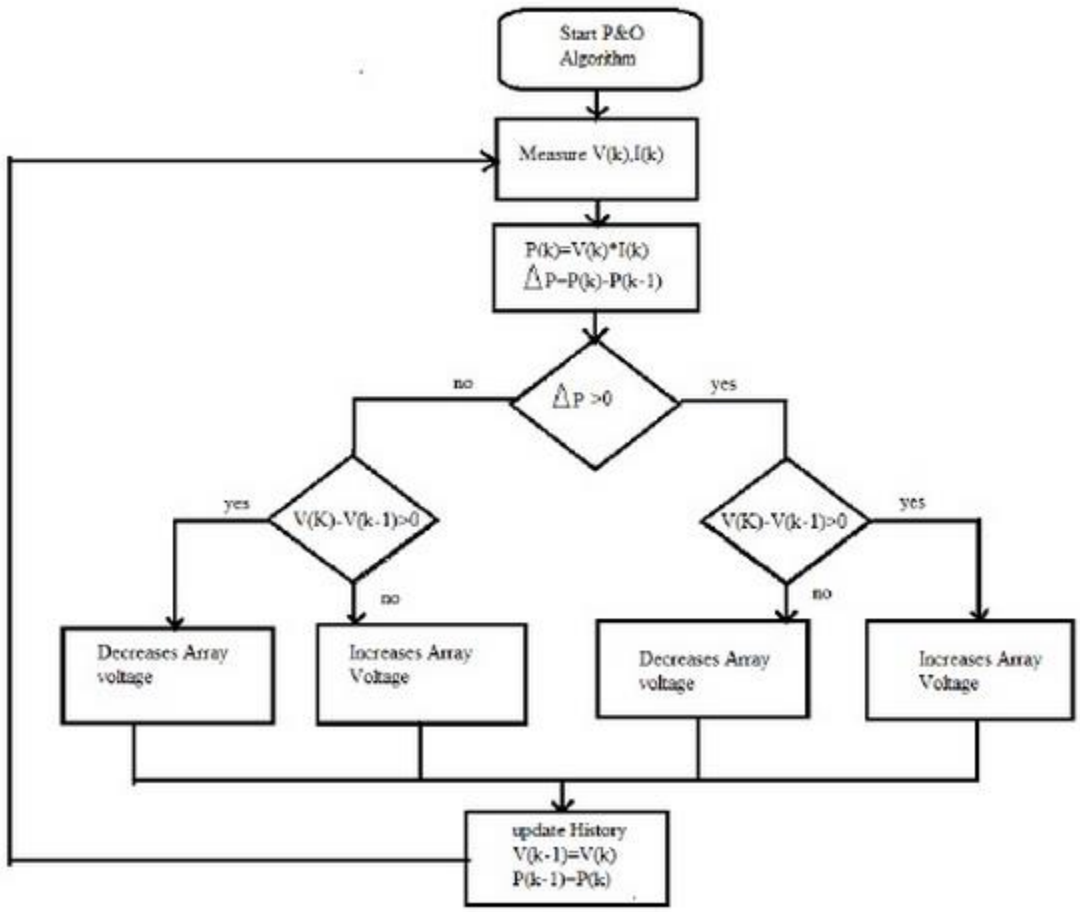


Figure: 3.13 Flow chart of P & O algorithm

First, the power is calculated by the product of current and voltage, thereby the difference between two successive intervals of power is calculated. In a similar way, difference between two successful intervals of voltage is calculated.

When $\Delta P > 0$ where $\Delta P = P_k - P_{k-1}$

Case 1: $\Delta P > 0$ and $V_K - V_{k-1} > 0$

This shows that the operating point perturbed in the right direction. The operating point has also shifted towards MPP; hence, the perturbation should be continued in the same direction.

Case 2: $\Delta P > 0$ and $V_K - V_{k-1} < 0$

Here, when power increases, voltage decreases. This shows that the voltage should be reversed

Case 3 When $\Delta P < 0$ and $V_K - V_{k-1} > 0$

In this the power is drifted away from MPP. See Figure 3.14.

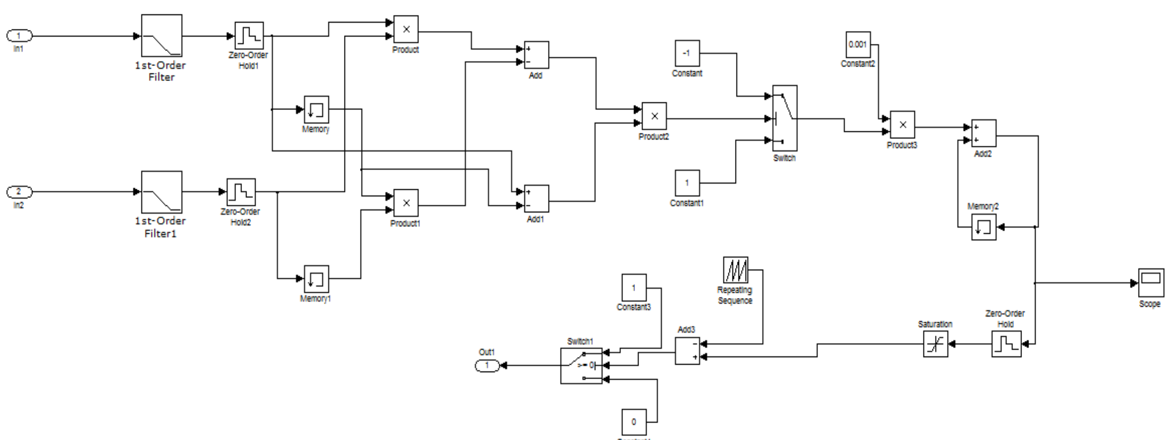


Figure: 3.14 Simulation model of perturb and observe MPPT

3.3 Boost Converter

3.3.1 Mathematical modelling of Boost converter

The boost converter is operated in continuous inductor current mode; the large inductor is required for this. As the output voltage of solar cells is low, boost converter is used to improve the output voltage. A boost converter using MOSFET is shown in the Figure 3.15 below. See also Figure 3.16.

