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Design and Simulation of a Self-Reconfiguring Domestic Solar Power System

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Abstract - Frequent power interruptions in residential areas highlight the need for reliable and sustainable energy solutions. This paper presents the development of a self-reconfiguring domestic solar power system that integrates solar photovoltaic (PV) panels, a battery bank, and grid connectivity to ensure continuous power supply. The system employs Maximum Power Point Tracking (MPPT) using the Perturb and Observe (P&O) algorithm to maximize energy extraction under varying irradiance conditions. A smart control unit monitors the State of Charge (SOC) of the battery and dynamically switches between solar, battery, and grid power based on availability and demand. The design incorporates DC-DC converters (buck and boost), an inverter, and an intelligent switching mechanism to manage power flow efficiently. Simulation studies were conducted using MATLAB/Simulink to verify the performance of each subsystem and the overall architecture. Results confirm the system's ability to maintain stable AC output while reducing dependency on the grid and optimizing solar usage. This hybrid configuration provides an effective solution for residential energy management, particularly in regions with inconsistent grid reliability.

***Key Words*: Hybrid solar inverter, Perturb and Observe (P&O) algorithm, Renewable energy, Grid-tied inverter, State of Charge (SOC), MATLAB/Simulink, Domestic energy management**.

1. INTRODUCTION

The growing demand for uninterrupted power in residential sectors has led to an increased reliance on renewable energy solutions, particularly solar photovoltaic (PV) systems. Traditional home inverters, while commonly used during grid outages, are limited by their dependence on grid-based charging and lack the intelligence to efficiently manage multiple power sources. To overcome these limitations, hybrid solar systems with integrated control logic and storage solutions have emerged as a viable alternative.

This paper presents the design and simulation of a self-reconfiguring domestic solar system that intelligently switches between solar PV, battery storage, and the utility grid based on real-time energy availability and load demand. The system integrates Maximum Power Point Tracking (MPPT) using the Perturb and Observe (P&O) algorithm to ensure optimal energy harvesting under variable environmental conditions. A comprehensive simulation study was carried out using MATLAB/Simulink to validate the system's performance. The simulation models include PV arrays, buck and boost converters, battery charging and discharging logic, and a single-phase inverter with an LC filter. The controller monitors the battery's State of Charge (SOC) and dynamically reconfigures power flow to ensure continuous supply and efficient energy utilization.

Simulation results confirm the system's ability to maintain a stable 230 V RMS, 50 Hz AC output while minimizing grid dependence and maximizing the use of solar energy. This simulation-based validation demonstrates the feasibility and effectiveness of the proposed system for enhancing residential energy reliability and sustainability. An open loop strategy is considered for the MATLAB Simulation of the three main types of PWM inverters available in the market. A brief description of PV array, charge controller and battery is also presented in this paper. An endeavour is made to compare the different inverter or the inverter system available in various aspects.

Among the inverters considered, the micro inverter which is a grid tied, with sine wave output has got the better flexibility and efficiency. The existing standalone systems that are used to feed power from solar photo voltaic (PV) array to off-grid loads require several stages of power conversion thereby reducing its reliability and efficiency. In order to address the aforementioned limitations of the existing standalone PV systems, a topology involving a novel boost inverter which does not require the increment in the voltage levels of the PV array and/or battery is proposed in this paper. Detailed analytical studies of the system are carried out. The efficacy of the proposed scheme is verified by means of detailed simulation studies.

2. OBJECTIVE

This work aims at maximizing the use of solar energy by charging the battery as well as by supplying it to the loads when in excess. This system is implemented using two subsystems namely a charge controller and a Power Flow Management System(PMS). The charge controller is used to control the power flow from the PV module to the battery by operating in two modes. The Maximum Power Point

Tracking mode(MPPT) extracts maximum power from PV panels. A PV system implemented in houses involves two power sources (PV and utility), a power sink (load) and a power source/sink (battery), and hence a Power Flow Management system(PMS) is required to balance the power flow among these sources. A PMS has been used to control the operation of the bidirectional converter in Grid Connected PV systems. In the proposed system, the power flow control is achieved by switching the grid supply to the existing home inverter which inherently controls the power flow between the DC bus and the loads. The switching is done depending on the SoC of the battery as the criterion to effectively utilize the power from the PV panels after sufficiently charging the battery. Thus the total energy consumption from the utility grid is reduced.

