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Optimal Sizing of Renewable Autonomous Hybrid system based on Costs using Grey Wolf Optimization

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Abstract:
Ensuring low-cost and highly reliable electricity generation while meeting the demand load poses a significant challenge. Power plants operate continuously to produce power, with the Programmable Logic Controller (PLC) control system playing a crucial role in managing all the equipment. Power deficiencies in the PLC rooms can lead to equipment disturbances and potential damage to the plant. To address this problem and utilize the abundant solar energy in Libya, this study introduces the optimal sizing of an autonomous hybrid storage system using an optimization method. The Net Present Costs (NPC), Loss Power Supply Probability (LPSP), and Levelized Cost of Energy (LCOE) are employed to extract a suitable function database. The proposed system generates 7 kW of power to meet demand and is implemented in MATLAB. The Grey Wolf Optimization (GWO) method is applied to determine the optimal number of PV panels and BESS capacity for the autonomous hybrid system. The optimal solution obtained through GWO is determined to be 40 PV panels and a 60Ah BESS capacity.

***Keywords*–**Autonomous System, Renewable energy, GWO, Optimization methods, LCOE, Hybrid system.

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الحجم الأمثل للنظام الهجين المستقل والمتجدد على أساس التكاليف باستخدام تقنية Gray Wolf Optimization

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الملخص:

تلبية الطلب على الكهرباء بتكلفة منخفضة وموثوقية عالية هو جوهر رئيسي في توليد الطاقة، ومن الجانب الآخر ، تشكل تغطية الحمل الطلب تحديًا كبيرًا. تعمل محطة توليد الطاقة بشكل مستمر لإنتاج الطاقة، ونظام التحكم بالمنطق القابل للبرمجة (PLC) يعتبر جزءًا أساسيًا من محطة توليد الطاقة، ويجب أن يعمل بشكل مستمر للتحكم في جميع معدات المحطة. قد يؤدي نقص الطاقة في غرف PLC إلى حدوث اضطراب في المعدات وبالتالي قد يتسبب في تلف المحطة وللتغلب على هذه المشكلة واستغلال توافر الطاقة الشمسية في ليبيا، يتم تقديم تحجيم النظام المستقل لنظام التخزين الهجين بأفضل طريقة تحسين. يتم تطبيق تكلفة القيمة الحالية الصافية (NPC) واحتمالية فقدان إمداد الطاقة (LPSP) وتكلفة الطاقة المستوحاة (LCOE) لاستخلاص قاعدة بيانات مناسبة للدالة المناسبة. يولد النظام المقترح 7 كيلوواط لتغطية احتياجات الطاقة، ويتم تطبيقه في برنامج MATLAB. لتحديد العدد الأمثل للوحة الشمسية وسعة نظام التخزين الهجين المستقل، يتم تطبيق تحسين الذئب الرمادي (GWO). يتم تحديد الحل الأمثل بواسطة GWO بـ 40 لوحة شمسية وسعة نظام التخزين الهجين بـ 60Ah.

الكلمات المفتاحية ـ النظام المستقل، الطاقة المتجددة، GWO، طرق التحسين، LCOE، النظام الهجين.