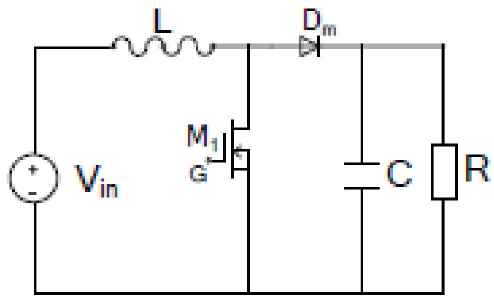


Figure: 3.15 Boost converter [5]

Mode 1: When switch is ON, inductor acquires and stores the energy from solar cells. The current rises through L. The full supply voltage is applied across the inductor L:

$$V_s = L\frac{di}{dt}$$

$$uc/R = C\,\frac{duc}{dt}$$

Mode 2: When switch is OFF, inductor current flows through load, then the energy which is stored in the inductor and the source is transferred to the capacitor and the load.

$$V_s = L\frac{di}{dt} + uc$$

$$I_L = C\frac{duc}{dt} + \frac{uc}{R}$$

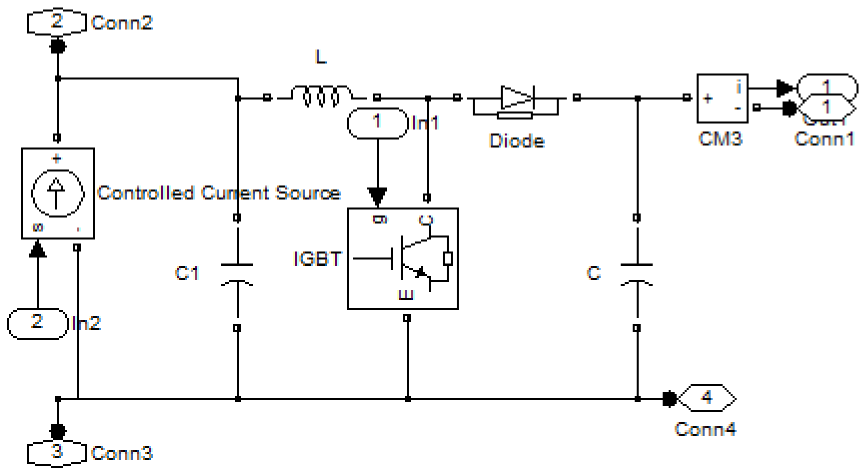


Figure: 3.16 Simulink model of boost converter in MATLAB/SIMULINK

3.4 Voltage controller

In case of grid-connected system the voltage is controlled by the grid whereas in stand-alone solar house system the voltage is uncontrollable so, in order to protect the load from bad voltages, voltage loop controller is designed as shown in the Figure 3.17 below.

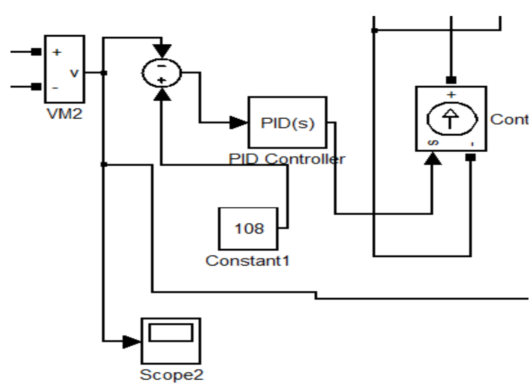


Figure: 3.17 Voltage controller loop

The current controller which is shown in the Figure 3.18 is used as an energy storage system which is used to supply the load during night and when there is no solar power.

3.5 PID controller tuning

PID tuner provides a fast and widely applicable single-loop PID tuning method for the Simulink PID controller blocks with this method [1].A typical design workflow with PID tuner involves the following tasks:

- Launch the PID tuner.
- Tune the controller in PID tuner by manually adjusting design criteria in two design modes.
- The tuner computes PID parameters that robustly stabilize the system.
- Export the parameters of the designed controller back to the PID controller block to verify controller performance in Simulink [1].

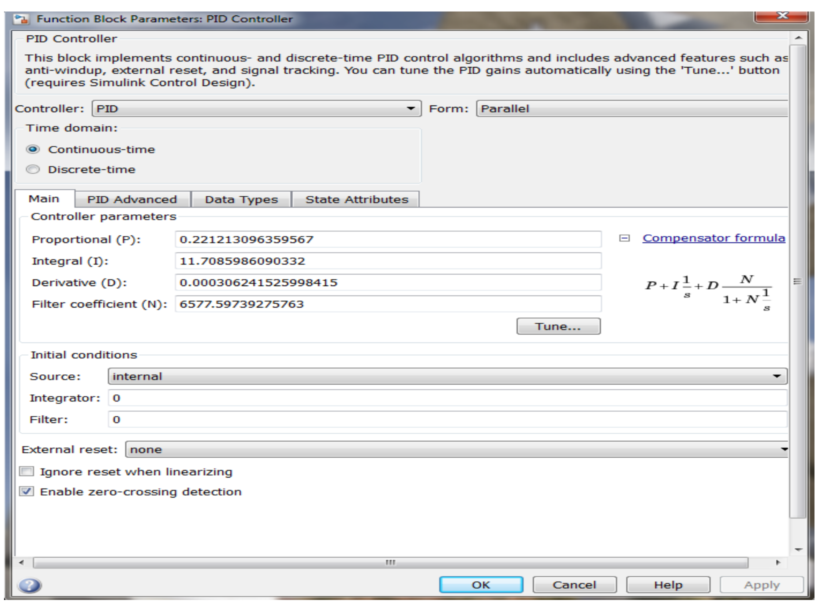
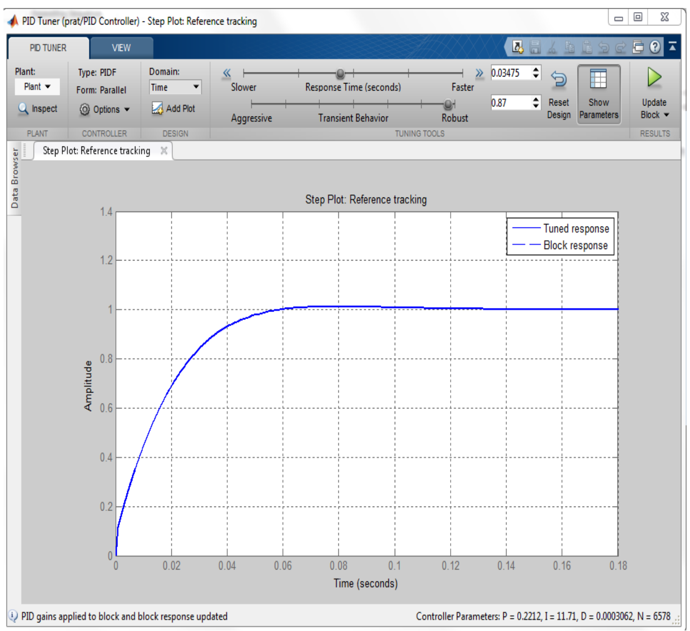


Figure: 3.18 PID controller tuning

Open the PID tuner. In the main tab click Tune, when the PID tuner launches, the software computes a linearized plant model seen by the controller. The software automatically identifies the plant input and output, and uses the current operating point for the linearization.

Figure 3.19 shows the adjusted PID design which is obtained after reducing the overshoot by increasing the response time. The parameters are shown in the Figure 3.19. The settling point is decreased by adjusting the response time and increasing robustness to get the stable output. Then the block is updated to check the nonlinear model [1].



