Hybrid Invasive Weed Optimization - Particle Swarm Optimization Algorithm for Biomass/PV Micro-grid Power System

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***Abstract*— Agricultural waste is a stable source of biomass for generating energy. Model analysis for a hybrid biomass-PV micro-grid was carried out in this study. The model analysis shows the ability to meet the power demand requirements of a joined irrigation and a household demand of a farm fruits in Egypt. In this manuscript, an efficient hybridization of two metaheuristic mechanisms, addressed Invasive Weed Optimization (IWO) and Particle Swarm Optimization (PSO), were presented. The new algorithm is named (HIWO/PSO) and applied to take out the optimum sizing of the suggested system. The total net present cost (TNPC), the loss of power supply probability (LPSP) and the excess energy fraction (EEF) have been applied as an exponent to estimate the competence of the introduced micro-grid.**

Keywords-- Biomass/PV Micro-grid, Invasive Weed Optimization, Viability Study, Particle Swarm Optimization, HIWO/PSO

I. INTRODUCTION

Among different Renewable energy resources, biomass plays an essential role because it's long duration of using. The biomass is boosted of bio remains of agricultural outputs, organic trashes (containing plant and animal substances), forests and concerning industries, as well as manufacturing and civilized decomposable trashes.

Solar PV systems with storage system have proved to be a very attractive way to provide electricity to remote locations, but due to its intermittent characteristics, the solar PV system is not capable of producing steady electric power, where solar irradiance approaching the face of the ground is based on geographical position, the time interval of the day, and clearness of the sky. Hence, when utilizing solar PV systems in a microgrid, the intermittent power consequence of the solar PV system must be recompensed. One solution is applying energy storage systems such as batteries, where the overabundant power outputted by the PV system is stocked in the batteries.

Another cucumber for overcoming the choppy behavior of solar energy in generating fixed rated energy is using a micro-grid, which combine the PV system with another renewable source to maintain a stable supply of electrical power. Solar power and biomass have shown some characteristics that they can be sources of clean power, and they are always available in nature.

Many studies have been conducted on the stand-alone micro-grid systems, which integrate considerable renewable energy resources (e.g. solar, wind, hydrogen, biomass, etc) has been offered in the review articles [1–12]. The chief purpose of this research is to appraise renewable resources available in Egypt and determine the best to adhere to the electric supply of demand for the community using hybrid PV/biomass/battery micro-grid system.

The optimization techniques are used extensively in the power generation field. Genetic algorithm (GA) is well-known optimization technique that was presented in many power systems including renewable energy source for optimal control and optimum design [13]. GA is also used for the optimal power flow analysis and consequently optimum design of power systems [14, 15]. Particle Swarm Optimization has many applications in the electric power generation field.

II. STUDY AREA AND ENERGY RESOURCES

This study will present design of an off-grid renewable energy system (RES) to feed a fruit farm located on an area of 100 acres in the new city of Borg El Arab in Alexandria, Egypt. The farm uses drip irrigation and artesian wells. The farm consists of 60 acres planted with apple trees and 40 acres of grapes, and it has a farmhouse for the agricultural engineer, 10 houses for the workers' housing, and a warehouse.

A. Load profile

Precisely expecting the load requirements in the position is decisive for optimum system layout. Two categories of loads are specified and predictable. The premier category of load needs is the household load created by habitation residences for farm operators. In this article, the estimating used relied on fifty operators live in the region and accountable for the 100 acres.

The second category of load need is created by water pumping and irrigation effectiveness, which symbolizes the bulk of aggregate needs requirements in the intended 100 acres plantation.

1) Household Load

The migrant needs of the household load with an average load of 14 kWh/day and a peak load of 2.33 kW is shown in Fig. 1.

2) Irrigation Load

The necessary power for pumping water is named water horse power (WHP) and predestined [16]:

$$\mathrm{WHP} = \mathrm{Q} \times \mathrm{H}/3960 \quad (1)$$

Where:

Q: Pumping power in gallons/min (GPM), and

H: Overall lift, in feet.

The production of the introduced plant should be higher the water horsepower due to the pump's capacity. The efficiency of the pump utilized in this research is about fifty percentages.

The brake horsepower (BHP) is predestined as:

$$BHP = \frac{WHP}{(pumping\ plant\ efficiency)} \quad (2)$$

In this study, the water pump with superior stream value of 14 m^3/h peak head of one hundred and forty meter and power of 7.5 kW was used. The migrant load profile of the irrigation load with an average of 32.7 kWh/day and an extreme of 8.62 kW is shown in Fig. 2.

