Modelling and implementation of a photovoltaic system through improved voltage control mechanism

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ABSTRACT

Renewable energy dependence is increasing daily due to the decaying of conventional energy sources. Another primary reason is the increment of pollution as well as global warming. Various alternate energy sources are being used to replace conventional ones. Among them, the prominent photovoltaic source provides clean and green energy. This research focuses on energy production through the photovoltaic source. The photovoltaic cells combination is used along with the boost converter to get the maximal power output. The maximum power point tracker was designed and implemented to obtain the optimal power from the photovoltaic cells, which do not provide the desired results. Therefore, the voltage control method is an alternative to the maximum power point tracker. Both methodologies compared at different intensities of solar light. The load is attached to the photovoltaic output to test its reliability and smooth performance. The system is designed using MATLAB simulation, and the desired results are obtained.

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1. INTRODUCTION

The world is being polluted, affecting the climate and geography. Global warming is changing the dynamics, and we must cater to this problem. The said problems are mainly using conventional energy sources such as gasoline, and coal. The solution is to extract energy from renewable energy sources such as wind and photovoltaics [1]. This research focuses on the photovoltaics system and the improved power output acquired through various techniques. The system consists of a photovoltaic cell, boost converter, maximum power point tracker, and voltage control.

One of the most valuable resources on the planet is solar energy; thus, it should not be disregarded. Address the energy needs of a constrained region, and photovoltaic panels are employed to transform solar power through the sun into usable electrical power. Today, various energy storage strategies are utilized to ensure electrical energy availability at night. Active and passive are two fundamental methods for obtaining solar energy from the sun. The two options for using solar energy from the sun are these two. The ancient people employed a passive solar energy system in which they constructed their homes out of clay or stone that received energy in the form of heat through the sun during the day and maintained their homes at a comfortable temperature at night. Therefore, they utilize this to keep their homes warm all night. Builders to capture solar energy are using the same technique [2]. There are times when stone floors, architectural approaches, and strategically positioned windows are efficient ways to capture passive solar energy through the sun to maintain heat in the structures [3]. The active solar energy system is the second method of using solar energy. It functions similarly to a passive solar energy system, except that it employs fluid to collect solar heat. The practical solar energy system most frequently uses water as a fluid to collect heat from the glowing sun. Additionally, a straightforward solar collector is built on the roof to heat the fluid circulated throughout the structure to maintain heat [4].

The electrical circuit comprises the following variables and components. I_L is the same as a current source that produces light. Diode current is I_d. Shunt resistance is R_{Sh}. Resistance in series is R_s.

$$I_d = I_0 \left[\exp\left(\frac{V_d}{V_T}\right) - 1\right] \quad (1)$$

$$V_T = \frac{kT}{q} \times nI \times Ncell \quad (2)$$

Here in the above equation I_d represents the diode current measured in amperes (A) while V_d denotes the voltage of the diode (V), and I_0 symbolizes the saturation current of a diode (A). nI represents the ideal factor for diode, which is near to one, while K stands for the Boltzmann constant, and its value is $1.3806e^{-23}$J.K^{-1}. Here q represents electron charge and is equivalent to $1.6022e^{-19}$ C. T denotes the cell's temperature measured in kelvin, while N_{cell} denotes the quantity of cells in the module that are linked in series [5]. The PV system is more complex than active and passive solar energy systems and incorporates photovoltaic cells, solar panels, and other current technologies. They are utilized to convert solar energy into electrical energy and are built of thin silicon sheets. These sheets have the benefit of being less expensive and straightforward to put on a roof. Most individuals who live in isolated places, on islands, or on mountaintops utilize PV systems to power their homes since it is the most practical and affordable choice for them [6]. Different materials and their unique features are used to make solar cells. The PV system needs to be handled with extreme caution if you want to get the most efficiency out of it [7]. Various factors that affect the working and efficiency of the photovoltaics system are presented in Figure 1.