Controller Parameters

	Tuned	Block
P	0.22121	0.22121
I	11.7086	11.7086
D	0.00030624	0.00030624
N	6577.5974	6577.5974

Performance and Robustness

	Tuned	Block
Rise time	0.0349 seconds	0.0349 seconds
Settling time	0.0504 seconds	0.0504 seconds
Overshoot	1.25 %	1.25 %
Peak	1.01	1.01
Gain margin	Inf dB @ NaN rad/s	Inf dB @ NaN rad/s
Phase margin	87 deg @ 57.6 rad/s	87 deg @ 57.6 rad/s
Closed-loop stability	Stable	Stable

Figure: 3.19 PID controller tuning with parameters.

3.6 Transient Load

Incandescent bulbs, Ac electric motors like induction motors and transformers are the different types of transient loads. In this thesis in order to reduce complexity of a DC to DC transients. DC current-controlled source is used as a transient load shown in Figure 3.20 in addition to a resistive load.

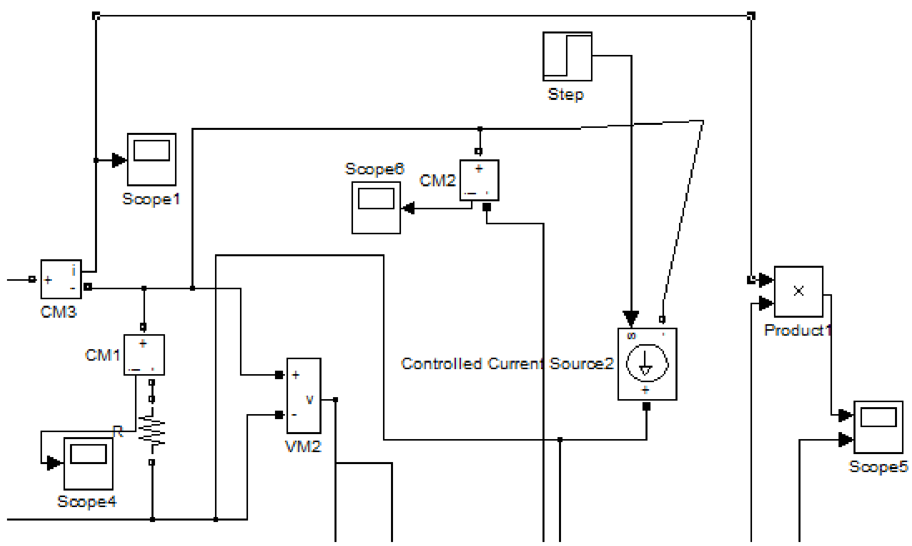


Figure: 3.20 Circuit showing transient load

High inrush currents drawn by the transient loads on DC bus can result in large dip in connected bus voltages. Incandescent lamps, electric motors and transformers draw several times their normal current when first energized. Power converters also have higher inrush currents than their steady-state currents due to charging of the input capacitance. Due to these inrush currents, voltage drop occurs at bus-connected loads. Voltage dips during starting of large motors can also trip some of the motors operating on the same bus. This can also affect computers and other electronic devices connected to the bus.

CHAPTER 4

SIMULATION AND RESULTS

The entire Simulink model of analysis of DC bus transients for solar stand-alone system with its blocks like PV array, boost converter, MPPT, voltage control loop with PID control tuning and the transient load is shown in the Figure 4.1 below.

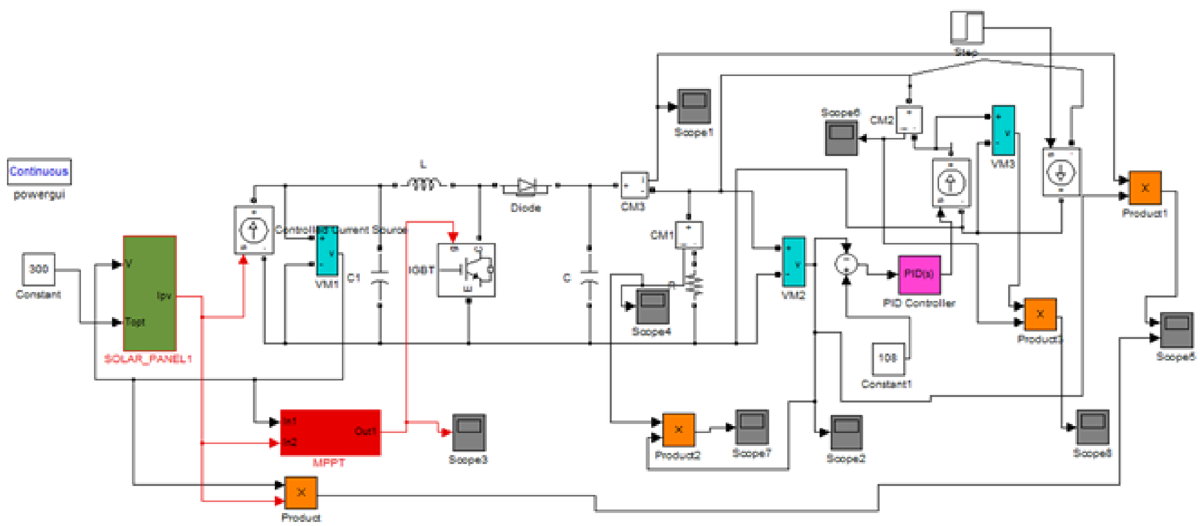


Figure: 4.1 Simulink block of solar stand-alone system with transient load

Analysis of DC bus load transients for solar stand-alone system was done based on the parameters of solar panel discussed in Chapter 3 with transient load.

- Number of solar cells = 8 cells in series and 6 cells in parallel = 48 cells
- Number of solar panels = 8 panels in series and 6 panels in parallel = 48 panels
- Transient load is a step signal with 15 sec and 10 amps.
- Resistive load = 2000 watts
- Temperature = 300k
- Reference voltage = 108 V
- Irradiance = 1000 w/m^2 (ideal case)

4.1.1 Irradiance =1000 watts/m^2

The solar Simulink model is simulated for 0 watts/m^2/day.

4.1.2: Converter current

Figure 4.2 shows the output current drawn by the boost converter with a spike (high inrush currents) of about 10 amps which is due to the transient load with step time of 15 seconds. The converter current is about 138 amps and due to inrush current it reached 148 amps. The current goes to steady state due to maximum power point tracking technique, as MPPT matches the source with load.

