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Optimization of Photovoltaic System and Algorithm Development

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Abstract

This paper presents the optimization of photovoltaic (PV) systems and development of optimization algorithms for the power output of a solar PV system. The aim of the study was to investigate and understand the various existing optimization techniques and methods, then develop an algorithm that can optimize a solar PV system and compare the results. The optimization method used was MPPT (maximum power point tracking) and (Perturbation and observation) P&O algorithm. The (Instantaneous and Incremental conductance) INC algorithm and Genetic algorithm were developed. Development and simulation of the optimization methods and developed algorithms was achieved with the use of Matlab Simulink software. For this study, the output of the optimized system with the MPPT method trained with P&O optimization, INC algorithm and Genetic algorithm were compared with the output of an unoptimized system under different atmospheric conditions and then to each other. The results of the optimized system were compared with the result of the unoptimized system. From the result, it was found out that the optimized system has a better response, lesser error, better accuracy and tracking speed than the unoptimized system. The study revealed the need of optimization in PV system and the step-by-step process of developing an optimization algorithm was shown

1. Introduction

Due to the many benefits of photovoltaic power generation, commonly known as solar power, it is attracting a lot of interest. It allows for the development of sustainable electricity without harmful emissions due to its clean and non-polluting energy production capabilities. Sunlight is immediately converted into electricity by photovoltaic systems, making it a dependable and sustainable source of power [1].

Electricity production near to the user is one of the main benefits of photovoltaic power generation [2]. This lowers transmission losses, which occur when power is delivered over long distances, making the supply of energy more efficient [3]. Furthermore, photovoltaic systems require less maintenance, which adds to their allure. Additionally, solar systems have a particularly long lifespan that enables long-term electricity production. Because of their durability, engineers and investors seeking dependable and sustainable energy solutions appreciate them [4].
The power output of a photovoltaic (PV) grid array has been optimized using a variety of optimization approaches and control algorithms [5].

PV optimization is crucial for maximizing energy production, boosting system effectiveness, and increasing the PV installations' economic feasibility. PV systems may capture more sunlight and

convert it into electricity by optimizing factors including system configuration, module orientation, and tracking devices, which increases energy generation and overall energy yield [6]. Through the use of algorithms that evaluate data, simulate system behavior, and pinpoint ideal operating points, optimization also minimizes energy losses and maximizes power production [7]. By altering system components in real-time, this ensures that PV systems run as efficiently as possible [7].
Genetic algorithms and machine learning are two recent examples of technology that have benefited the field of PV optimization [8]. These cutting-edge algorithms allow for effective exploration of complicated parameter spaces while taking into account a variety of factors and restrictions to identify the ideal PV system configurations and operational approaches [8]. By fine-tuning optimization algorithms, PV systems produce more energy, are more efficient, and are less expensive while operating at their peak capacity [9]. PV installations can give optimum performance while overcoming obstacles and constraints thanks to this exact control and optimization [10].
According to [4], for the purpose of optimizing the location of solar panels, [4] suggested a brand-new method based on genetic algorithms. Their strategy intended to optimize the solar system's total energy production by taking into account elements including panel orientation, geography, and shade.

Modeling of photovoltaic system and design of MPPT controller using PSO algorithm" by [4,8]: Particle swarm optimization (PSO) is a method that [7] developed for the positioning of solar panels. Real-time weather information was used in their research to dynamically improve panel location, resulting in greater energy production efficiency.
[8] In his thorough examination of sun tracking algorithms, [8] contrasted numerous strategies including azimuth-elevation, two-axis tracking, and slanted tracking. Their study assessed how various algorithms affected energy production and system cost-effectiveness.
Solar tracing by network adaptive techniques" by [6]**:** With the use of machine learning methods, [6] suggested an adaptive control system for solar tracking that would dynamically change the orientation of the panel in response to outside factors in real time. Their approach enhanced energy production while also improving tracking accuracy.
[12] Created a shading analysis program that evaluates the impacts of shade on solar panels using 3D modeling methods. Their study intended to maximize energy output by minimizing shadowing and optimizing the arrangement of solar panels.

In order to maximize the power output of a photovoltaic (PV) grid array, various techniques and control methods have been proposed [13]. One such method is the Maximum Power Point Tracking (MPPT) control, which aims to find the optimal operating point at which the PV system can generate the maximum power output. The MPPT control method involves estimating the process by perturbing the system and observing its response. Typically, the estimation and perturbation processes are repeated at regular intervals to continuously search for the maximum power output of the PV grid array. An advanced version of this method is the estimate-perturb-perturb (EPP) method [8], which significantly improves the tracking accuracy and speed of the MPPT control.
Most of the reviews make reference to positing of the PV, optimizing solar systems using one method, developing algorithms using one method. The results showed that the proposed technique is applicable, but comparison was not done for their study.