3. MODEL CONFIGURATION

The solar energy from the sun is converted into electrical energy by the solar panel. The MPPT technique ensures that maximum power is being drawn from the panel. The output (DC) from the solar panel after MPPT is fed to the battery. The battery stores the energy from the solar panel as well as supply power to the load after being boosted by the boost converter and inverted into alternating form by the inverter. The controller provides digital signals to the switches to turn it on and off and switched between the battery power and grid power in accordance with the state of charge of the battery and availability of solar power.

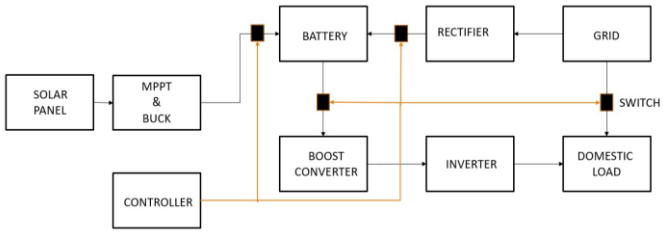

Figure -1: Basic Block Diagram

3.1 Maximum Power Point Tracking

Maximum power point tracking (MPPT) or sometimes just power point tracking (PPT) is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to

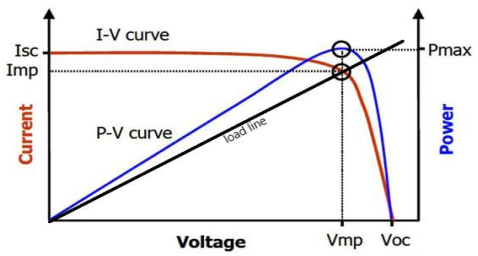

Figure -2: Power-Voltage and Current-Voltage Curve of a PV panel

Maximum power point tracking is a technique used commonly with solar system to maximize power extraction under all conditions. The Figure-2 consists of both IV and PV curve at a specific irradiance and temperature. The straight line from the origin that intersects the i-v curve is called the load line and the point of intersection is called the operating point. In this graph the operating point corresponds to the maximum power point. P_m is the maximum power. A line drawn through P_m to x-axis from operating point gives the maximum power point voltage and the y-axis intercept gives the maximum power point current. When a load is connected to the solar panel, the operating point will rarely be at the peak power. The impedance seen by the panel determines the operating point. So, we can move the operating point towards the peak by varying the impedance seen by the panel.

A DC-DC converter is used to transform the impedance of the source to the load. The duty ratio of the converter is adjusted to change the impedance seen by the panel. At a particular duty ratio, operating point will be at the peak power. There are different types of maximum power point tracking methods. In this project, the perturb and observation algorithm is used for tracking the maximum power. Microcontrollers are usually employed to implement these algorithms. Perturb and Observation algorithm was used due to its ease of implementation and may result in top-level efficiencies.

In this method, the MPPT algorithm is based on the computation of the PV output power and the power change

by perturbation of both the PV voltage and current. The tracker operates by incrementing or decrementing the solar array voltage continuously at regular interval.

For a given perturbation, if there is increase (decrease) in the output power of the PV, it leads to subsequent perturbation in the same (opposite) direction.

As a result, the duty ratio of the DC-DC converter is varied accordingly and the process is repeated until the maximum power point has been reached. The perturb and observation algorithm is explained in the form of a flowchart in Figure 3.