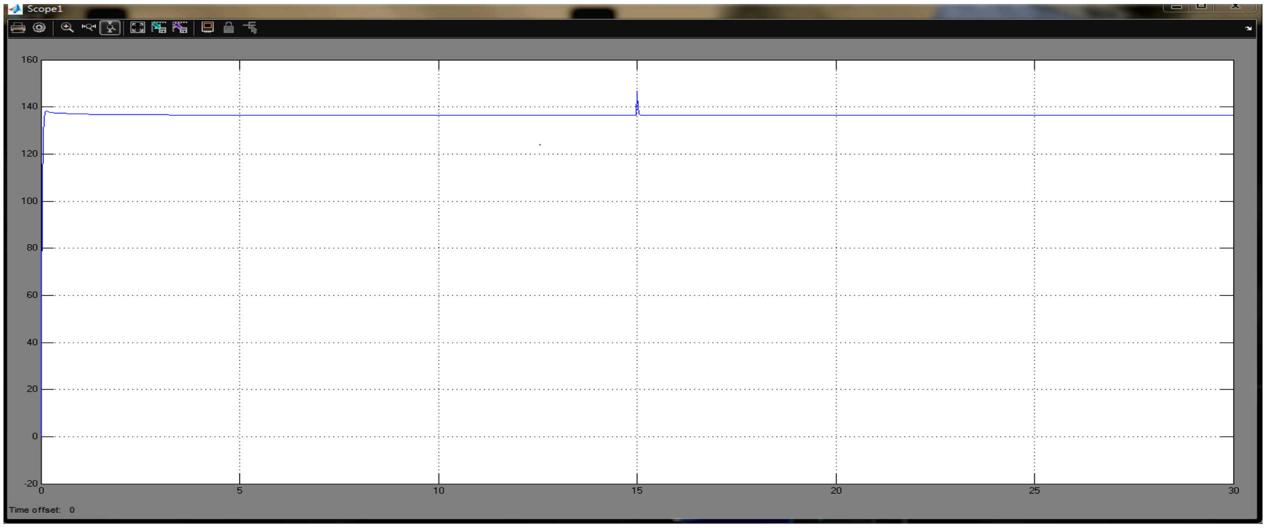


Figure: 4.2 Graph showing converter current

<u>4.1.3 Current through resistive load</u>

As the solar model proposed in this thesis is a stand-alone system, the load requirement considered should be maximum hourly load consumption. The maximum hourly power consumption is 1.92 KW. So the resistive load is designed to carry 2000 watts energy (R = 5.8 ohm). The drop in the current is due to transient load inrush currents connected to the DC bus as shown in the Figure 4.2.

<u>4.1.4 Voltage through Resistive load</u>

The voltage through resistive load is shown in the Figure 4.2; it drops from 700 volts to 108 volts. This is done by the voltage control loop, as the reference voltage at the bus is set to 108 V. As proposed due to high transient currents, the drop in voltage at the other DC bus-connected load is about 50% of its voltage. This may also trip the motors and other electronics connected to the bus.

4.1.5 Power across resistive load

The load is designed to carry 2000 watts energy as the maximum hourly energy consumption is 1.92KW [5]. The load draws 2000 watts as proposed and with transient at 15 seconds due to transient load is shown in the Figure 4.3.

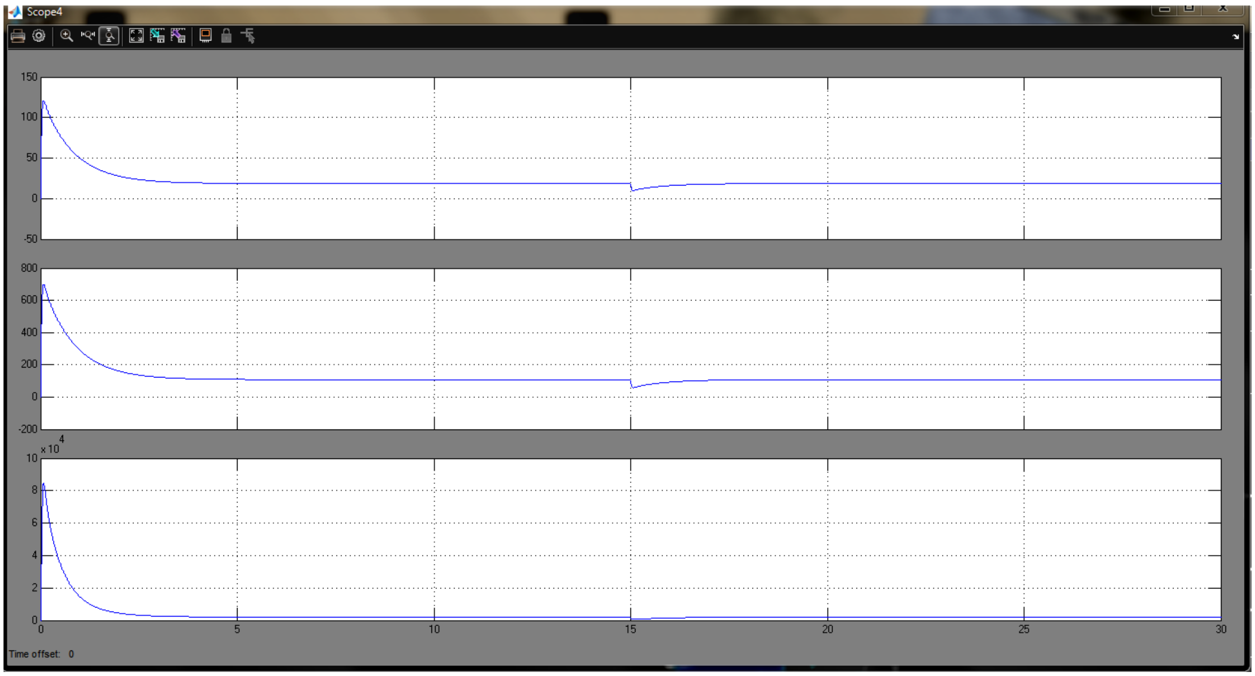


Figure: 4.3 (i) Current, (ii) voltage, and (iii) power across resistive load

4.1.6 Output power

Power supplied by 48 solar panels is 14.7 KW (Figure 4.4).