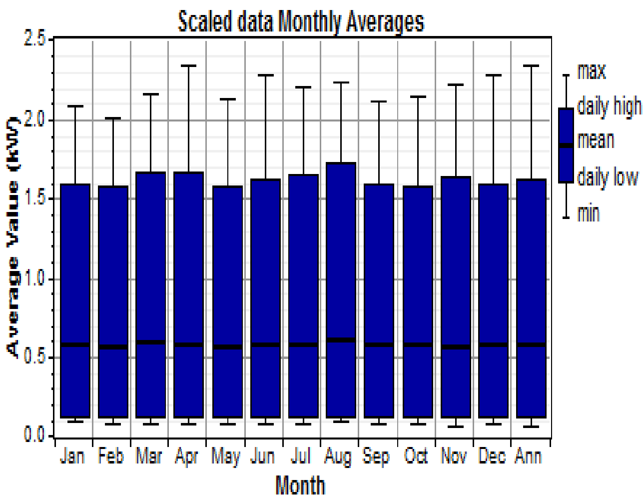

Fig. 1: The seasonal load distribution of the domestic load

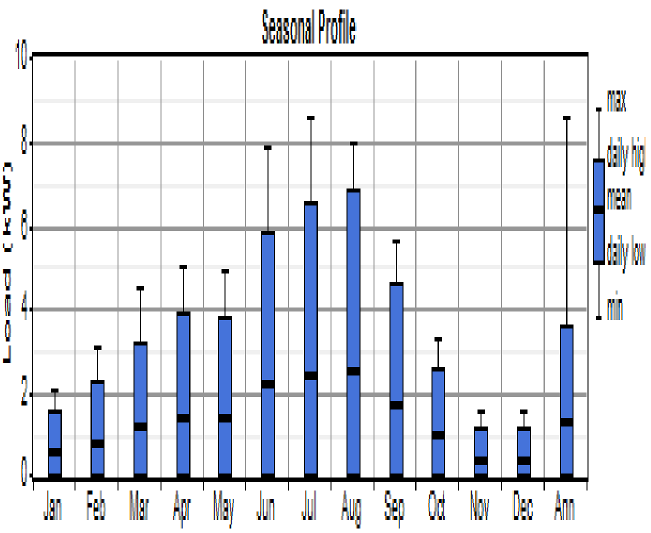

Fig. 2: The migrant load distribution of the irrigation load.

The mean load of the farm is 46.7 kW, and an ultimate of 10.3 kW, utilizing a load parameter of 0.19.

B. Renewable Energy Sources

1) Solar Radiation:

The farm is placed at 30°49' N latitude and 29°35' E longitude. The hourly information of the heliacal irradiation and the temperature applied for the studied location was acquired by utilizing the Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service v3.0 all-sky irradiation (derived from satellite data) [17].

Figure 3 clears the everyday mean heliacal irradiation in the presented location. March to September is the months having somewhat larger heliacal irradiation at the presented location (greater than 5 kWh/m^2/day) and lower in November to February (less than 5.0 kWh/m^2/day). The overall yearly mean amount of the global heliacal irradiation is 5.58 kWh/m^2/day. This information was obtainable for one year from Jan. to Dec. 2018.

In this paper, an 4.86 kW solar system was used which consists of 18 Canadian Solar CS6K-270P Black Poly PV modules and an 4400 Watt clear sinusoidal wave converter wired on a perfect energy station [2].

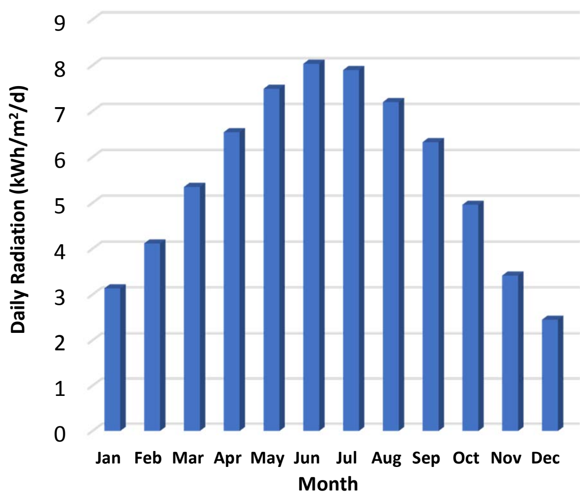

Fig. 3: Per month mean everyday heliacal radiance for the presented region.