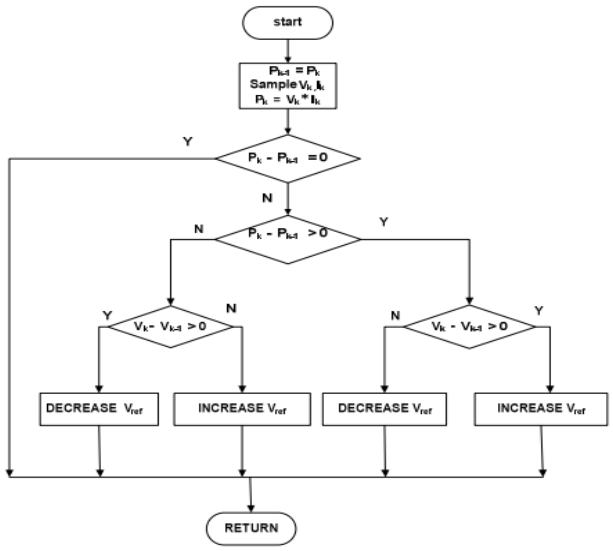

Figure -3: P & O Algorithm

3.2 SIMULINK PROGRAMME FOR P&O ALGORITHYM

```
function duty = MPPT algorithm ( vpv , ipv , d e l t a )
duty_init = 0.1;
duty_min =0;
duty_max = 0.7;
persistent Vold, Pold, duty_old;
if isempty (Vold)
        Vold =0;
        Pold =0;
        duty_old = duty_init;
end
P= vpv * i p v ;
dV= vpv - Vold;
dP= P - Pold;
if dP ~= 0
        if dP < 0
                if dV < 0
                        duty = duty_old + delta;
                else
                        duty = duty_old - delta;
                end
        e l s e
                if dV < 0
                        duty = duty_old - delta;
                else
                        duty = duty_old + delta;
                end
        end
e l s e
        duty = duty_old;
end
if duty >= duty max
        duty = duty max;
else if duty < duty min
        duty = duty min;
end
duty_old = duty;
Vold = vpv;
Pold = P;
```

3.3 BUCK CONVERTER

Inductor Selection:

The higher the inductor value, the higher is the maximum output current because of the reduced

ripple current. Equation 1 gives a good estimation for the right inductor:

$$L = \frac{V_o(V_{in} - V_o)}{\Delta I_L \times f_s \times V_{in}} \quad (1)$$

where, V_o= desired output voltage, V_{in}= typical input voltage, f_S = minimum switching frequency

of the converter and ΔI_L = estimated inductor ripple current.

The duty cycle, D, for the maximum input voltage is given by Equation 2

$$D = \frac{V_o}{V_{in}} _ \times 0:9 \quad (2)$$

A good estimation for the inductor ripple current is 20% to 40% of the output current.

Inductor Ripple current (ΔIL) is given by the Equation 3.

$$\mathbf{\Delta I_L = 0:2 \times I_{out\ max}} \quad (3)$$

V_{in} = 84 volts Vo = 55 volts fs = 50 KHz

therefore, **L = 6:48_10^{-5} H**

Output Capacitor Selection

Equations 2 & 3 can be used to adjust the output capacitor values for a desired output voltage

ripple:

$$C = \frac{\Delta I_L}{8 \times f_s \times \Delta Vout} \quad (4)$$

C = minimum output capacitance, ΔI_L = estimated inductor ripple current, f_S = minimum

switching frequency of the converter ΔV_{out} = desired output voltage ripple.

C = 3.3 x 10^{-5} H

3.4 BOOST CONVERTER

A Step Up Chopper or boost converter which increases the input DC voltage to a specified DC output voltage.

Inductor Selection

Equation 5 gives a good estimation for the right inductor:

$$L = \frac{Vs(Vo - Vs)}{\Delta IL \times fs \times Vo} \quad (5)$$

where, V_o= desired output voltage, V_s= typical input voltage, f_S = minimum switching frequency

of the converter and ΔI_L = estimated inductor ripple current.

The duty cycle, D, for the minimum input voltage is given by Equation 6

$$D = 1 - \frac{V_s}{V_o} \times 0.9 \quad (6)$$

The Maximum Ripple current is given by,

ΔI_L = 0:2 x I_{out} (7)

V_s = 48 volts; V_o = 325 volts; f_s = 30 KHz

L = 6:81 x 10^{-4} H

Output Capacitor Selection

Equations 3.11 & 3.12 can be used to adjust the value of the output capacitor for a desired

output voltage ripple:

$$C = \frac{\Delta I_{out} \times D}{f_s \times \Delta V_c} \quad (8)$$

$$\Delta V_c = V_0 \times 10\% \quad (9)$$

C = 1:64 x 10^{-4} F

3.5 INVERTER

A power inverter, or inverter, is a power electronic device or circuitry that changes direct current (DC) to alternating current (AC).

L-C Filter Design:

Conversion between radians and frequency in hertz is given by Equation 11

$$\omega_0 = 2\pi f_0 \quad (10)$$

Cut-off frequency (f_o) of the LC filter is given by Equation 12

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (11)$$

L and C values can be derived assuming the desired cut-off frequency, ω_o is known using

Equation 13 & 14.