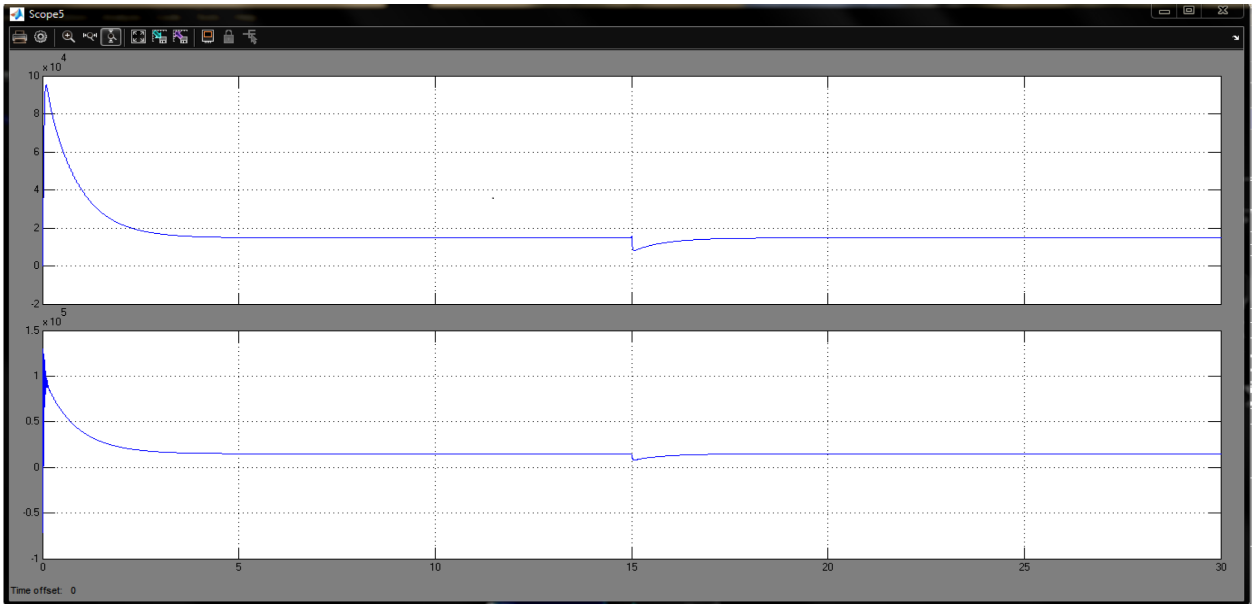


Figure: 4.4 Output power and solar panel output power

4.1.7 Battery power, current and voltage

The load draws 2000 watts; the rest of the power (which is 12 KW) is drawn by the battery (current controlled source) as shown in the Figure 4.7. The drop in power is shown due to transient load.

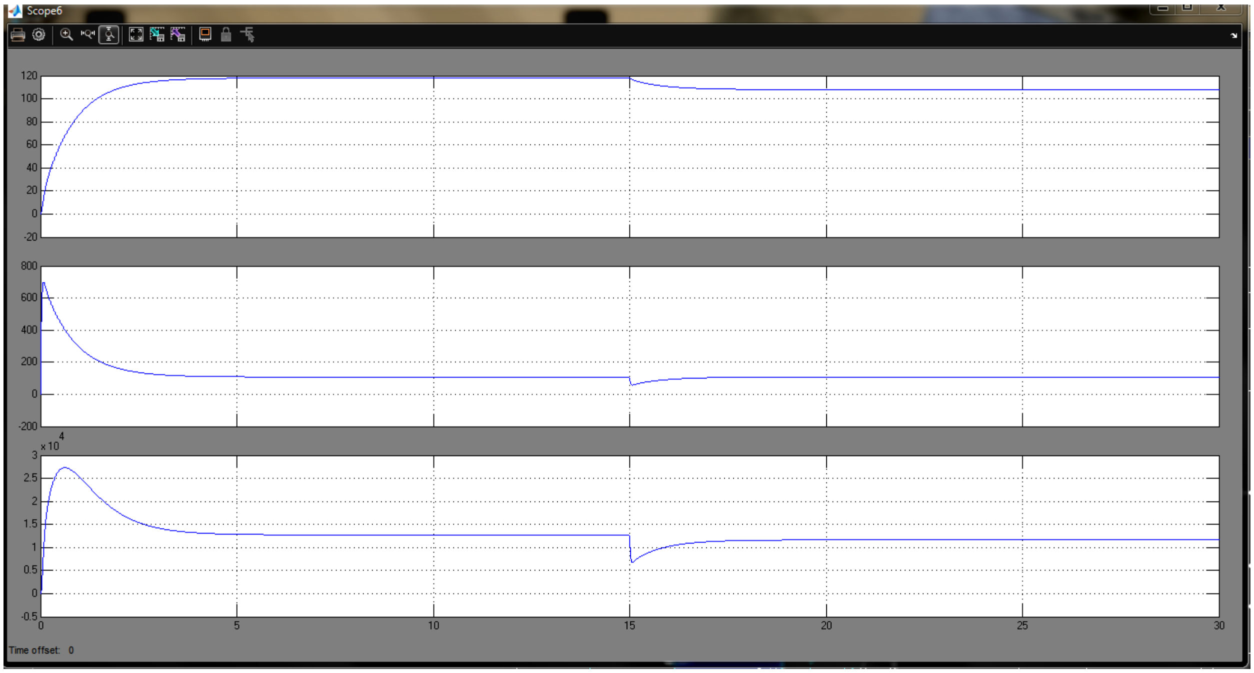


Figure: 4.5 (i) Battery current (ii) Battery voltage (iii) Battery power

4.2 Case study

The solar Simulink model is simulated for 0 watts/m^2/day and 500 watts/m^2/day. The simulations results are shown below. The investigation has been performed for different irradiation levels to check the effect of transient load on the system. It is noticed that whatever the range of irradiance might be, the effect of transient load does not change on the system.

4.2.1 Irradiance = 0 watts/m^2/day (Figure: 4.6-4.9)

The converter current is 0 A as there is no current from the solar panel and spike is due to the transient load of 10 amps. The transient current reaches steady state immediately due to maximum power point technique, which matches the source with load.

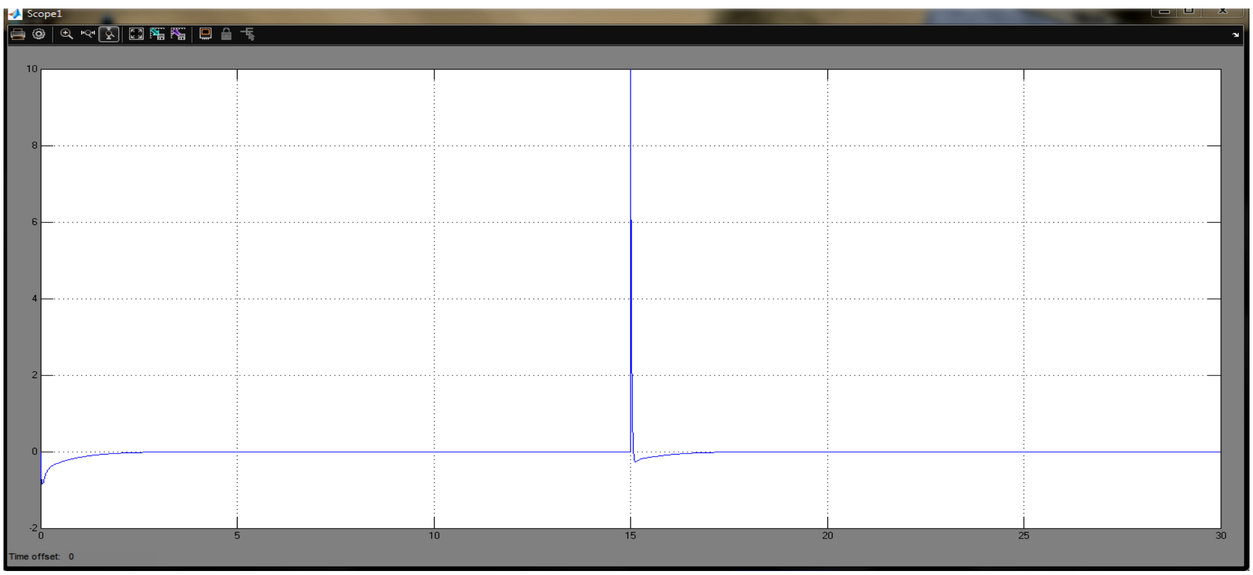


Figure: 4.6 Converter current for 0 watts/m^2/day

The Figure 4.7 below shows the load current, load voltage and load power for irradiance = 0 watts/m^2/day. It is noticed that there is no effect in the transients for different irradiation levels.