2) Biomass Resources

In this section of the study, the focus was on estimating the availability of agricultural residues at the studied zone.

To maintain good fruit productivity pruning must be performed every year. According to the instructions of the Egyptian Ministry of Agriculture, the pruning of the apple trees takes place during the summer period (in the months from June until August), while the pruning of the grape trees takes place during the winter period (in the months from December until February). During pruning, manual scissors, electric shears or mechanical discs are used to cut useless or sick branches and form the appropriate shape of the tree [18]. The cut branches are put on the ground for further treatment/ utilization.

Care must be taken after finishing the pruning trees to exclude pruning products outside the farm with the speed of disposal in a safe manner. So, leaving pruning's in the farms may lead to a long-term lowering of fruit productivity and consequently, financial losses. The conversion of pruned biomass into usable heat, however, seems to be an economically feasible option for the farm owners [19].

The amount of pruned biomass from farm is 4.7 kg/Tree [20]. Year, assuming the amount of the apple trees are 240 trees per acre and the amount of the grape trees are 160 trees per acre and then the total annual biomass yield can be estimated as:

$Total\ annual\ biomass\ yield =$

$$4.7 \times \left[\left(240\frac{Tree}{acre} \times\ 60acre\right) + (160\frac{Tree}{acre} \times\ 40acre)\right] = 18{,}800\ kg/year \quad (3)$$

The Gross Calorific Value (GCV) of the pruned biomass is considered as 18.69 MJ/kg. The tree pruning products will be stored in a farm warehouse. In the current study, a STAK-10 K Stratified Downdraft Gasifier is exercised [2, 9].

3) Energy Storage Devices

In this manuscript, one hundred ampere hour, 5.8 kWh Nickel Iron batteries were used with depth of discharge (DOD) of 0.8 and oneself discharge of 0.01 per everyday [2, 9].

III. Proposed System Configuration

Figure four illustrates, the suggested system which constitutes of PV modules, biomass generator with syngas engine, batteries, and a converter.

The system is designed so that the solar PV system feeds the load during the daytime while the biomass system feeds the night load and any excess energy is fed to the batteries to be used when needed. The batteries are utilized to mask the load necessities via the durations of less energy creation by the proposed micro-grid. On the other hand, any excess energy after charging the battery bank is considered as waste energy and it will be supplied to a Dump load.

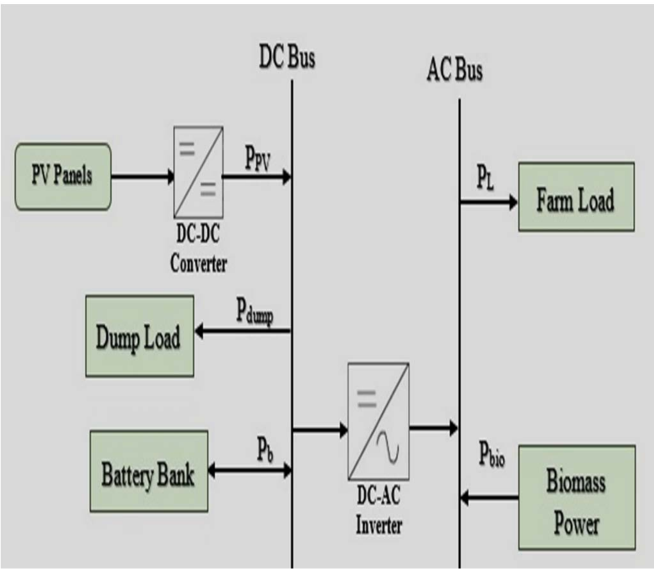

Fig.4: General block diagram of the proposed system

A. Literal Function and Restrictions

The target is to locate an optimum combination of the system devices to achieve a minimum worth of the required TNPC.

Thus, minimization of TNPC is given by the following formula:

$$Minimize\quad TNPC\ \{N_{PV}, N_{bat}, N_{gen}\} \quad (4)$$

Subject to:

$$N_{PV}^{min} \le N_{PV} \le N_{PV}^{max},$$
$$N_{bat}^{min} \le N_{bat} \le N_{bat}^{max},$$
$$N_{gen}^{min} \le N_{gen} \le N_{gen}^{max},$$
$$0 \le LPSP \le LPSP_{max},$$
$$0 \le EEF \le EEF_{max}$$

Where:

N_{PV} is the PV modules digits.