This paper presents maximize the electrical power of the PV panel, the technique which is based on exploring the various methods of solar PV optimization system. Optimization of solar PV system and develop two algorithms for solar optimization. Comparison of optimized system to unoptimized system in each of the system will be done.

2. Methodology

The study employs a simulation-based approach to evaluate and compare the effectiveness of the optimization methods. A computational model representing a typical PV system will be developed, and various scenarios are simulated to analyze the impact of each optimization technique on energy output and system efficiency will be done. The PV system will be optimized using MPPT optimization method, while P&O algorithm, INC algorithm and Genetic algorithm will be used for PV system optimization, these algorithms will be developed in MATLAB Simulink. The response of an optimized system (P&O and GA) will be compare with an unoptimized system under different conditions using MATLAB Simulink. Also the response of the P&O and GA algorithm was compared to each other.

2.1 Optimization Solar PV System Using MPPT

The growing need for clean, renewable energy has resulted in considerable breakthroughs in solar PV technology. However, solar energy production is heavily impacted by elements such as weather, shadowing, and panel temperature, all of which may have an impact on system efficiency and output. The goal of this research is to investigate and assess different PV optimization approaches in order to overcome these difficulties and improve the overall performance of solar PV systems. The proposed PV system for this study is shown in figure 1.

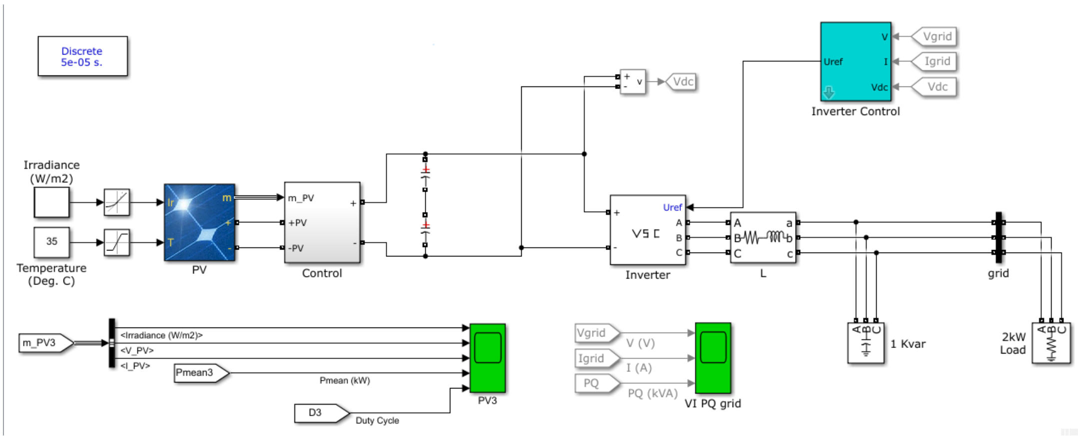


Figure 1: The photovoltaic system

The system uses 315W solar panels with the following specifications

Maximum power (w)	315.072
Open circuit voltage Voc (v)	64.6
Voltage at max. power point Vmp (v)	54.7
Temp. coefficient of Voc (%/deg.C)	-0.27269
Cells per Module (Ncell)	96
Short-circuit current Isc (A)	6.14
Current at max. power point Imp (A)	5.76
Temp. coefficient of Isc (%/deg.C)	0.061694

To obtain 3KW from the PV system, 10 solar panels was used approximately

$$no. of\ panels = \frac{3000}{315.072}$$
$$= 10\ panels\ (approx.)$$

The output from the panel is passed through a control circuit (optimization circuit), then an inverter and finally to the load.

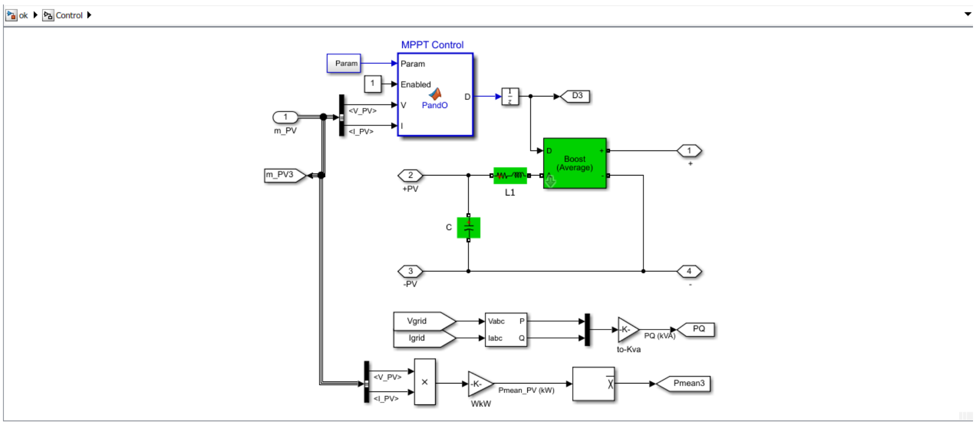


Figure 2 MPPT system

Figure 7. shows the MPPT system to be used in the simulation. The system is trained with P&O algorithm for PV optimization

2.2 Development of P&O algorithm

As previous discussed, there are a number of algorithms used with MPPT controller. In this section algorithm step by step using the perturb and observe approach (P&O) was develop. figure 9, shows the flowchart for the P&O algorithm.