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1. Itroduction

An autonomous DC system with a Photovoltaic (PV), Batteries Energy Storage System (BESS), and Micro Hydro (MH) is introduced to reduce costs and increase reliability) Strategy (PMS) [1]. An autonomous system, PV/Wind Turbine (WT), Supper condenser Storage System (SCSS), BESS, and hydrogen tank is presented to minimizing costs and increasing reliability, the BESS is reduced to 56% and the level of hydrogen is increased to 98% [2]. Off-grid in the north-east Indian states with a PV and hydrogen Fuel Cell (FC) system generating 5.75 kW is presented to be optimized based on the Levelized Cost of Energy (LCOE) and Lowest Net Present cost (NPC). Hybrid microgrid AC/DC with an Energy Storage System (ESS) is modeled, the results show the flexibility of hybrid microgrid is improved [3]. To develop the battery's aging, hybrid PV/BESS with Flywheel Energy Storage System (FESS) and without FESS is presented. The BESS lifetime is enhanced by 1.72% and increased two years with low cost [4]. An autonomous system of PV/WT/BESS/FESS is presented to reduce the total cost, operation and maintenance costs (O&M), and life cycle using power sharing [5]. Two systems configuration PV/Deasil Generator (DG)/BESS and WT/DG/BESS, are presented with Homer Pro software and RET screen Expert to find out the optimum configuration. The result was that PV/DG/BESS is more economical than WT/DG/BESS, to minimize the LCOE of an autonomous system, the Power Pinch Analysis (PPA) is applied in [6]. Two loops of optimization are implemented with, Economic Model Predictive Control, and Genetic Algorithm Optimization (GAO) to find out the optimum numbers of components [7]. Different loads are implemented on PV/BESS by using GAO to find out the optimal sizing of the system [8]. Nine system structures of PV/WT/BESS/SC are applied with HOMER based on reliability and economic concepts [9]. PV/BESS structure is applied based on reliability and economical concepts to cover the load village demand [10]. In this paper, the Grey Wolf Optimization (GWO) method GW is implemented to find out the optimal sizing of PV panels and BESS capacity for the autonomous hybrid storage system. The autonomous system comprised of PV/BESS/SCSS is proposed to cover the demand load of three control rooms of Programmable Logic Control (PLC). The objective of this study is to find out the optimal PV panel number and BESS capacity of the system to satisfy theelectrical demand based on LPSL and NPC. The paper is structured into eight sections. The introduction and literature review are introduced in the first section, followed by the system description in the second section. The modelling of the system is allocated in section three. The system cost allocated in section four. The fifth section covers the system control. The optimization method of the system is organized in the sixth. The seventh section is results and dissection. The eighth section is the conclusion.

2. System Discription

The autonomous hybrid energy system comprises PV/BESS/SCSS. It consists of two types of Energy Storage System (ESS), they are applied to enhance the characteristic of charging and discharging behavior. The system is implemented to be more friendly with environmentally. The autonomous system is supported with a control system to manage the charging and discharging based on the power consumption behavior of PLC control rooms. The proposed system is designed to generate 7 Kw for covering the demand of PLC control rooms; therefore, the average ampere consumption of the three PLC control rooms per day for six months is collected. The average Ampere consumption is about 9.5 A with 220 V AC and the average power is about 1980 W for each control room, that means 5960 W for three PLC control rooms. The proposed of the autonomous system can produce about 7000 W with 31 A and 220 V DC. The schematic diagram of the autonomous hybrid energy system is illustrating in Figure 1.

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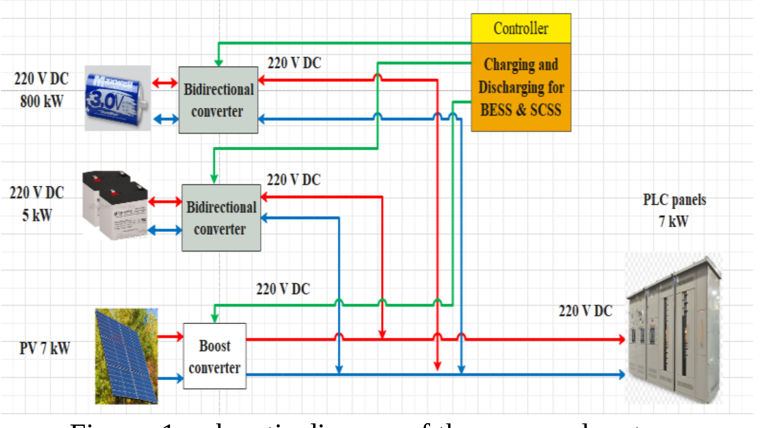

Figure. 1: schmatic diagram of the proposed system.

3. Modeling of the System

3.1. PV System

Photovoltaic is usually used to be as alternative solution, especially in sunshiny states such as Africa state. The solar energy system is classified to two types, Single-diode Method (SDM) and Double-diodesMethod (DDM) [11]. The current-voltage and power-voltage curves are effect by the ambient temperature. The current of PV can be obtained from equation (1) [13]. Figure 2 illustrates the PV SMD circuit.