Load Resistance, R_L = 20

$$L = \frac{R_L \times \pi}{\omega_0 \times 2} \quad (12)$$

$$C = \frac{2}{\omega_0 \times R_L \times \pi} \quad (13)$$

Therefore,

L = 0.1 H

C =1.01 x 10^{-4} F

4. CONTROL LOGIC

The control logic ensures that the power supply to the load is continuous. It constantly monitors the SOC of the battery and provides signals to the switching devices. In the absence of solar power, if the battery doesn't have enough charge to meet the load requirement, the control logic switches to supply the load from the grid power as well as charge the battery until SOC is greater than the predetermined value. Control logic in this project divides the system operation into three operating conditions based on the solar power, battery charge and load condition.

Case I: Sunshine hours, SOC > 25%

The green line represents the path of power flow as shown in Figure 4. When sufficient solar power is available, the panel charges the battery continuously. Since the battery has SOC greater than 25%, it can directly provide the power to the load. In this case, the controller switches off the supply from the grid.

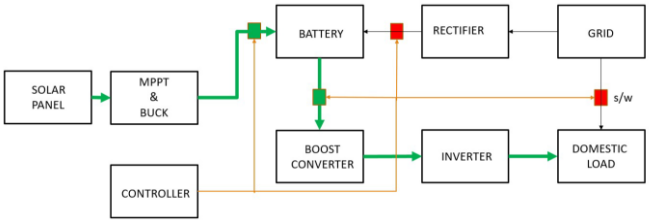

Figure - 4: Sufficient solar power available

Case 2: Non Sunshine hours, SOC > 25%

The green line represents the path of power flow as shown in Figure 5. During non-sunshine hours, the panel does not produce energy to charge the battery. Since the battery has a SOC > 25%, it can be used to power the load until the SOC decreases down to a value less than or equal to 25%. In this case, the supply from the panel as well as the grid is off.

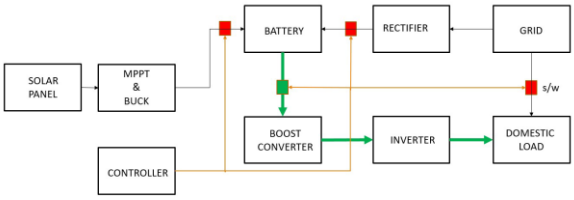

Figure - 5: Solar power not available

Case 3: Non Sunshine hours, SOC < 25%

The green line represents the path of power flow as shown in Figure 6. In this case, the panel does not produce energy to charge the battery. Since the battery has a SOC < 25%, it is not used to power the load. So, the supply from the grid is used to simultaneously charge the battery and to supply power to the load.

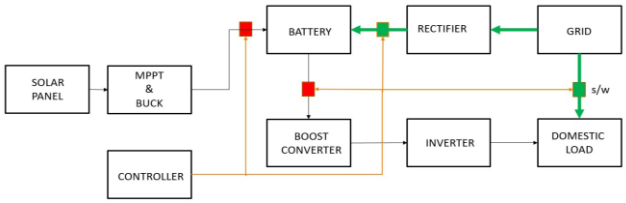

Figure - 6: SOC of battery less than 25%

5. SIMULATION STUDIES

This chapter gives the simulation results of various components obtained using MATLAB Simulator. To anticipate the outcome of the system, the parts of the whole system was individually simulated and justified to the desired output values in SIMULINK.

- Specifications of Solar Panel (at STC) for Simulation
- Power Rating: 249W
- Open Circuit Voltage: 50.9V
- Short Circuit Current: 6.2A
- Maximum Power Point Voltage: 42.8V
- Maximum Power Point Current: 5.84A

The simulation circuit of the buck converter with MPPT is shown in Figure 7. The voltage and current output of the panel is given as input to the MPPT algorithm and a suitable value of duty cycle is given to the PWM generator. The simulation circuit of the boost converter is shown in Figure 8. Input to the boost converter is the battery at 48 volts which it steps up to a value of 325 V dc. The converter is designed for maximum current capacity of 20A.