Step 1: MATLAB System block was obtained from Simulink fundamental library. This block in figure 8, allows taking measurement of the PV parameters and writing the code for the optimization algorithm.

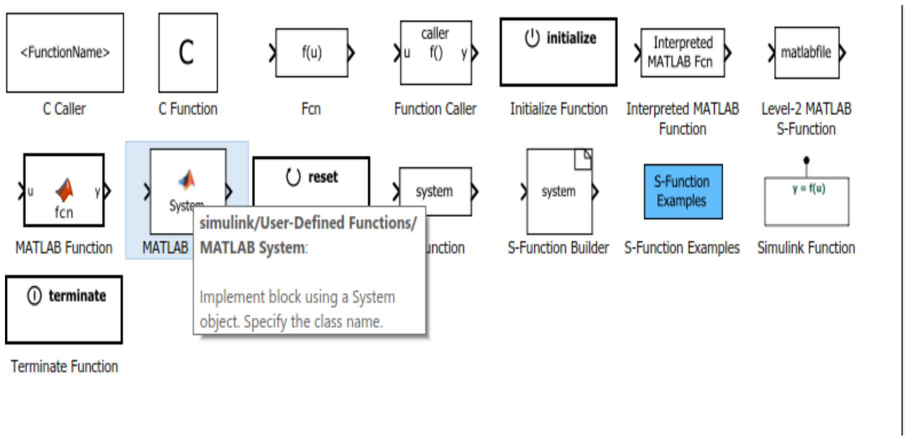


Figure 3: obtain MATLAB System block

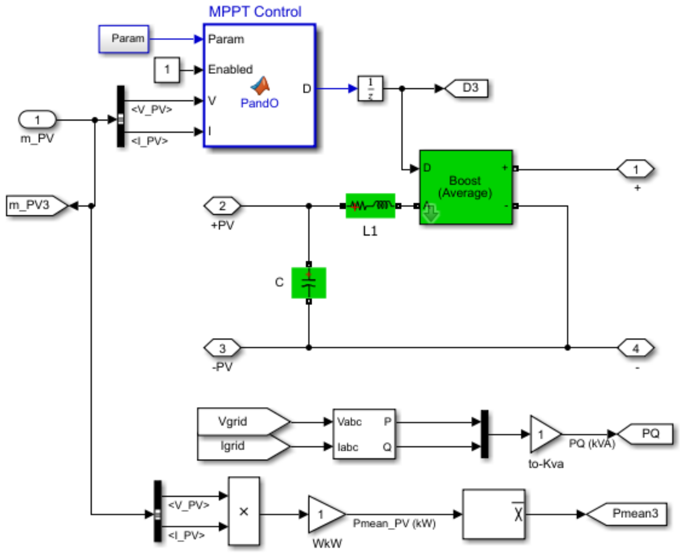


Figure 4: P&O System

Step 2: figure 10, set constant parameters for the algorithm, the minimum duty cycle, maximum duty cycle, duty cycle steps

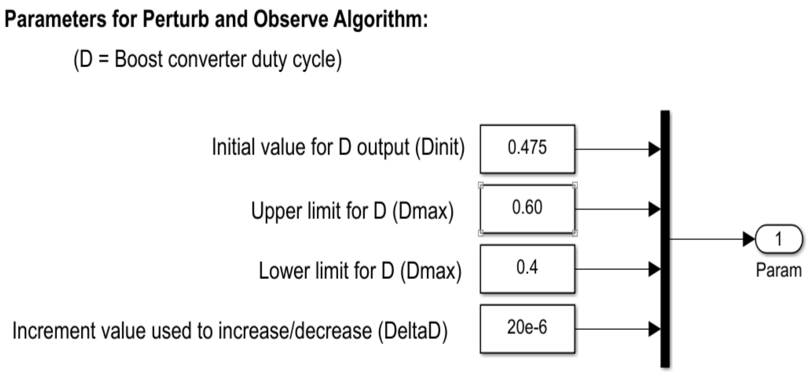


Figure 5: parameters for P&O algorithm

Step 3: obtained voltage and current from the PV module to calculate power. The measure power and voltage are compared to the previous reading from the PV module

```
if isempty(Vold)
   Vold=0;
   Pold=0;
   Dold=Dinit;
end
P= V*I;
dV= V - Vold;
dP= P - Pold;
```

Step 4: track maximum power of the PV module by checking to see if the newly measured voltage and power is less than the previously measured voltage and power.

```
if dP < 0
      if dV < 0
         D = Dold - deltaD;
```

```
        else
            D = Dold + deltaD;
        end
    else
        if dV < 0
            D = Dold + deltaD;
        else
            D = Dold - deltaD;
        end
    end
```

On request for the complete code of the algorithm.