Here, as no power is supplied from the solar panel, power is supplied by the battery.

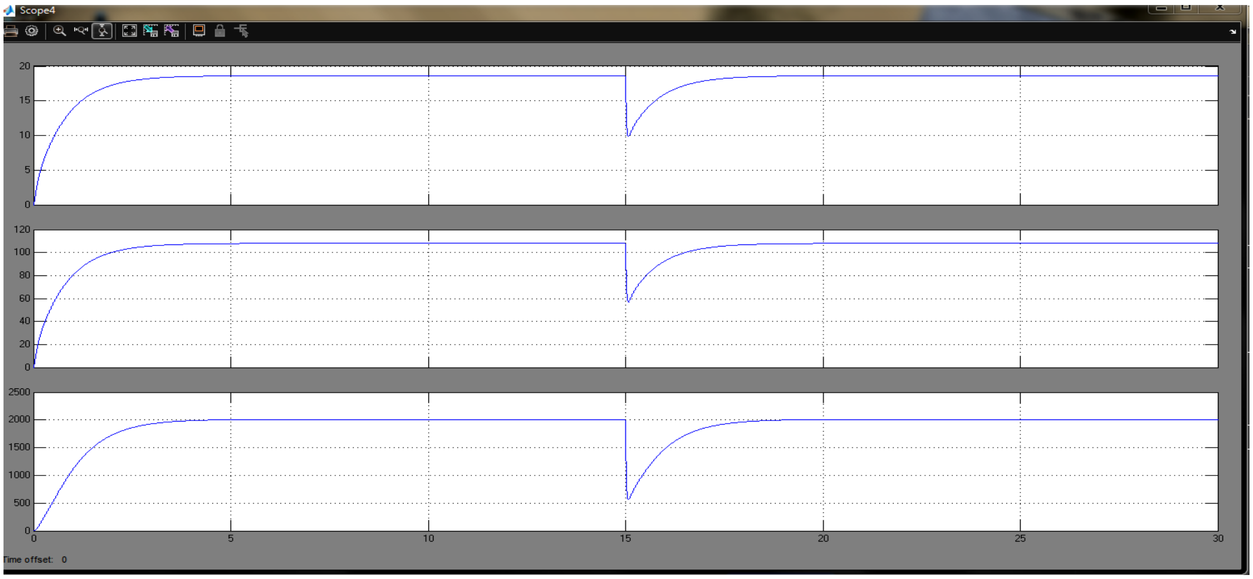


Figure: 4.7 (i) Load current, (ii) load voltage and (iii) load power across resistive load for 0 watts/m^2/day.

For 0 watts/m^2/day irradiance battery is discharging to supply power to the load as there is no supply from the solar panel. The below Figure 4.8 from top to bottom shows the battery current, battery voltage and battery power across resistive load.

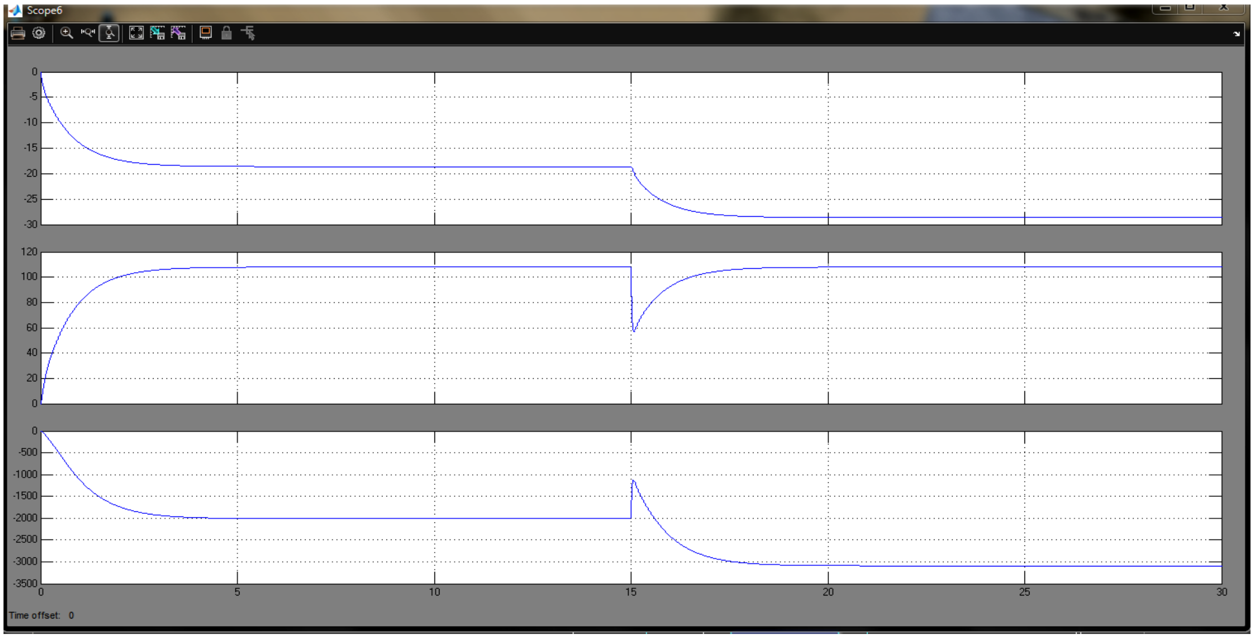


Figure: 4.8 (i) Battery current, (ii) battery voltage and (iii) battery power across resistive load for 0 watts/m^2/day.