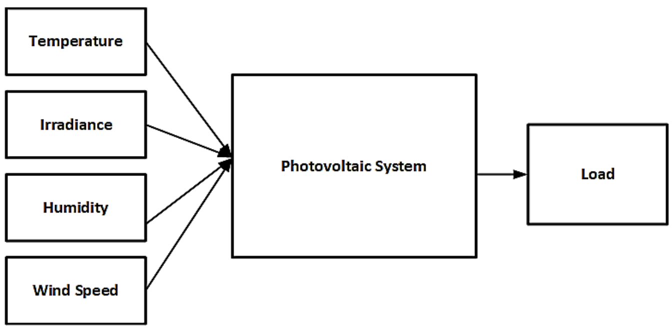


Figure 1. Factors affecting photovoltaic system

A boost converter is a DC power converter that raises voltage while lowering current from the input source to the output load. In this type of switched-mode power supply, there must be at least two semiconductors, a diode, and a transistor, and one of the following energy storage components: a capacitor, an inductor, or even both [8]. The output and input of such a converter often include filters built of capacitors, sometimes in conjunction with inductors, to decrease voltage ripple [9]–[11].

In Figure 2, V represents voltage, and L stands for inductance. D symbolizes the diode element, while C is for the capacitor. S is used for the switch, and R is the resistance. Suppose the switch goes to the closed (in the "on" state). In that case, the inductor creates a magnetic field, and current flows through it clockwise, allowing the inductor to store some energy [12]–[16]. The left side of the inductor has positive polarity. The current will decrease due to the high impedance in the switch's open or "off" state. The initial energy of the magnetic field will be reduced so that the current continues to flow through the load. Thus, the polarity will be reversed (which means the inductor's left part is changed to the negative) [17]–[21]. The capacitor would be charged to a greater voltage using diode D, as both sources are in series. Proposed a system in which maximum power point and voltage control techniques are used to get the results [22]. Suggests the optimal solutions for photovoltaic systems where various optimization techniques are employed [23].

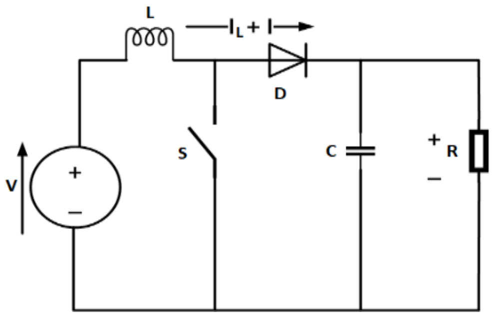


Figure 2. Boost converter schematic diagram

Investigate the maximum power point tracking and voltage control strategy to extract the power output from the photovoltaics system [22]. The authors provide a review of the maximum power point methodologies [24], [25]. The authors discuss the control strategies for the photovoltaic system [26].

2. DESIGNED MODEL

As discussed, the system consists of photovoltaic cells along with the boost converter, and the output is optimized through the maximum power point tracker and the voltage control. The load that is connected to the system is domestic load. The rating of the system is 3.5 kW. The proposed model is presented in the Figure 3. A variety of factors influence the effectiveness of solar cells. Several significant variables, including humidity, radiation, temperature, wind speed, and dust, affect the performance of solar cells. The term "environmental impacts" refers to these elements. Other elements like shade, angle, and the load coupled to the solar cells might affect their efficiency. Therefore, carefully considering each parameter for greater solar cell efficiency is crucial. Extract the most cost-effective and best output power; there is a trade-off between temperature and efficiency that allows for the use of better solar material at higher temperature locations and vice versa. At a constant temperature of 250 C and irradiance of 1000 w/m^2, the PV systems function at their optimum efficiency illustrated in Figure 4.