2.3 Development of INC Algorithm

The INC algorithm is another popular algorithm used with MPPT controller. In this section algorithm step by step using the incremental conductance algorithm was developed. Figure 11 shows the flowchart for the INC algorithm.

Step 1: obtain the function block as discussed in the previous section.

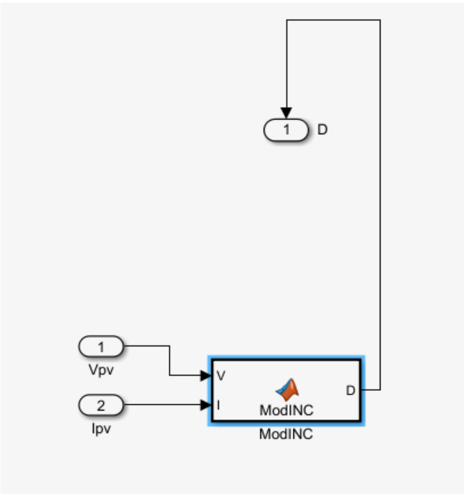


Figure 6: INC system

Step 2: set the limits of the algorithm and obtain the current and voltage from the PV system to be optimized

```
function D=ModINC(V, I)


Dinit = 0.6;  %Initial value for D output
Dmax = 0.65;   %Maximum value for D
Dmin = 0.1;   %Minimum value for D
deltaD = 0.002; %Increment value used to increase/decrease the duty cycle D
```

step 3: track maximum power by checking for changes in current and voltage

```
if M < 0.005
    D=Dold;
else
    if dV == 0
        if dI == 0
```

```
            D=Dold;
        elseif dI>0
            D=Dold - (M*deltaD);
        else
            D=Dold + (M*deltaD);
        end
    else
        if dI/dV == -I/V
            D=Dold;
        elseif dI/dV>-I/V
           D=Dold - (M*deltaD);
        else
           D=Dold + (M*deltaD);
        end
    end
end
```

step 4: adjust the duty cycle to maintain maximum power. The complete code can be found on request.

2.4 Development of a Genetic Algorithm

The Genetic algorithm is another popular algorithm that is inspired by nature. In this section algorithm step by step using the Genetic algorithm was developed.

Step 1: obtain the function block as discussed in the previous two sections as shown in figure 12.

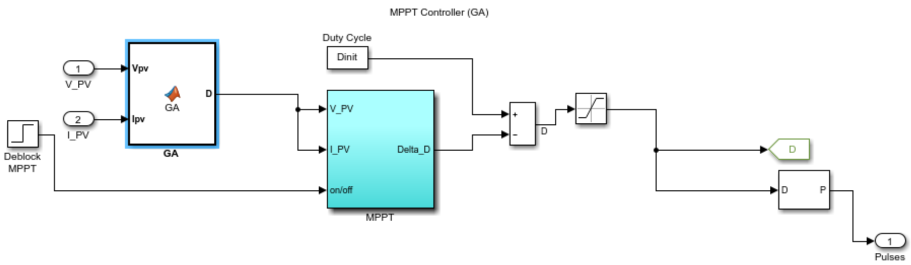


Figure 7: GA System

Step 2: obtain the current and voltage from the PV system to be optimized

```
function D = GA(Vpv,Ipv)
%#codegen
persistent u;
persistent dcurrent;
persistent pbest;
persistent p;
persistent dc;
persistent v;
persistent counter;
persistent gbest;
if(isempty(counter))
    counter=0;
function D = GA(Vpv,Ipv)
```

```
%#codegen
persistent u;
persistent dcurrent;
persistent pbest;
persistent p;
persistent dc;
persistent v;
persistent counter;
persistent gbest;
if(isempty(counter))
   counter=0;
```

step 3: check if the previously calculated change in counter, voltage, current and power is zero. Set to a default value if yes.

```
if(isempty(dcurrent))
   dcurrent=0.5;
end
if(isempty(gbest))
   gbest=0.5;
end
if(isempty(p))
   p=zeros(4,1);
end
if(isempty(v))
   v=zeros(4,1);
end

if(isempty(pbest))
   pbest=zeros(4,1);
end
if(isempty(u))
   u=0;
end
```

step 4: calculate the input power and compare with the previous power. Adjust output parameters accordingly. The complete code can be found on request.

2.5 Comparison of Optimized PV System to Unoptimized PV System

The research implemented using two cases to assess resilience of the proposed system built in MATLAB under rapidly changing atmospheric circumstances. First, considering the performance of the system at 25^0C and rapidly while varying the irradiation as a simple case, secondly, adjusting the temperature and irradiation simultaneously to simulate real environmental conditions.
The performance of the unoptimized is compared to the P&O and GA optimized system under the stated conditions. However, the time response, oscillation and stability are the three most important factors to consider when evaluating the effectiveness of any PV algorithm.
Results of these simulations are presented in section 3.3 of this study.