N_{bat} is the batteries digits.

N_{gen} is the biomass generators digits.

$LPSP_{max}$ is the most admissible LPSP, while EEF_{max} is the ultimate permissible EEF given [2, 9]. The treated simulation time interval is to be one hour and operates with information in an annual of 2018. Two levels of LPSP were considered in this study, which are (2%, and 5%) with three maximum limits of EEF (20%, 25% and 30%).

The optimization is to be completed, compelling a group of limitations, which can be categorized in the next scenarios:

a) Energy Balance Limitation

$$E_{PV}(t) + E_{Bio}(t) \pm E_{Bat}(t) - E_{dump}(t) \ge E_{load}(t) \quad (5)$$

Where:

E_{PV} is the PV generator energy.

E_{Bio} is the Biomass generator energy.

$\pm E_{Bat}$ is the energy outfitted and applied by the battery bank.

E_{dump} is the wasted energy due to excessive load.

b) Battery Storage Borders Constraint

The stored energy in the batteries at any time t is liable to the subordinate limitations:

$$E_{Bat,min} \le E_{Bat}(t) \le E_{Bat,max} \quad (6)$$
$$E_{Bat,max} = E_{Bat,cap} \quad (7)$$
$$E_{Bat,min} = E_{Bat,max}(1 - DOD) \quad (8)$$

Where $E_{Bat,min}, E_{Bat,max}$ are the lower and peak energy stored in the batteries. This allows that the batteries should not be on top of discharged or extra charged at any period.

The net present cost of the system can be calculated:

$$TNPC = \sum_x C_I + C_R + C_{O\&M} + C_F - S \quad (9)$$

$$TNPC = \sum_{n=0}^{N_{proj}} \left(C_I(n) + C_R(n) + C_{O\&M}(n) + C_F(n) - S(n)\right) \times \frac{1}{(1+I_r)^n} \quad (10)$$

$$C_I = \sum N_{PV} C_{I\,PV} + N_{bat} C_{I\,bat} + N_{gen} C_{I\,gen} \quad (11)$$

$$C_R = \sum N_{PV} C_{R\,PV} + N_{bat} C_{R\,bat} + N_{gen} C_{R\,gen} \quad (12)$$

$$C_{O\&M} = \sum N_{PV} C_{O\&M\,PV} + N_{bat} C_{O\&M\,bat} + N_{gen} C_{O\&M\,gen} \quad (13)$$

$$s = \sum N_{PV} S_{PV} + N_{bat} S_{bat} + N_{gen} S_{gen} \quad (14)$$

$$C_F = \sum N_{gen} C_F \quad (15)$$

Where:

N_{proj} = Project lifetime.

C_I = the initial capital cost.

C_R = the replacement costs of the components.

$C_{O\&M}$ = Operating and maintenance costs.

S= salvage value.

C_F = the biomass fuel cost.

I_r = real interest rate

The real interest rate is calculated by Fisher's formula

$$I_r = \frac{i - i_f}{(1 + i_f)} \quad (16)$$

- interest rate (i) = 17.75 % (in 2018)
- inflation rate (i_f)= 20.86% (in 2018)

S was estimated applying the attached Eqn.

$$S = C_R \left(\frac{N_{comp} - \left(N_{proj} - N_{comp} \times INT\left(\frac{N_{proj}}{N_{comp}} \right) \right)}{N_{comp}} \right) \quad (17)$$

Where:

N_{comp} is the component lifetime (years).

N_{proj} is the project lifetime (years)

INT is the function applied to regain the integer value of a real number.

C_F is acquired by applying the attached Eqn.

$$C_F = C_{bio} \times M_{total} \quad (18)$$

Where, C_{bio} is the biomass fuel estimate, and M_{total} is the overall wood exhaustion of the generator (kg/y).

LCOE is a cost of producing energy for the appointed system. It`s an frugal appraisal of the estimate of the energy creation system, containing all the estimates over its lifetime.

$$LCOE = \left(\frac{TNPC}{E_{served}} \right) \times \left(\frac{i\left(1 + \left(\frac{i + I_f}{1 + I_f}\right)\right)^{R_{proj}}}{\left(1 + \left(\frac{i + I_f}{1 + I_f}\right)\right)^{R_{proj}} - 1} \right) \quad (19)$$

Where, E_{served} is the elementary load provided (kWh/year).