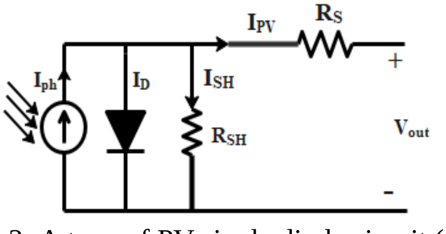

Figure2: A type of PV single diode circuit (SDM).

$$I = I_L - I_o\left[e^{\frac{IR_S}{a}} - 1\right] - \frac{IR_s}{R_{sh}} \quad (1)$$

Where the I_L and I_o represent the diode current and the reverse saturation current respectively , R_s represents the series resistance, a represents the modified ideality current, R_{sh} represents the shunt resistance [12]. PV energy output based on solar energy and ambient temperature can be gotten by equation (2).

$$P_{PV} = Y_{PV-rated} f_{PV} \frac{H_T}{H_S}\left[1 + K_{PV}\left(Tc - T_{ref}\right)\right] \quad (2)$$

Where $Y_{PV-rated}$ represents the rated power of PV based on standard test conditions (STC), f_{PV} representsthe derating factor of PV, *H*$_T$represents incident solar radiation on the surface, *Hs* represents constant (1kW/m^2 ·STC), K_{PV} is the temperature coefficient. *Tc* represents the PV cell temperature and T_{ref} is constant STC (25 ºC) [13]. Table 1 illustrates PV profile.

Table1: PV Array Profile

V$_{mp}$ of Panel	I$_{mp}$ of Panel	P$_{PV}$ of Panel	Price/ one	Lifetime
50.3 V	8.15 A	410 W	75 $	25 y

3.2. BESS and SCSS Components

Energy storage system usually used with autonomous hybrid system for optimization; each one has own technologies characteristics for energy storage, they are used for support the autonomous hybrid system. Generally, BESS is two types: primary BESS and rechargeable BESS. They are store the surplus energy and use it when it is needed [14]. The BESS lifecycle is 1200–1800 cycles, with an efficiency of 75–80% and a lifetime of 5–15 years, table 2 shows the technical data of BESS. State of Charge (*SoC*) and charging time can be calculated by equations (3) and (4) [15].

$$SoC(t) = \frac{Q(t)}{Q_n} \quad (3)$$

Where $Q(t)$ is the current capacity of BESS, Q_n is the nominal capacity of BESS. The initial *SoC* and final *SoC* have a strong relationship with charging time replacement, the BESS charging time T_{B_Chr} can be calculated by equation (4).

$$T_{B_{Chr}} = \frac{(SOC_{end} - SOC_{inti})W_B}{P_{Ch\,a}} \quad (4)$$

$\mathrm{SoC_{end}}$ and $\mathrm{SoC_{inti}}$ represent the finished SoC and initial SoC respectively, W_B represent battery-rated capacity, and $P_{Ch\ a}$ constant charging power. Table 2 illustrates the BESS which technical data of proposed system.

Table 2: Technical data of BESS

BESS Volt	BESS Energy /Ah	BESS $ /One	Life cycle	Noof Paralle l	No of series	BESS Power /kW	Lifetime / year
Ni-Cd48 V	40	75	5000	5	5	5	10

Electric double-layer capacitor (EDLC) of SCSS is widely used with BESS, the SCSS and BESS are used together for support the system, EDLC stores the energy in the physical process, the combination of the supercapacitor and battery is complimentary [16]. Figure 3 shows the equivalent circuit of EDLC, where the Rs is a series resistance, R_c is constant resistance, Z_w is Warburg impedance, C_d is double-layer capacitance, and C_c is surface capacitance. The voltage v_1 and the current i_1 of the SCSS can be obtained by the equations (5) and (6) [17]. Table 3 shows the technical data of SCSS.