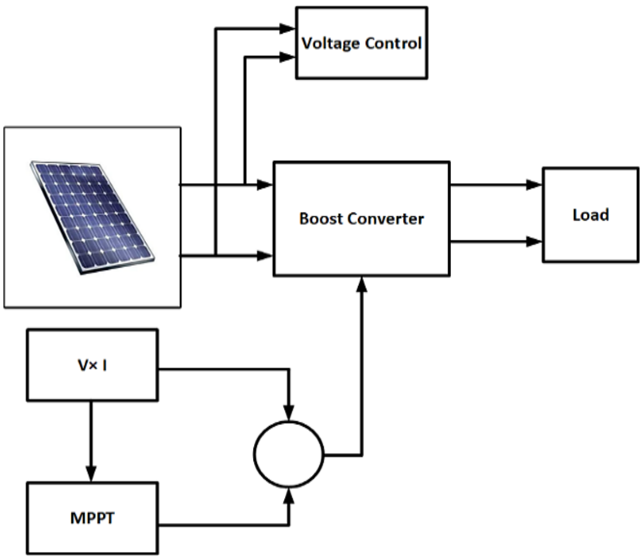


Figure 3. Proposed model of the photovoltaic system

The voltage falls as the temperature rises, whereas the current rises. Temperature is raised through 10 C; the current increases up to 0.05% while the voltage decreases by 0.37%, resulting 0.5% reduction in power overall. Solar cells can only be exposed to temperatures below 40 C while maintaining their effectiveness and lifespan. The efficiency and lifespan of solar cells are severely impacted at this maximum permitted temperature.

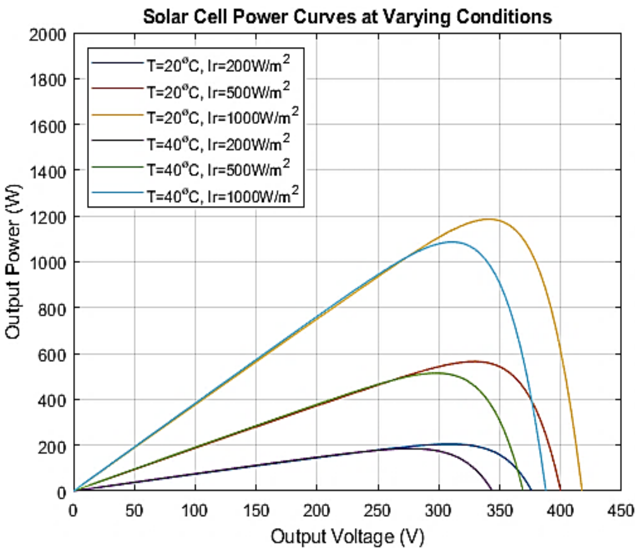


Figure 4. Solar cell power variation at various temperatures and irradiance

Depending on the degree of shadow, the solar cell's output changes when it is covered. Two main categories of shades impact the performance of solar cells: a) soft shade and b) hard shade. The current reduces when the solar cell is in mild shadow, which reduces output. Hard shadow causes voltages to drop significantly, which reduces power. The findings of the analysis of the impacts of various shadings, including corner, bottom, and no shadings, are displayed in Table 1. The algorithm for the maximum power point tracking algorithm is presented in Figure 5.