B. *The Energy Management Organization of the Suggested System*

In the current research, the suggested biomass-PV micro-grid sizing pattern is progressing related to the amount of LPSP. The LPSP is followed by the current limitation, $0 \leq LPSP \leq 1$.

The introduced research methods examine the optimum grouping of PV, biomass power systems, and batteries that mitigated the estimate of the considered *LPSP* according to the simulated scenario. In the proposed system, there are three basically cases that might happen:

- ***Case A:*** the created energy from RES's is equal to the wanted demand; the batteries will not be applied.
- ***Case B:*** the created energy from RES's greater than load: the over energy will be stocked in the batteries. If there is still remaining energy after charging the batteries, that energy will be consumed in an artificial load.
- ***Case C:*** the created energy from RES's is not reuniting the demand: the deficit is drawn from the storage battery bank.

C. *Hybrid Invasive Weed and Particle Swarm Optimization (HIWO/PSO)*

Invasive weed optimization and PSO have two diverse procedures for optimization. IWO gives excellent reconnaissance and variety, while PSO is very simple compared with the other optimization algorithms [21, 22].

In the proposed HIWO/PSO, the IWO mechanism performs the function of leading the germination and PSO technique serves as an adjutant. The intercommunication among the dispersion way of IWO technique and the velocity of PSO technique dominates the equilibrium among home and comprehensive explorations in the issue space. Figure 5 demonstrates the pseudo code of the proposed technique.

A computer program was made applying MATLAB™ 2019 package to execute the energy management organization of the presented system and the optimization algorithm.

1. Generate random population of N_0 solutions.
2. For iter = 1 to the maximum number of generations.
   a. Calculate *fitness* for each individual.
   b. Compute maximum and minimum fitness in the colony.
   c. Set P_g as the best position of all individuals.
   d. For each individual $w \in W$.
      i. Set P_i as the best position of individual w in comparison with its predecessors.
      ii. Compute number of seeds of w, corresponding to its fitness.
      iii. For each seed s calculate each particle's new position based on the new velocity vectors according to:

$$V_{i,d} = \omega V_{i,d} + C_1 R_1 \left(P_{best,i,d} - X_{i,d}\right) + C_2 R_2 \left(G_{best,i,d} - X_{i,d}\right)$$

$$X_{i,d} = X_{i,d} + V_{i,d}$$

      iv. Randomly distribute generated seeds over the search space with normal distribution around the parent plant (w).
      v. Add the generated seeds to the solution set, W.
   e. If $(|w| = N) > P_{max}$
      i. Sort the population W in descending order of their fitness.
      ii. Truncate population of weeds with smaller fitness until $N = P_{max}$
3. Next iter.

Fig. 5: Pseudo code of the proposed HIWO/PSO algorithm

IV. RESULTS AND DISCUSSIONS

A fruit farm located in the new city of Borg El Arab in Alexandria, Egypt has been used to examine the optimization of sizing a small stand-alone Biomass/PV micro-grid. From the existing data, the average solar radiation is 5.58 kWh/m^2/day, while the total annual biomass yield of the farm is 18,800 kg/year. Frugal and creative criteria correlated with elements used in this study have been displayed in Table 1.

TABLE I: ECONOMIC ANALYSIS PARAMETERS AND ESTIMATE

PV System [9]		
Parameter	**Unit**	**Value**
Mean power	kW	4.86
Age	years	20
Premier price	$	11,562
Operation & Maintenance price	$	50
NI-Fe Battery [2]		
Parameter	**Unit**	**Value**
Energy	kWh	4.8
Age	years	20
Premier price	$	3,880
Surrogate price	$	3,880
Operation & Maintenance price	$	5
Biomass Power System		
Parameter	**Unit**	**Value**
Premier price	$	12,195
Surrogate price	$	7,930
Fuel cost	$/kg	0
Operator salary	$/h	0.3
Engine operating life	h	25,000
Fuel curve intercept (F_0)	kg/h	0.48
Fuel curve slope (F_1)	kg/h/kW	0.286
Gasification efficiency	-	70%

In this article the HIWO/PSO is considered for the optimization of a biomass-PV microgrid, the optimal solution is presented in following section. The feasible solutions for the proposed optimization algorithm are presented in Table 2. While the conversion curves are shown in Fig. 6.