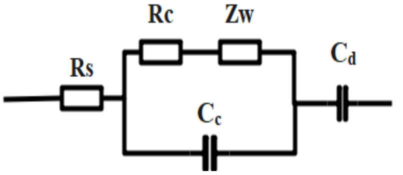

Figure 3: Equivalent circuits of EDLC supercapacitor.

$$v_1 = \frac{-C_0+\sqrt{C_0^2+2C_vQ_1}}{C_v} \quad (5)$$

$$i_1 = C_1\frac{dv_1}{dt} = \frac{dQ_1}{dt} = (C_0 + C_1v_1)\frac{dv_1}{dt} \quad (6)$$

Table 3: Technical data of SCSS

Supercapacitor	Parameters
Cell Capacity	3400 F
Cell Voltage	3 V
Rs	0.15 mΩ
Ns	70 pcs
Np	1 pcs
Delivered power	800 W
Discharged time	5 min.
NT	70 pcs
Price for Cell	35 $
Lifetime	10-15 y
Lifecycle	500000

3.3. Boost conveerter

Theoretically, the DC-DC boost converter transforms the input power to output based on the duty cycle, when the transistor switch has got ON, then the inductor current is begging to increase up to fully charging, when transistor switch is OFF, the inductor current goes to the capacitor and the load [18]. The DC-DC boost converter is an essential element in RES. In practical applications, the efficiency is between 70% and 95% [19]. Figure 4 shows the boost converter circuit diagram with its components. Table 4 illustrates the boost converter parameters, the input of the boost converter by PV is about 205 VDC and 35 A; it is controlled to be 220 VDC and 31 A based on the its components. The V_{out} of boost converter gain and peak-to-peak ripple current (ΔI_L) can be calculated by equations (7) and (8) [20].

Table 4: Boost converter parameters.

Parameters		Values
Voltage Input	V_{in}	205 V DC
Current Input	I_n	35 A
Voltage output	V_{out}	7000 V DC
Current output	I_{out}	31 A
Power output	P_{out}	7 kW

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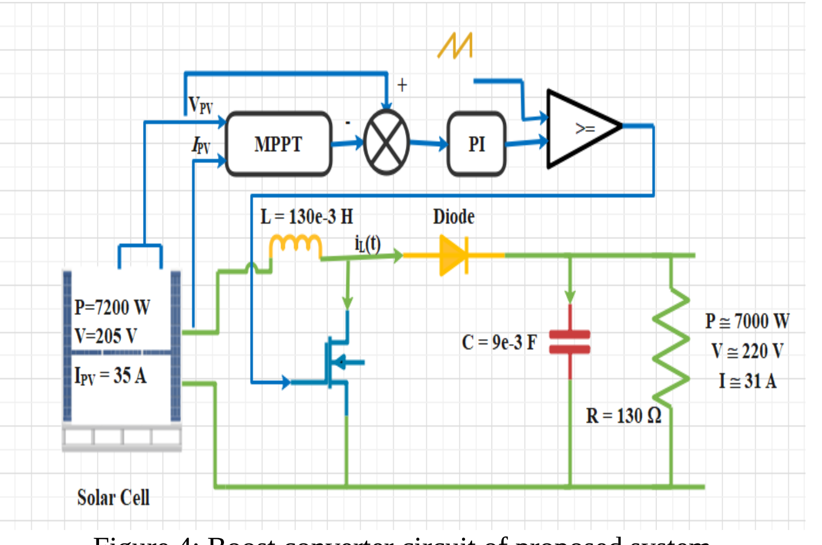


Figure 4: Boost converter circuit of proposed system

$$V_{out} = \frac{V_{PV}}{(1-k)} \quad (7)$$

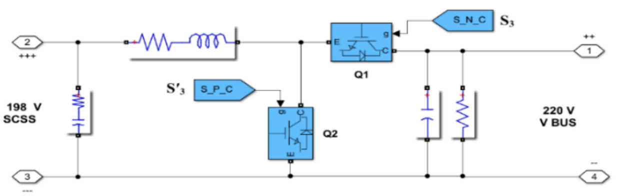
$$\Delta I_L = \frac{V_{PV}\, k}{f\, L} \quad (8)$$

Where V_{PV} is voltage output of PV system and *k* is duty cycle, *f is* Switching Frequency, L is inductor value.