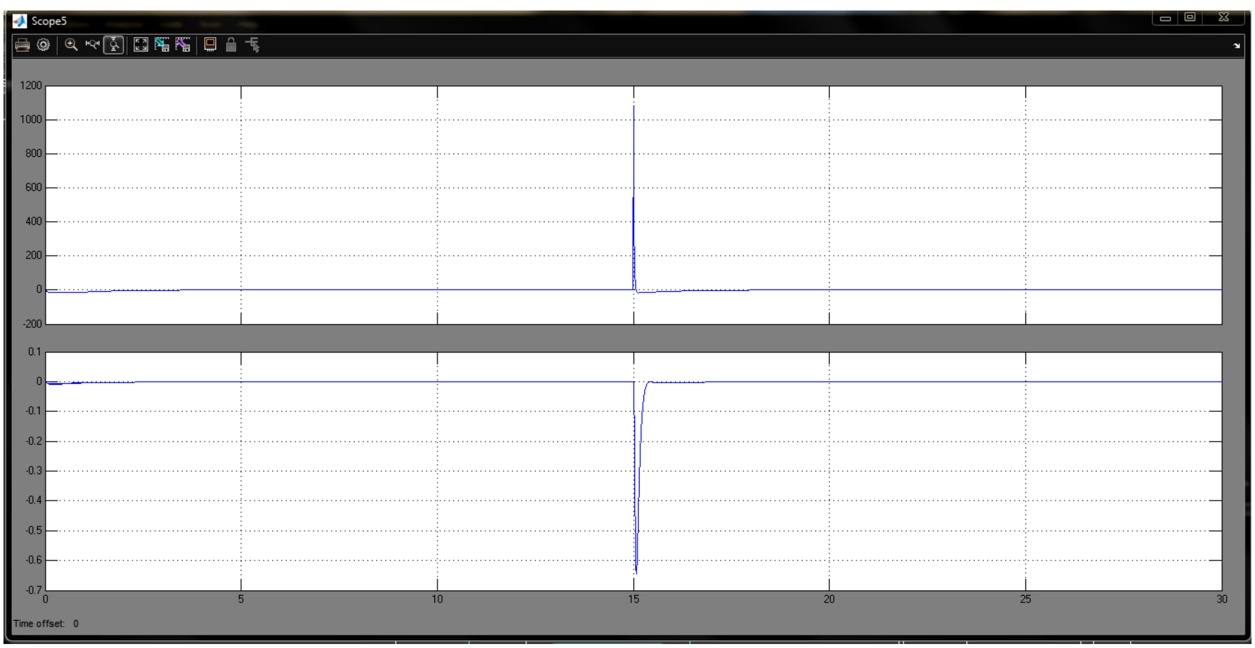


Figure: 4.9 (i) Output power of the whole system and (ii) output power of Solar panel for 0 watts/m^2/day

4.2.2 Irradiance = 500 watts/m^2/day (Figure 4.10 – 4.13)

The Simulink model is simulated for 500 watts/m^2/day. The Figure 4.10 below shows the converter current. Here power is supplied by both solar panel and battery. The converter current is about 68 amps and due to inrush current it reached 78 amps the current goes to steady state due to maximum power point tracking technique, As MPPT matches the source with load.

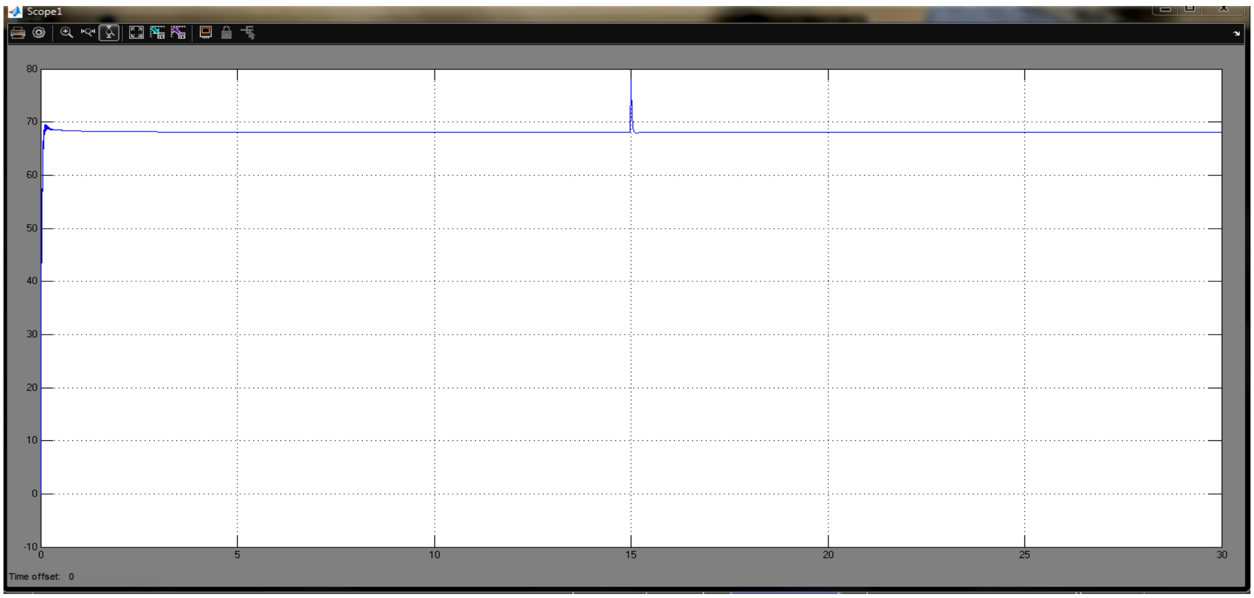


Figure: 4.10 Converter current for 500 watts/m^2/day

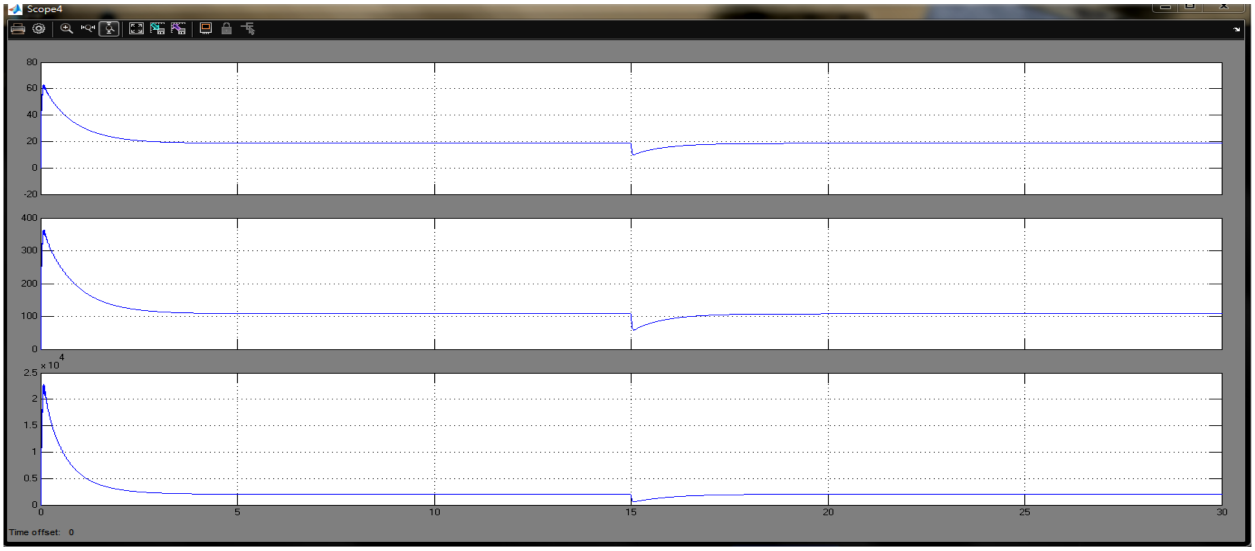


Figure: 4.11 (i) Load current, (ii) load voltage and (iii) load power across resistor for 500 watts/m^2