3. Results and Discussion

The code of the various optimization methods, the code was developed and debugged in MATLAB Simulink.

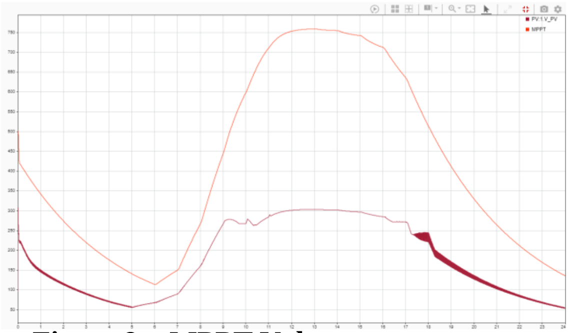


Figure 8a: MPPT Voltage

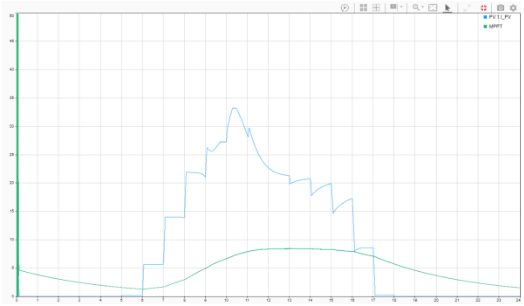


Figure 8b: MPPT curren

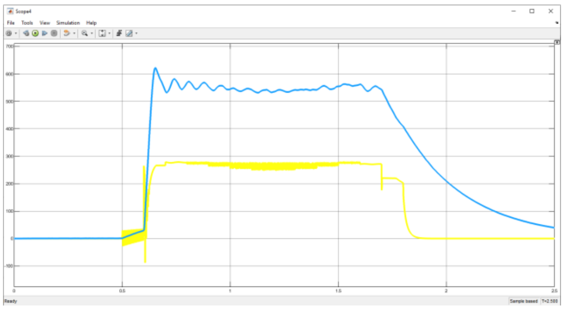


Figure 9a: GA optimized voltage

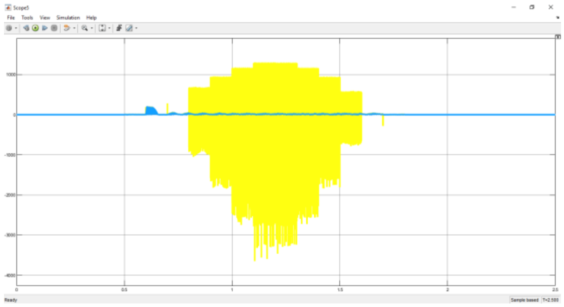


Figure 9b: GA optimized current

Figure 10a: Output Power P&O optimized system

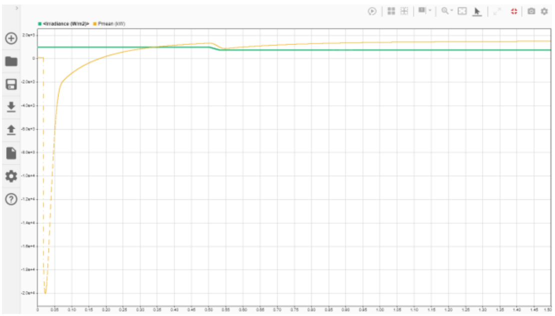


Figure 10b: Output Power unoptimized system

Figure 11c: Output Power unoptimized system

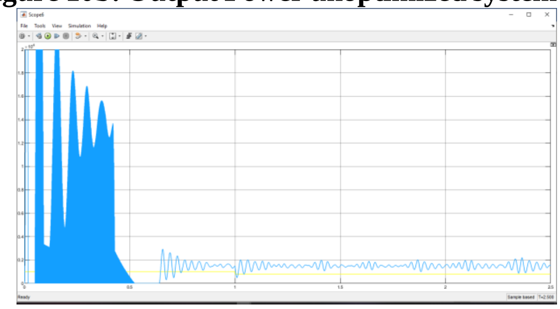


Figure 11d: Output power of GA optimisation

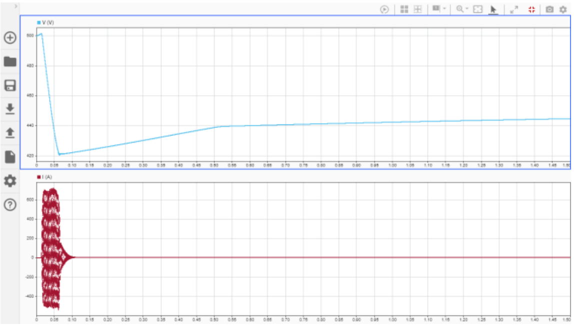


Figure 12a: Voltage and Current of P&O system

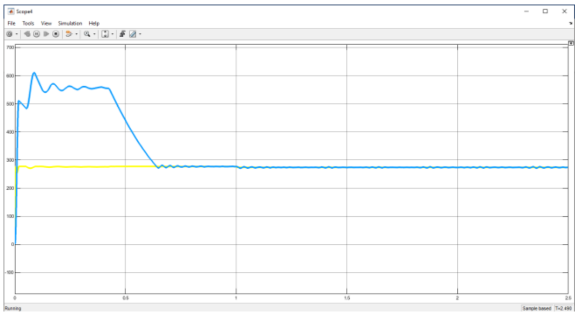


Figure 12b: Voltage and current of optimized system

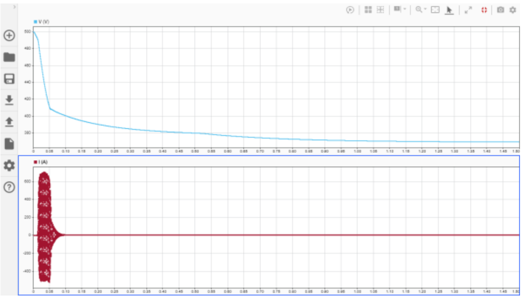


Figure 13c: Voltage and Current of unoptimized system

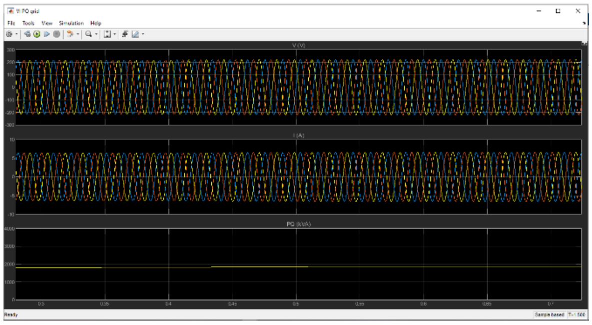
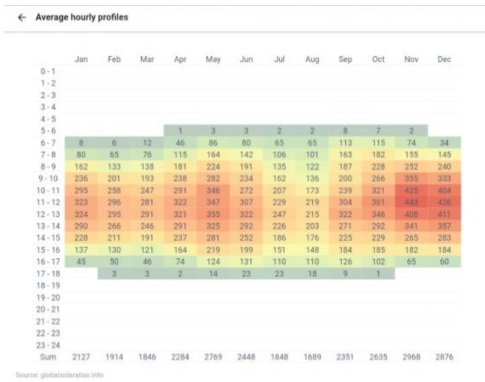