TABLE II: OPTIMAL SIZING RESULT OBTAINED BY OPTIMIZATION ALGORITHMS

ALGO.	LPSP (%)	EEF (%)	LCOE ($/kWh)	N_{PV}	N_{gen}	N_{bat}	TNPC ($)	Execution Time (sec)
HIWO/PSO	2.00	20.0	0.462	20	2	141	898,121	1191.55
HS [2]	2.00	20.0	0.462	20	2	141	898,121	5314.84
PSO [23]	1.97%	19.8%	0.464	20	2	142	902,064	5314
FPA [7]	1.93	19.8	0.486	20	2	148	944,621	5324.14

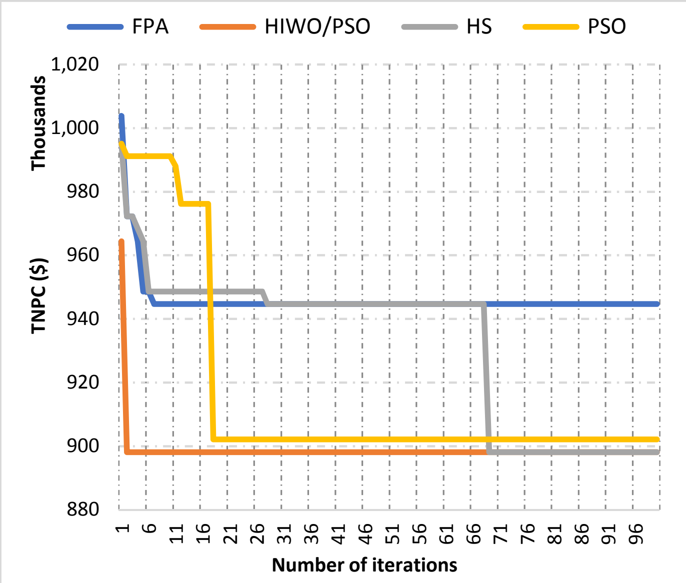

Fig. 6: A comparison between algorithms responses for LPSP=2% and WEF=20%

It can be noticed from Fig. 6 that the HIWO/PSO constantly meets to the optimum solution faster than the Harmony search (HS), the PSO, and the Flower Pollination Algorithm (FPA).

Due to the current system is for a plantation, a low LPSP system is too costly for it. Furthermore, high LPSP system will impact the farm operation. For a LPSP of 2% the optimal system of the Biomass/PV Microgrid consists of 20 solar PV power systems (97.2 kW), 2 Biomass power systems (20 kW), and 181 Nickel Iron battery. The system will be designed to work at TNPC of $ 898,121 which results LCOE of 0.462 $/kWh. For these conditions, the lost energy percentage of the optimum system is 20.

The expense of energy is analogous to that offered in prior manuscripts [2, 23]. The noticed price of energy is to be $0.47/kWh for WT/PV/Battery system energizing a hamlet in the east-southern part of Bangladesh by 8,915 kWh annually [24]. Again, the price of energy is $0.54/kWh for Wind-PV-Battery system energizing a demand of 35,405 kWh annually wanting retardation [25]. While for a farm in Toshka area, Egypt a PV/WT hybrid was designed to produce energy at a cost of $0.597/ kWh. Naqvi et al study the viability of waste gasification based an island grid energy production, the authors found that the LCOE fluctuates through $0.29/kWh and $0.40/kWh depending on the station loading and the capacity parameter [26].

1) Techno-Economic Analysis of the Optimum System

The benevolence of either device to the TNPC of the current system is lighted in Fig. 7. The net present cost (NPC) of the batteries is to be of 52.30% from the overall NPC of the optimal system and for PV and biomass systems is appearing to be 13.94%, and 33.76% respectively of the aggregate TNPC.