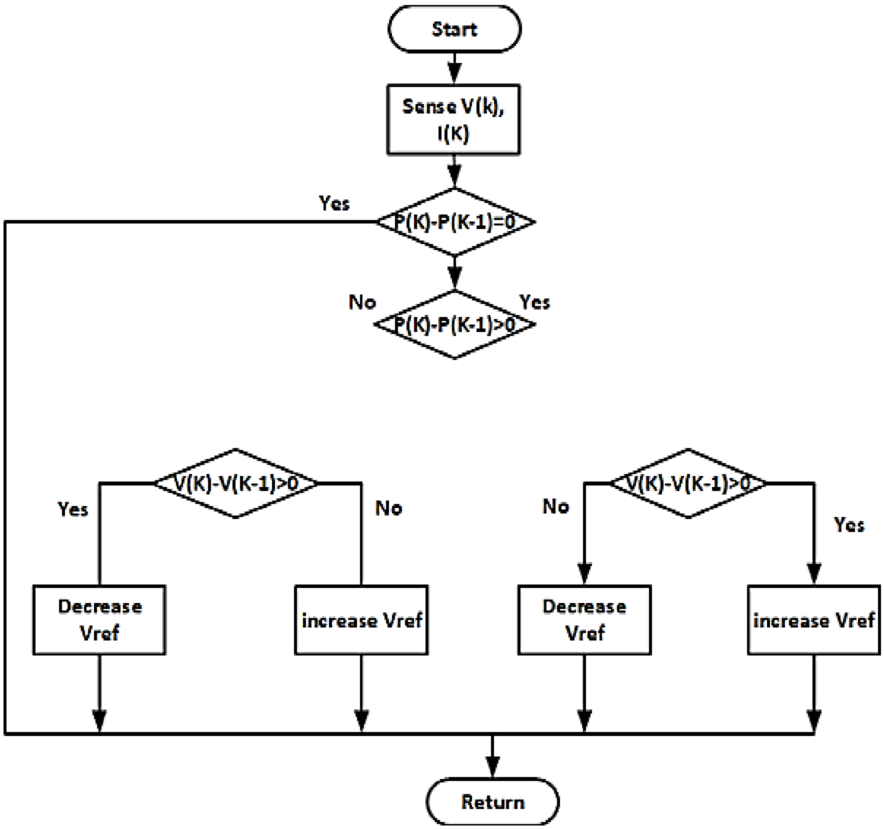


Figure 5. The algorithm for the maximum power point tracking

Table 1. Shading effect on the solar cell

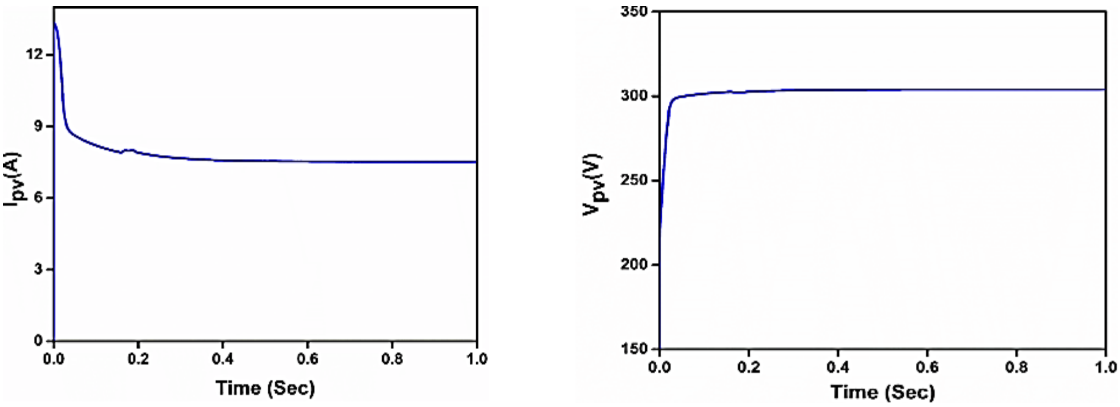
Irradiation (*W/m²*)		Temperature (°*C*)	Pm (*W*)	Um (*V*)	Im (*A*)
Not shaded	443	31.5	75.5	27.9	2.706
	533	32.6	99.94	27.4	3.246
	650	33	138.58	27.3	4.967
	682	35.8	141.94	27	5.257
	443	31.5	75.5	27.9	2.706
Middle Shading	403	31	46.97	30.9	1.495
	423	32	51.2	31.2	1.592
	503	33	51.9	31.9	1.694
	610	35.8	70.43	32.5	2.30
Corner Shading	405	30.9	60.8	19.1	3.257
	430	31	65.15	17.7	3.573
	540	32	84.35	19	4.593
	677	34.73	91.75	18.93	5.473
Bottom Shading	375	31.5	51.15	19.1	2.915
	470	31.9	62.35	17.95	3.537
	515	33.9	60.95	19.2	3.537
	715	35.7	94.53	16.9	5.375

3. SIMULATION RESULTS AND DISCUSSION

The designed system was implemented through the MATLAB Simulink. Simulations were performed at various irradiances to test the capability of the developed model. The irradiances are 800 w/m² and 1000 w/m² respectively. The model is tested through different techniques, and simulation results are acquired. The simulation results are quite effective and proving the efficacy of the method.

3.1. Simulation results at 800 w/m² irradiance

The designed model is tested at 800 w/m² irradiances. The current of the photovoltaic system is shown in Figure 6(a). Initially, there was a surge, and the photovoltaics current line got smoother and more stable. The photovoltaic voltage acquired by the system is presented in Figure 6(b), which is approximately 300 volts, and there are no ripples. Figure 7 illustrates the photovoltaic output power and the load connected to the system. The load is fed by the power supply provided by the photovoltaic system, which is adjusted per the load's requirements.