Figure 14: Output from inverter

Figure 16: Average Solar irradiance for
for Edo State Nigeria (chart)



Average hourly profiles

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				1	3	3	2	2	8	7	2	
6 - 7	8	6	12	46	86	80	65	65	113	115	74	34
7 - 8	80	65	76	115	164	142	106	101	163	182	155	145
8 - 9	162	133	138	181	224	191	135	122	187	228	252	240
9 - 10	236	201	193	238	282	234	162	136	200	266	355	333
10 - 11	295	258	247	291	346	272	207	173	239	321	425	404
11 - 12	323	296	281	322	347	307	229	219	304	361	443	426
12 - 13	324	295	291	321	355	322	247	215	322	346	408	411
13 - 14	290	266	246	291	325	292	226	203	271	292	341	357
14 - 15	228	211	191	237	281	252	186	176	225	229	265	283
15 - 16	137	130	121	164	219	199	151	148	184	185	182	184
16 - 17	45	50	46	74	124	131	110	110	126	102	65	60
17 - 18		3	3	2	14	23	23	18	9	1		
18 - 19												
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	2127	1914	1846	2284	2769	2448	1848	1689	2351	2635	2968	2876

Source: globalsolaratlas.info

Figure 17: Average Solar irradiance
Edo State Nigeria (Table)