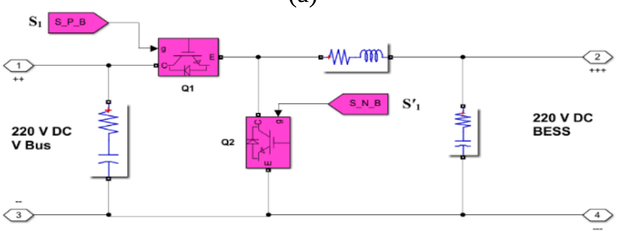
3.4. Biderctional

❖ **Bidirectional Buck Boost Converter**

Power electronics is a part of autonomous system, it is continuously improving, that leads to enhanced the power transformation in RES [21]. The bidirectional converter is combined between the buck and boost converter. In the buck state the Q1 is ON and Q2 is OFF modes and when Q1 is OFF and Q2 is ON become boost converter, all these sequences are done by duty cycle of the converter. Two bidirectional converters for BESS, and SCSS are executed in autonomous hybrid energy system. The role of the bidirectional converter is to control the states of charging and discharging. The Figure 5 (a and b) illustrates the SCSS and BESS converters respectively, SCSS converts from the voltage 198 V DC and about to 220 VDC and vice versa based on the signal S_3 and S'_3. The direction of BESS power is controlled by the signal of S1 and S’1.



(a)



(b)

Figure 5: a (Bidirectional converter of SCSS) b (BESS)

4. System costs

The most important factor in the system is the total cost of the system. Three costs are considered for the proposed system: Net Present Cost (NPC), Replacement Cost (RC), and Operation and Maintenance cost (O&M). Table 5 shows the system’s components cost, the number of items, their cost and the lifetime. The NPC of the proposed system is about 8170 $. The components in the table 5 are selected components to of the proposed system.

Table 5: system components

Items	Number of items	P_T/kW	Total Price/$	Lifetime/years
PV Array	40 panel	4	3000	25
Boost Converter	1	1	395	15
BESS	25	5	1875	10
SCSS	70	0.8	2450	10-15
Bidirectional converters	1	4	350	10

Bidirectional converters	1	0.8	100	10
Capital Costs	8170 $			

5. System control

The control system is applied to control the charging and discharging of two-energy storage system BESS and SCSS. The role of the control is to enhance the energy storage system to increase the power reliability of the proposed system. Figure 6 illustrates the management sequences system of the PV/BESS/SCSS.