(a) (b)

Figure 6. For the irradiance 800 w/m² (a) solar current and (b) solar voltage

3.2. Simulation results for the irradiance 1000 w/m²

The same designed model is implemented at an irradiance of 1000 w/m² to get optimal results. The Figure 8(a) shows that with the increment of irradiance, a photovoltaic system's output current is also increased compared to fewer irradiances. Figure 8(b) illustrates that the output voltage attained through the photovoltaic system is slightly higher than that of the 800 w/m² irradiance level.

The voltage control mechanism is explained in Figure 9. In which voltage is compared with the new voltage value acquired from the PV array, and the previous power value is compared with the new power value attained. If the difference suggests that the newly gained value is lesser, then the whole process is repeated; otherwise, proceed to the next step.

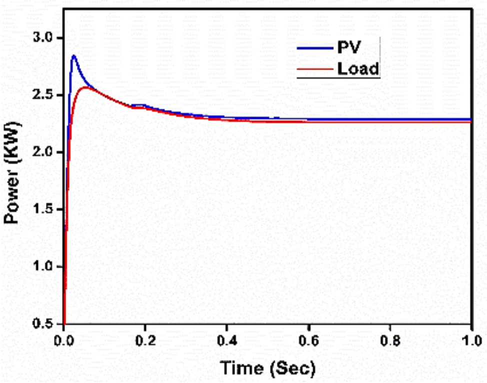
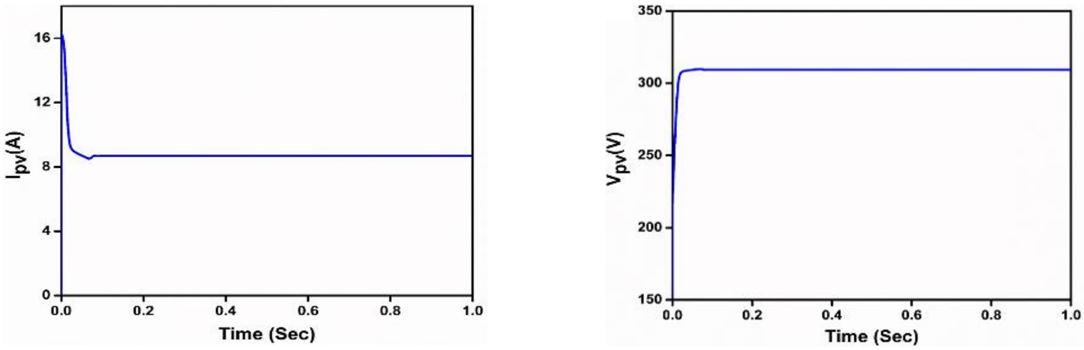


Figure 7. Solar power for the irradiance 800 w/m^2



(a) (b)

Figure 8. For the irradiance 1000 w/m^2 (a) solar current and (b) solar voltage

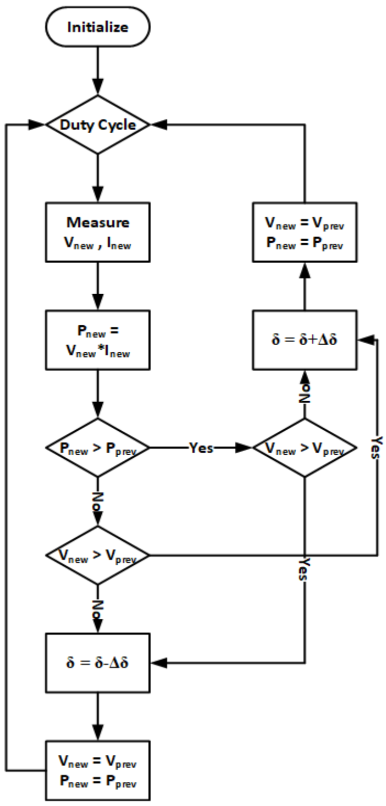


Figure 9. Flow chart of the voltage control mechanism

Figure 10 represents the photovoltaic system output power along with the load connected to the system. The system feeds the variable load as per the demand, and the output power is increased as compared to the 800 w/m^2 output power. Figure 11(a) represents the output current attained through the photovoltaic system by implementing the voltage control technique at 1000 w/m^2. The output current acquired through this technique is greater than the maximum power point tracking technique employed on the proposed model. Figure 11(b) illustrates the voltage value using the voltage control method. Figure 12 represents the photovoltaic system output power and the load power that is connected to the system. There is a slight surge in output power of the photovoltaic system that is adjusted instantly, and good quality power is fed to the load.