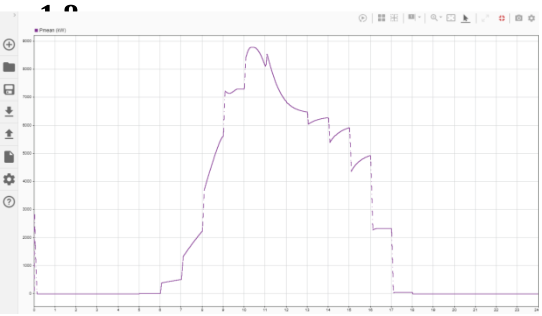


Figure 18: Simulated Output power for the month of April

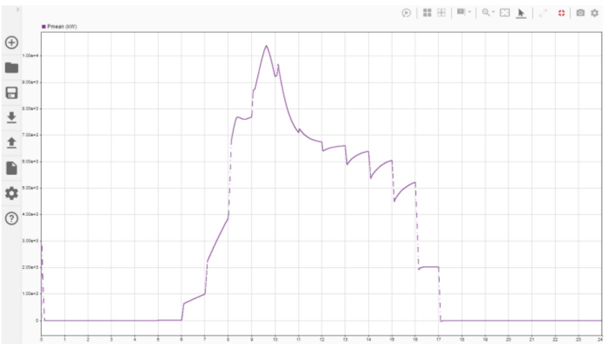


Figure 19: Simulated Output power for the month of November

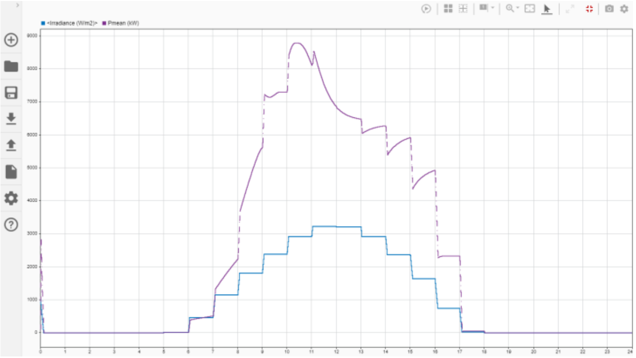


Figure 20a: Output for P&O optimization algorithm

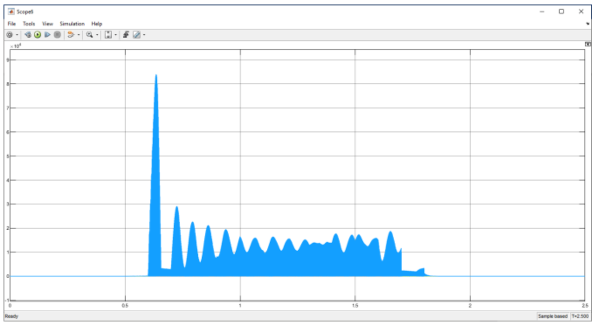


Figure 20b: output of GA optimized system

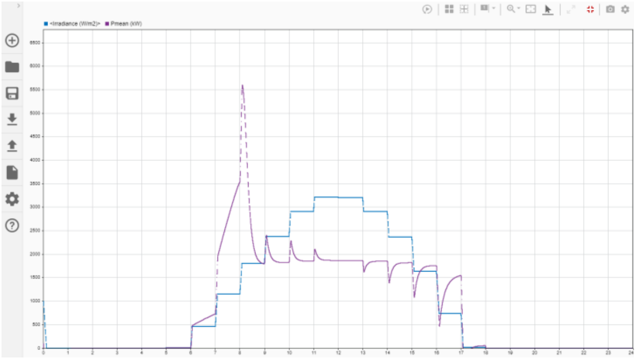


Figure 20c: Output for unoptimized system algorithm

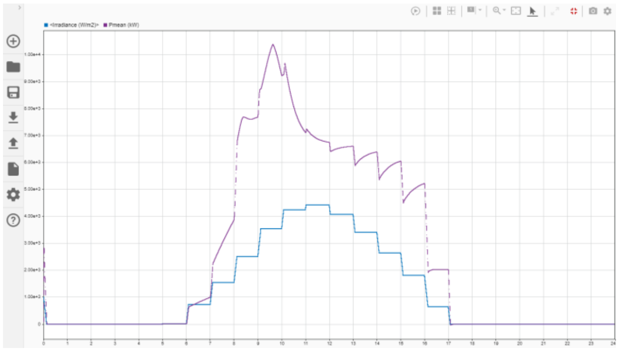


Figure 21a: Output for P&O optimization

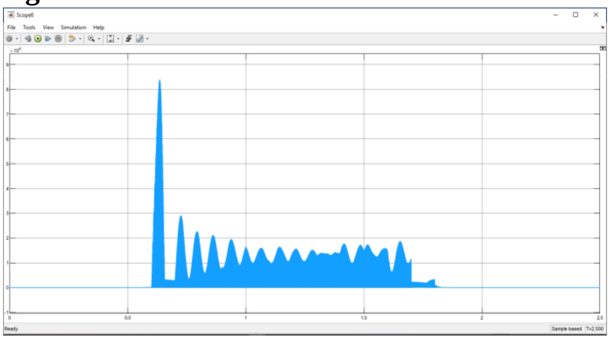


Figure 21b: Output of GA optimized algorithm system

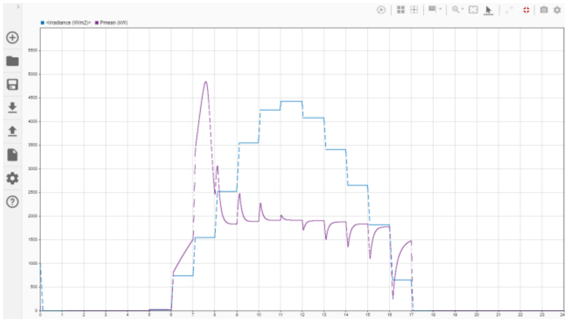


Figure 21c: Output for unoptimized

Table1 Analysis of the performance of proposed methods

Optimization Technique	Sensed variable	Steady state error	Tracking Speed	Tracking accuracy	Efficiency	Complexity
P&O	V, I	Less	Faster	Stable	High	High
GA	V, I	Less	Very Fast	Stable	Very High	Very High
Unoptimized	None	Moderate	Slow	Less stable	Moderate	Low