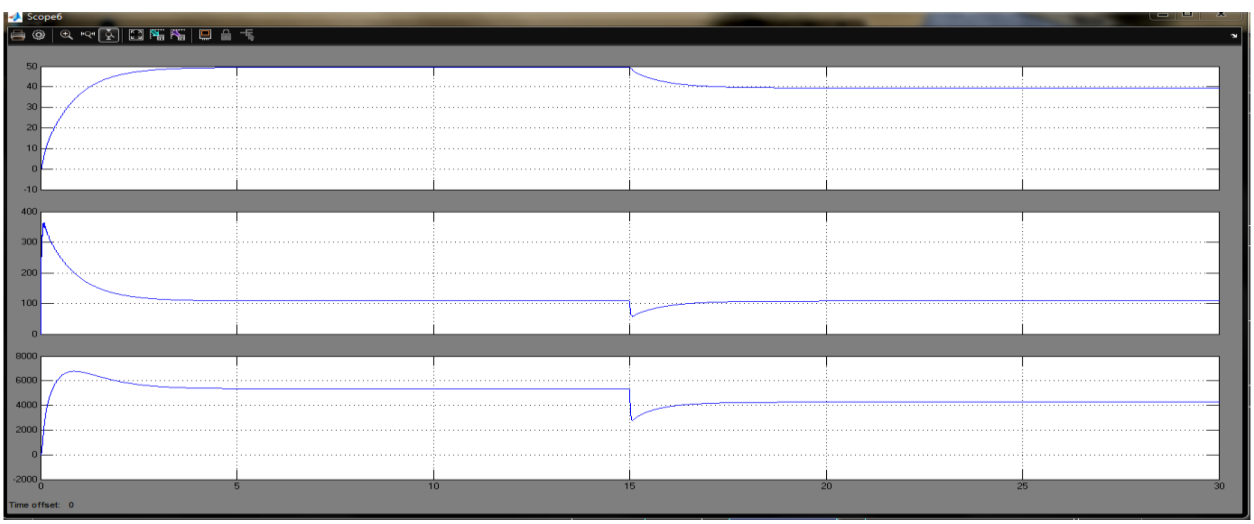


Fig: 4.12 (i) Battery current, (ii) battery voltage and (iii) battery power for 500 watts/m^2/day.

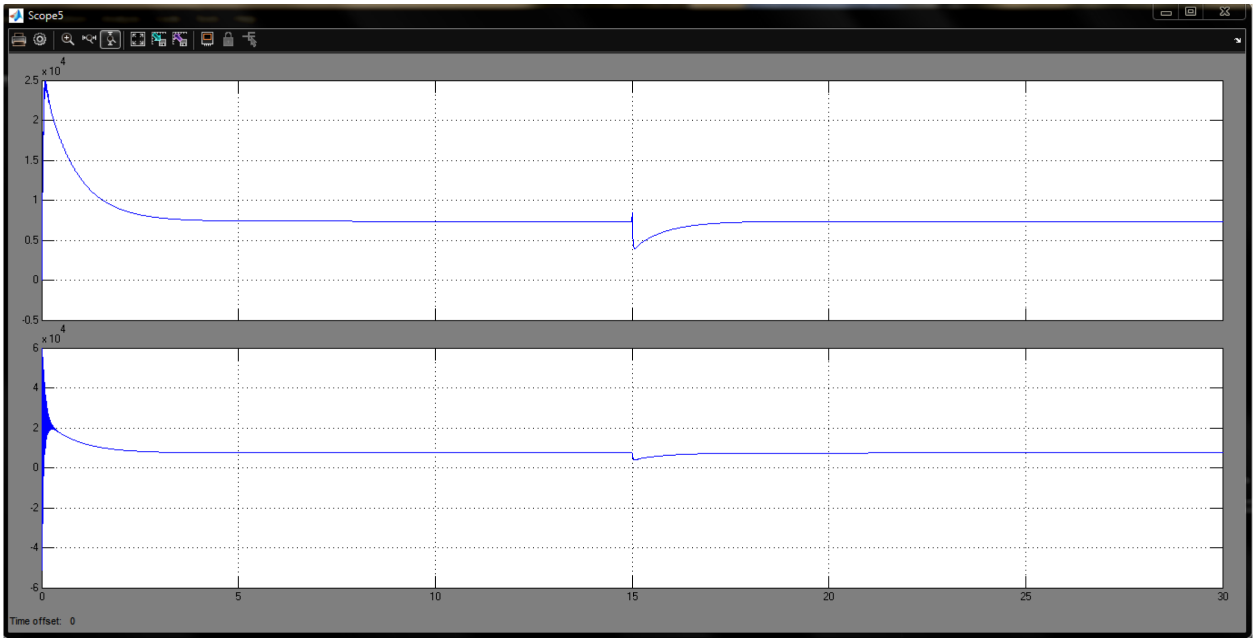


Figure: 4.13 (i) Output power of the whole system and (ii) output power of the solar panel output for 500 watts/m^2/day

4.2.3 Comparison of two irradiances

The whole system is simulated for which different irradiation levels to check the efficiency of the circuit. The load power and transient load power is maintained constant for different irradiation levels, this shows the efficiency of the designed model. The power from the boost converter is flowing through the battery, the positive power shown is charging the battery and negative power is discharging (i.e. supplying power into the circuit) (Table 2).

Table: 2 Comparison of Simulation Results for Different Irradiation Levels

I_{rr} (w/m^2)	**Load Power(R) (watts)**	**Transient Load Power(R) (watts**	**Battery power (watts)**	**Output power of the boost converter (watts)**	**Solar panel power (watts)**
0	2000	1080	-3000	0	0
250	2000	1080	572	3663	3690
500	2000	1080	4200	7360	7490
750	2000	1080	8000	11000	11000
1000	2000	1080	12000	14750	15000

CHAPTER 5

CONCLUSIONS

The objective of this thesis was to design the solar stand-alone system with a transient load on a DC bus using MATLAB/Simulink software and to analyze the DC bus load transients. Here in this thesis a home was tied to solar panel system while storage is provided by current controlled source (energy storage system). A voltage control loop and two types of loads, transient load and resistive load was also connected to the DC bus.

The transient load consists of a DC current step of 10 amps with a time of 15 seconds to introduce high starting currents in the system. These transient load starting currents of transient load lead to voltage drops across the resistive load connected to the same bus as proposed transient voltage drops across a resistive load of more than 50% of its output voltage, are shown as proposed, and it reaches steady state due to a PID control loop. The Simulink model involved solar panel, MPPT, boost converter, voltage control loop, PID controller and transient load.

A PID control tuning was done for stable output. A voltage control loop was designed to control the DC bus voltage, and a reference voltage of 108V was maintained on the DC bus.

5.1 Future Scope

Better design of the technical system can be done to avoid start-up currents and voltage drops across other bus-connected loads. In this thesis in order to reduce complexity, analysis of DC (Crabtree & Lewis, 2007)bus load transients was done. AC bus load transient analysis can be done as an additional work.

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