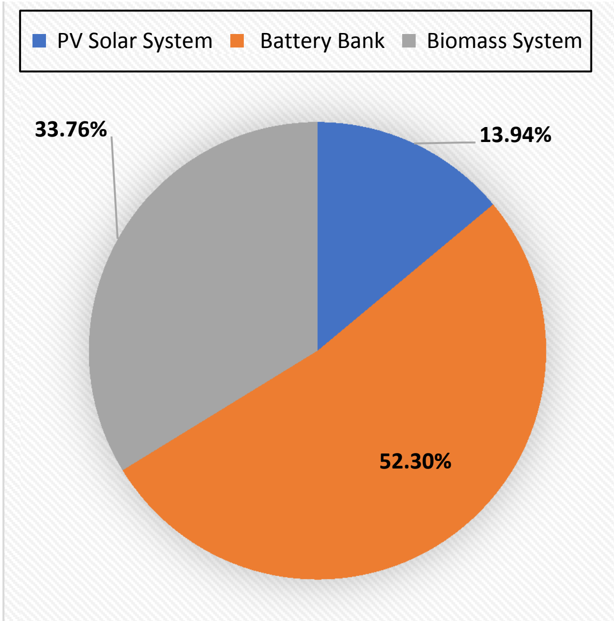

Fig. 7: The benevolence of every device to the total TNPC of the current system

Figure 8 displays the benevolence of every source category to the TNPC. It can be seen that the principal estimate considered as the highest portion of the TNPC which is 77.76%, followed by the commutation estimate, and the operation and maintenance cost by 16.49% and 5.20% respectively. Finally the fuel estimate demonstrates the lower part of the TNPC which evaluated by 0.55%.

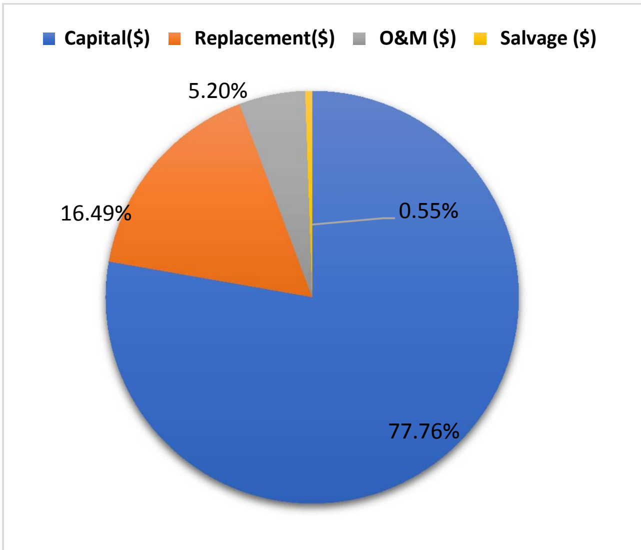

Fig. 8: The benevolence of every estimate category to the TNPC of the current system

Figure 9 explains that the biomass energy system is the commanding reproducer of power with 81.89% of the aggregate producing power.

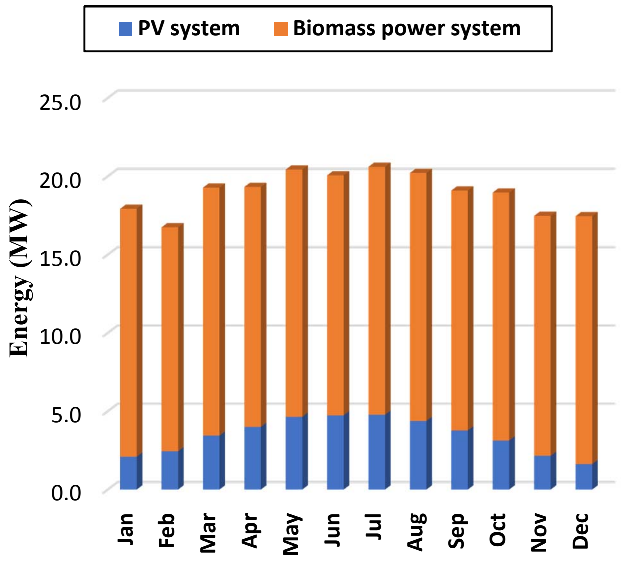

Fig. 9: Per month energy production from the optimized system

V. CONCLUSIONS

A Micro-grid constitutes of a Biomass and PV has been designed and optimized using the HIWO/PSO, the results was compared with the HS, PSO and FPA algorithms. By analyzing the results, it can be concluded that the HIWO/PSO algorithm was the best one among the four algorithms, it converges to the optimum consequences faster using few iterations comparing to the other algorithms.

The purpose of the current layout is applied to discover the optimum sizing of every investigated technology and confirms it's financial, ecological and social potential in pleasurable existing and tomorrow power needs while looking changeable and principal estimate. This manuscript can supply considerable corroboration for effective exploitation resolutions needed by stakeholders and resolution creators.

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