3.1 Results of Optimization of Solar PV System Using MPPT

MPPT method of solar PV optimization was used in this study for PV optimization, for the figures x axis represent the power and y axis represent the time, figure 13a and figure 13b shows the result of MPPT method in solar optimization.

Figure 13a shows the MPPT voltage to the PV voltage from the solar cell. From the figure, it can be seen that MPPT optimization method removes disturbance seen on the PV output voltage.

3.2 Results of Developed P&O Algorithm for Solar Optimization

Perturb and Observed algorithm was developed in this study, the complete code of the algorithm can be found on request. This algorithm was implemented into the MPPT method used.

3.3 Results of Developed GA Algorithm for Solar Optimization

Genetic algorithm was developed in this study, the complete code of the algorithm can be found on request. This algorithm was implemented into the MPPT method used. Figure 14a and figure 14b shows the performance of the system with GA optimization.

3.4 Results of Comparison between Optimized PV System to Unoptimized PV System

The MPPT optimized solar model developed in MATLAB Simulink is compared with an unoptimized system that uses a fixed duty cycle. Simulations were run for two cases, firstly, using a simple case where the irradiation was varied between 750W/m^2 and 1000W/m^2. The results obtained are in section 3.4.1. Secondly, simulation was performed using real life solar isolation data for Edo state, the data was obtained from Global Solar Atlas official site. The results of this simulation is presented in section 3.4.2.

3.4.1 Results from Simple Case

Initially considering only two irradiation conditions (1000W/m^2 and 750W/m^2) as simple cases and keeping the temperature constant at 25^{0}C, the irradiation was allowed to drop rapidly to 750W/m^2 at 0.5 seconds to simulate the transitory condition to determine how both the optimized and unoptimized respond to transient state.

Figure 15a shows result for the P&O optimized system, this result shows that P&O optimized system has a stable power tracking, the output power is above 2KW compared to the output power of the unoptimized system which has not been kept stable at a specific value and during the same condition has less value (<2KW) as shown in figure 15b. figure 15c shows the zoomed graph of figure 15b.

Figure 15d. shows the result for the GA optimized system, this result shows that the GA algorithm is superior to both P&O and the unoptimized system.

When the radiation changed from 1000W/m^2 to 750W/m^2, it is observed that the time response for the P&O algorithm trained system was less than that of the unoptimized system.

The voltage and current curves for the same case, in figure 16, it is observed that the voltage curve for P&O has a stable performance and recorded a constant value and current. On the other hand, the unoptimized system recorded fluctuating voltage. The current fluctuation at the beginning for P&O compared to the unoptimized system is less. Figure 17, shows the output voltage, current and power from the inverter.

3.5 Results from Real Life Parameters

Solar data obtained for Edo state, nigeria from Global Solar Atlas official site is presented in figure 18 and 19. simulation was performed using non uniform irradiance and temperature patterns on the solar array. Radiation started rising from zero to a specific value and then back to zero. This simulation was performed for April and November using 24 seconds to map 24 hours in a day.

Figure 20 and 21 shows the output power of the system after simulation using the irradiance information for April and November.
With increasing solar irradiation and duration, the acquired power rises and decreases with decreasing power. Figure 22a, 22b and 22c shows the PV characteristics with P&O, GA and unoptimized system for the month of April.
Figure 23a, 23b and 23c shows the response of both system to the irradiation values for the month of November.
From the simulation result, it can be seen that optimization help to improve the efficiency of the PV system, it does this by sensing the voltage and current variable (P&O algorithm) and alter the system output in response. Optimization improves tracking speed and tracking accuracy. Table 1 summarizes the performance of the optimized system in comparison to an unoptimized system.

4. Conclusion

In this study, the various optimization methods and algorithm was discussed, an optimization algorithm was then developed and the effectiveness and performance of an optimized PV system based on the algorithm was examined. The simulation was implemented using two cases to assess resilience of the proposed system built in MATLAB under rapidly changing atmospheric circumstances. The output of the P&O trained by PSO algorithm was compared to the output of an un-optimized system. The P&O algorithm suggest an improved efficiency of the system and resistance to atmospheric irradiation changes

The P&O system performed better than the un-optimized system, having a faster time response, tracking speed and less oscillation of the output power. Although the un-optimized system was able to produce almost constant power, the P&O optimized system was more effective with an excellent performance.

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