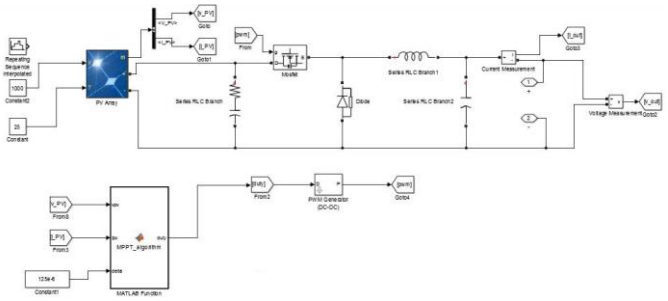

Figure - 7: PV Array with Buck Converter

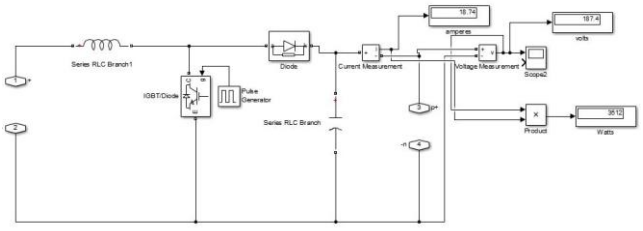

Figure - 8: Boost Converter Circuit

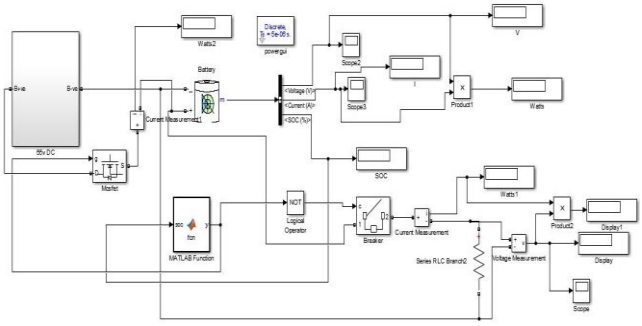

Figure 10: Battery Charger

The output voltage waveform obtained across the load is shown in Figure 12. The output of the panel varies as the amount of irradiance and temperature of the solar panel vary. The design of the converters and inverters are so as to meet the load requirements. There is a calculated usual demand of 3100 Watts. The battery capacity is 300 Ah at 48 V. The input to the buck converter is 84 V. The boost converter gives an output of 325 V to the inverter. The value of inductor and capacitor that forms the LC filter are 0.1H and $1.01x10^{-4}$ F The output voltage waveform has a voltage of 310 V, 50 Hz AC.

The output of the DC-AC inverter is expected to be a 230 V AC rms, 50 Hz sine wave.

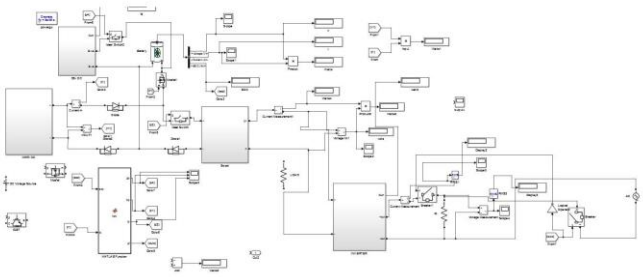

Figure 11: Complete simulation

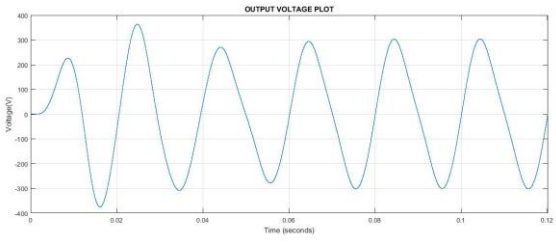

Figure 12: Output Current and Voltage waveform

6. CONCLUSIONS

The major issues with the frequent power interruption can be solved to an extend by the installation of this designed solar system which is an alternative sources of energy that is clean and renewable. The project aims to design and implement a self-reconfiguring grid interactive solar system capable of dealing with the change in working conditions and efficient load shifting. Solar energy act as the major power source to the system. MPPT technique is used to ensure that maximum power is being drawn from the panel. In this project, the Perturb & Observation algorithm was used to achieve maximum power point. The lead acid battery with a capacity of 300Ah and a nominal voltage of 48 Volt is used. The control logic ensures that the power supply to the load is continuous. It constantly monitors the SOC of the battery and provides signals to the switching devices. In this project, there is no two-way interaction between the electric grid and the proposed system, i.e., excess power generated in the panel is wasted if battery is fully charged and consumption is less. There is no provision to deliver excess power generated into the grid. There is a future scope of this work to integrate a two-way communication of the system with the electrical grid.

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