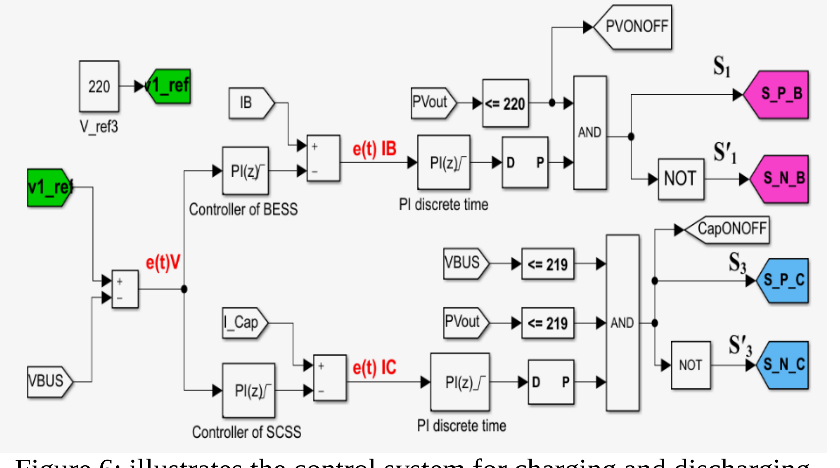


Figure 6: illustrates the control system for charging and discharging

The system has three scenarios: the first is the power load less than the power bus ($P_L < P_{bus}$), the second is the power load equal to the power bus ($P_L = P_{bus}$), and the third one is the power of the load more than the power bus ($P_L > P_{bus}$). The V_{BUS} denotes the generated power on the DC bus. V_{ref} denotes the set point value 220 V DC. The first comparator takes the difference between the V_{ref} and the $V_{BUS.}$ to calculate the first error, *e(t)V*of the BESS. that error passing through the first desecrate PI of BESS to generate two values, (31 or 0), these values are considered as I_{ref} value (31 A) based on the current consumption of PLC rooms. The second comparator will take the difference between the BESS current I_B and I_{ref} to calculate the *e(t)IB* of BESS for the second PI, the role of the second desecrate PI is to generate 1 or 0 for PMW, finally, the complement values are connected to the S_1 - S'_1 of the BESS bidirectional converter to determine the power direction form or to DC bus. The same process is applied for S_3 S'_3 of the SCSS directional converter.

6. Optimization methods

Before the implementation of the Grey Wolf Optimization (GWO) techniques, some have to calculated, such as NPC, LPSP, and LCOE. The LCOE and LPSP represent the economics and reliability of the system, they are calculated for four scenarios. Table 6, shows the obtained data set of the four scenarios based on PV panels number from 36 to 48 panels and the BESS from 50 Ah to 75 Ah. The four scenarios are represented with PV1, PV2, PV3, and PV4. The LPSP, NPC, and LCOE factors are significant to determine the optimal PV panels and BESS capacity. They can be obtained by the following equations: (9), (10), (11), (12) [22].

$$LPSP = \frac{\sum_{t=1}^{T} H}{T} \quad (9)$$

$$NPC = \frac{C}{CRF(i, P_{(lifetime)})} \quad (10)$$

Where C is total annualized cost, *i* is real interest rate per annual, $P_{lifetime}$is the project lifetime, and Capital Recovery Factor CRF can be calculated by the equation (11)

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1}$$

(11) (11)

Where *i* is the annual real interest rate, and N is the project lifetime. The LCOE can be calculated by the equation (12).

$$LCOE = \frac{Total\ annual\ cost\ (\$)}{Electrical\ load\ served\ (kWh)}$$

(12) (12)

Based on the selected components and the calculation of all parameters, the curve fitting in MATLAB is used to find out suitable fitness function to be used with GWO. The fitness equation (13) is extracted based on the BESS and LCOE.

Table 6:System parameters of four scenarios

PV	BESS/Ah	LCOE/$/kWh	NPC/$	LPSP/%
(PV1)36 panels	50	*0.1*	7950	*0.19*
(PV2) 40 panels	60	*0.21*	8170	*0.1*
(PV3)45 panels	60	*0.25*	9200	*0.05*
(PV4)48 panels	75	*0.3*	10850	*0.0*

$$f(BESS, LCOE) = 96 - 15(BESS) + 0.5(LCOE) + (LCOE)^2 \quad (13)$$

The grey wolf optimization is used to minimize the objective function based on their constraints. PV-BESS combination with different scenarios of the autonomous hybrid system is implemented. Different optimization techniques are applied to obtain the optimum PV and BESS values. In this paper GWO is applied with MATLAB to determine the optimal PV panels number and BESS for four scenarios. Figure 7, illustrates the flowchart of GWO.