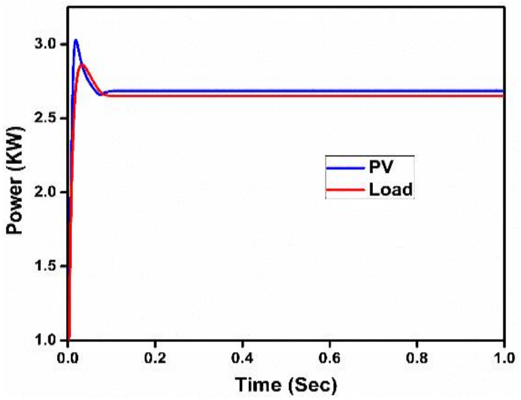


Figure 10. Solar power for the irradiance 1000 w/m^2

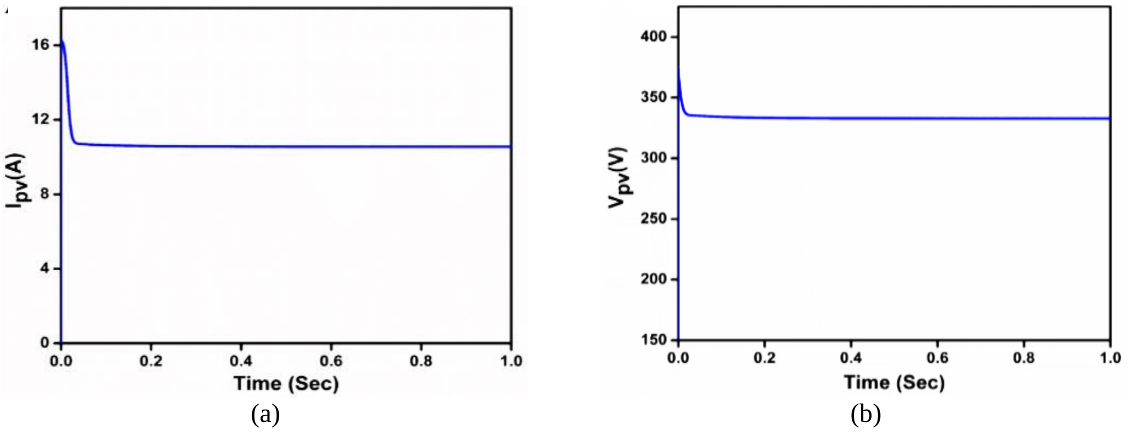


Figure 11. Voltage control mechanism (a) solar current and (b) solar voltage

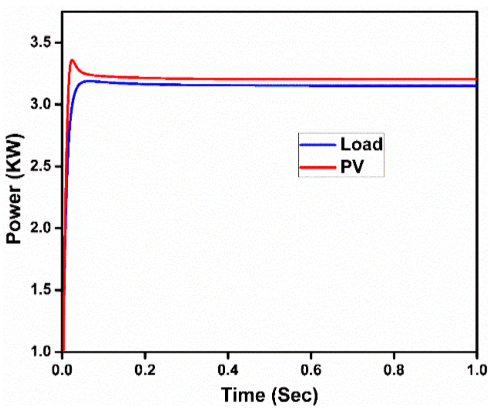


Figure 12. Solar power at voltage control mechanism

4. CONCLUSION AND FUTURE RECOMMENDATIONS

The photovoltaics system is designed to extract the optimal power output through various techniques such as a maximum power point tracker and voltage control. The output results acquired through the MATLAB simulations are pretty compelling. Output power at different irradiances is extracted, and a maximum power point tracking technique is employed to get the desired results. Load is attached to the photovoltaic system, and the proposed model fed it as per the requirement. The voltage control mechanism is quite effective compared to the maximum power point tracker technique in that it extracts more output power and feeds the load better. The proposed model can be improved by implementing the optimization techniques on the maximum power point tracking method through which maximal output power could be attained. Furthermore, the voltage control technique could improve along with the various optimization techniques.

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