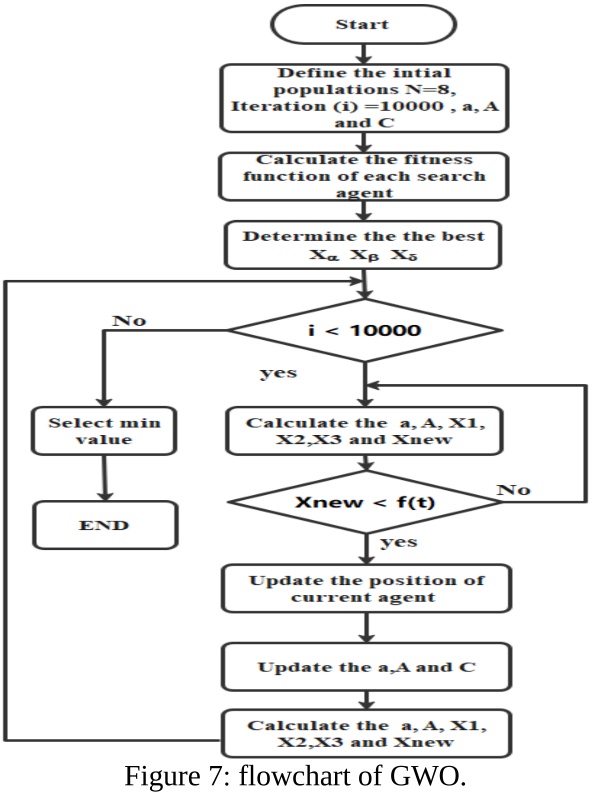


Figure 7: flowchart of GWO.

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7. Results and discussion

The GWO is implemented to find out optimal PV and BESS based on the minimize the cost acording to the BESS cabacity and LCOE, the equation (11) is implemented with GWO in MATLAB, the range of BESS from (50-75) and the LCOE (0.1- 0.3). The GWO gives the optimal number of PV is 39.9 ≈ 40, that mean the obtained value is based on the BESS and LCOE.

The GWO has steps:

1- Frist step is define the fitness function of the system which is determined with eqation (12)

```
% Grey Wolf Optimization with Two Variables
 % Define objective function and GWO parameters
f = @(x) 96 - 15 * x (1) + 0.5*x (2) + x (1) ^2;
```

2- Step 2 is defining the parameters of the variables and iteration of the loop

```
% GWO parameters
max_iter = 1000; % Maximum number of iterations
num_wolves = 5; % Number of wolves (search agents)
ub = [50, 75]; % Upper bound of variables
lb = [0.1, 0.3]; % Lower bound of variables
dim = numel (ub); % Number of variables
```

3- Step 3 determine the initialize the position of the wolfs, that are determinehere under

```
% Initialize the positions of the grey wolves
positions = repmat (lb, num_wolves, 1) + rand (num_wolves, dim).
* (repmat (ub - lb, num_wolves, 1));
% Initialize the best position and fitness
best_position = positions (1, :);
best_fitness = f(best_position);
```

4- Step 4 Implement the main loop based on the GWO mathematics to cover the iteration and the range of the variables.

```
% Main loop
```

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```
for iter = 1:max_iter
 % Update the position of each wolf
   a = 2 - iter * (2 / max_iter); % Linearly decreasing alpha
   for i = 1:num_wolves
      for j = 1: dim
         r1 = rand (); % Random number [0,1]
         r2 = rand (); % Random number [0,1]
         A1 = 2 * a * r1 - a;
         C1 = 2 * r2;
         D_alpha = abs (C1 * best_position(j) - positions (i, j));
         X1 = best_position(j) - A1 * D_alpha;
         r1 = rand (); % Random number [0,1]
         r2 = rand (); % Random number [0,1]
         A2 = 2 * a * r1 - a;
         C2 = 2 * r2;
         D_beta = abs (C2 * best_position(j) - positions (i, j));
         X2 = best_position(j) - A2 * D_beta;
         r1 = rand (); % Random number [0,1]
         r2 = rand (); % Random number [0,1]
         A3 = 2 * a * r1 - a;
         C3 = 2 * r2;
         D_delta = abs (C3 * best_position(j) - positions (i, j));
X3 = best_position(j) - A3 * D_delta;

 positions (i, j) = (X1 + X2 + X3) / 3;
      end
   % Apply the boundary constraints
   positions = max (positions, repmat (lb., num_wolves, 1));
   positions = min (positions, repmat (ub, num_wolves, 1));
```

5- Step 5 is updating the position of the grey wolfs to make the fitness.

```
   % Update the best position and fitness
   for i = 1:num_wolves
      fitness = f (positions (i, :));
      if fitness <best fitness
best fitness = fitness;
```

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```
best position = positions (i, :);
      end
   % Display iteration information
disp (['Iteration ', num2str(iter), ': Best Fitness = ', num2str(best fitness)]);
end
```

6- Step 6 is displaying the results of GWO after complete the iteration based on the range of BESS and LCOE

```
% Display the final result
disp (' ');
disp ('Optimization Result');
disp (['Best Position = [', num2str (best position), ']']);
disp (['Best Fitness = ', num2str (best fitness)]);
Optimization Result  Best Fitness = 39.9 PV panels
```

The results of autonomus hybrid energy storage system is determined by GWO $(39.9 \cong 40\ PV\ panales)$ based on two factors BESS and LCOE. Four sceinarios of autonomus hybrid energy storage system are proposed.These systems are represnted with fitness function equation (13), then are implemted with GWO with constrains, the result of GWO is (PV2) which alustrated in table 7.

Table 7 the optimal PV number and BESS cpacity

PV	BESS/Ah	LCOE/$/kWh	NPC/$	LPSP/%
(PV1)36 panels	50	0.1	7950	0.19
(PV2) 40 panels	60	0.21	8170	0.1
(PV3)45 panels	60	0.25	9200	0.05
(PV4)48 panels	75	0.3	10850	0.0

7.1. System output

The system output of the autonomous hybrid energy storage system is illustrated in Fig. 8. The PV, BESS, and SCSS are fulfilled to satisfy the demand load of the PLC rooms. The system has control to manage the priority of the energy storage systems for charging and discharge times. In the case of the PV off, that means the BESS/SCSS are the main sources, and they will support the demand

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load based on the control system behavior, which can be seen clearly in system output curves. Figure 8 illustrates the PV/BESS/SCSS (red line, black line, and yellow line, respectively), The exchange of the power sources between them can be seen in durations of 8:00–9:28 for PV/BESS/SCSS, 9:30–16:45 for PV/BESS, 16:48–17:10 for PV/BESS/SCSS, 17:15–20:00 for PV/BESS and finally from 20:00 to 24:00 for BESS/SCSS.

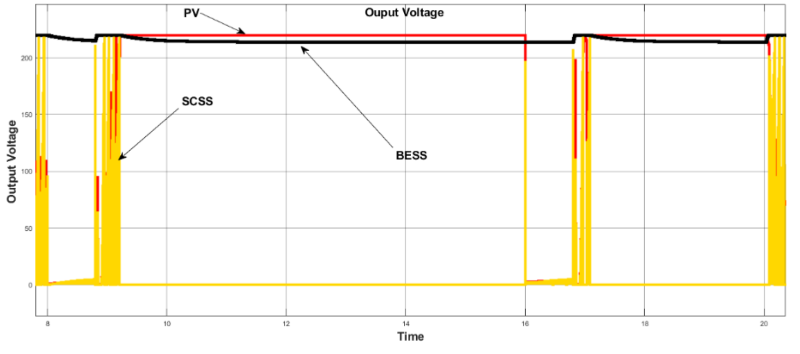

Figure 8: the output of the proposed system

8. Conclusion

The proposed autonomous hybrid energy storage system with PV/BESS/SCSS is implemented to satisfy the load demand and overcome the problem of deficit power in the PLC control rooms in the power plant. The system is designed to generate 7 kW with four scenarios based on the BESS capacity and LCOE. The goal of this stage is to determine precisely the optimal number of PV panels and BESS capacity based on the BESS and LCOE. The intelligence techniques GWO is applied to find out the optimal values of PV and BESS. The optimal PV panels number and BESS capacity are determined by the GWO. The optimization techniques determine the (PV2) 40 panels and BESS 60 Ah as optimum values. The optimum value has parameters LCOE = 0.21/$/kWh, NPC =8170 $, LPSP = 0.1 %, there for the researcher claims the problem is solved, that mean the proposed system is suitable to be used as alternative power supply for PLC rooms in case of the power shortage.

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