Techno-Enviro-Economic Evaluation for Hybrid Energy System Considering Demand Side Management

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Abstract- The rapid increase in global energy consumption and rising energy generation costs increased the necessity of renewable energy sources (RES) deployment. Integrating RES; e.g. solar and wind, helps overcoming the negative aspect of their intermittent characteristic. Demand side management (DSM) strategies have a significant role in declining hybrid energy system (HES) over sizing, total cost of energy (COE) and in the same time increase the load factor (LF).

The main aim of this study is to design an optimal HES power supply from technical, environmental and economic point of views. The system is proposed to cover the required energy for the National Research Centre (NRC) farm in Noubarya, Egypt. The HES is simulated and optimized using the Hybrid Optimization System for Electric Renewable (HOMER). Then DSM is implemented to increase the utilization of the generated energy from RES, enhance the system performance by shifting loads at low power generation and shaving the high peak of load profile. The results of comparison between the base case and DSM case are obtained according to economical, technical and environmental parameters. Finally, a sensitivity analysis had been performed to determine the benefits of DSM by varying the scaled annual energy demand and renewable contributions. The results showed that the case considering DSM strategy gave better outcome than the base case. The significant reduction is obtained in net present cost (NPC), COE and CO_2 emissions by 13.5%, 15.4% and 20% respectively.

Keywords Hybrid system; Demand side management; Optimization; Energy management; Renewable energy.

Nomenclature:

BBS: Battery bank system
COE: Cost of energy
CL: Curtailable loads
CNV: Converter
DG: Diesel generator
DS: Distribution pump
DSM: Demand side management
DU: Desalination unit
EMS: Energy management strategy
FD: Feed pump
GHG: Greenhouse gas
HES: Hybrid standalone energy system
HHP: High pressure pump
LF: Load factor
NPC: Net Present Cost
NRC: National Research Centre
RE: Renewable energy
RES: Renewable energy sources
RF: Renewable fraction
SOC: State of charge
SPL: Shiftable profile load
STC: Standard testing condition
SVL: Shiftable volume load
WT: Wind Turbine

1. Introduction

Rapid increase of world population has challenged the technical and scientific communities to supply quality power in a sustainable and ecological manner. As British Petroleum [1] mentioned about 80% of the world's electricity is currently generated from fossil fuels. Dependence on fossil fuels has caused the depletion of the reserves and significant impact on global environment [2].

The COVID-19 pandemic has affected energy utilization, technologies and markets. This pandemic has led to a sharp decline in fossil foil consumption as a result of the downturns in the global transportation and manufacturing industries. It will facilitate a rapid growth of RES that contributes to the ecological development [3]. However, the fossil fuels can't meet the future energy requirements because of their environmental and economic problems [4-5]. RES such as wind, solar and hydro have been widely well-known as efficient ways to overcome the issues connected with fossil fuel resources [6-9].

Recently, Egypt is targeting to develop and create various RE projects for rising the share of the clean energy in the overall generated power. RE generation had increased by 3% while the share of RES in global generated energy increased to around 28% till the end of 2019 [10]. It is expected that RE contribution in power capacity will reach about 42% by 2035 [11]. Solar and wind energies are the most used RES in Egypt securing adequate power generation, and facing the significant increases in CO_2 emissions [12-13]. Single RES has difficulty to maintain balance between the required and generated energy because of it's depended on weather changes [14-15]. Fortunately, the problems caused by variable nature of these resources can be partially overcome by hybridization of RE configuration such PV and wind turbine (WT) to achieve system stability and reliability [16]. There have been a number of studies carried out in the same field over the last few years.

Jeslin et al. [17] investigated a techno-economic analysis of a Hybrid Energy System (HES) designed at Engineering College in India. A comparison between on and off-grid operation had been performed under different control strategies such as load following and cyclic charging by using HOMER. The results showed that the HES on-grid system with load following dispatch has the optimal COE and NPC. While Abdulrahman et al. [18] focused on optimizing the performance of standalone HES consisted of WT/PV/battery the system had been sized to cover the required load for a residential house at different situation in Saudi Arabia by using Mathematical models and MATLAB.

Similarly, Halabi LM et al. [19] presented a comparison between hybrid PV with diesel generator (DG) system, PV/battery system and DG-only system which designed for two villages in Malaysia. The results showed that the PV/DG/BBS system had the lowest NPC in the first location while the DG system was the optimal system in the second but reduction of CO_2 emission wasn't taken into consideration. Ari Laitinen et al. [20] focused on hybrid system consisted of PV panels and WT to cover required energy of a district, the results showed that the optimal system required very high investments while the main asset should be made in WT, due to its higher rate compared to PV.

The main challenges and the recent developments come across to the integration of RES, electric vehicles and demand-side initiatives had been presented [21]. Also M.S. Ismail et al. [22] presented a sizing optimization for HES that comprised of WT, PV, battery bank system (BBS) and DG for supplying electricity in remote area. The optimization performed by genetic algorithm and the most economical solution based on the lowest COE. The results showed that the HES were cost-effective comparing to extending the main grid or using only DG system for supplying energy to these remote areas

Emad et al. [23] presented a mathematical model for optimizing PV/WT/BBS system to cover the required energy for remote areas in Sinai, Egypt. The determination of the economically system was based on the lowest COE. Similarly, Monowar et al. [24] presented a stand-alone WT/PV/BBS/DG for a touristic resort which fully depended on DG system to cover the energy needs. The estimated average and peak load were 13,048 kW/day and 1185 kW/day respectively. The economic and technical analysis performed by using HOMER. The results showed that the proposed HES had lower COE and NPC than the DG supply.

In another study, Tawfik et al. [25] presented hybrid PV/WT/DG/BBS off grid system which optimized by using IHOGA. And the results showed that BBS and PV represented around 22.8% and 23% from NPC. These results indicated that load profile doesn't match the generated energy from RES. As an important means of energy management system (EMS), Adel et al. [26] presented EMS for hybrid PV /WT system to minimize the COE by utilizing the storage usage to increase its lifespan.

Fadaeenejad et al. [27] presented PV/WT/BSS to supply electricity for remote area in Malaysia. The optimization process of HES obtained by using IHOGA but the results of this study didn't take into account that the high excess energy which was around 62% from the annual total load. Mohammad Reza et al. [28] examined the techno-economic feasibility for HES off-grid system to cover electric, heat and hydrogen load. The proposed system was comprised of PV, WT and an electrolyzer. For effective use of excess energy, a boiler proposed to be added for generating thermal energy at low peak periods.

Alramlawi et al. [29] presented Micro-grid system consisted of PV and BBS. The system was optimized using HOMER to minimize the COE taking into consideration the optimum depth of discharge for the BBS and PV tilt angle. Sinha et al., [30] presented a PV-battery system of 3504 kWh/yr with excess generated electricity of 1819 kWh/yr which represented around 51%. The authors then compared this result with the output of PV/WT system that generated 3477 kWh/yr and excess energy 2131 kWh/yr (61%).

It is found that most of the previous studies focused more on the optimal configuration for HES and techno-economic optimization realizing minimum NPC and COE. However, there are still some critical problems to be solved such as the mismatch between RE supply and the required demand that results in the relatively over sizing the storage system and the use of DG that have to be curtailed.

Hence, in this paper different configurations cases of a PV, WT, DG, BBS - as base case are modeled, optimized and evaluated based on the ranking scheme. All the parameters such as NPC, COE, CO_2 emissions, BBS requirements and renewable fraction (RF) are considered. Then implementing DSM can be applied to minimize the COE and increase the utilization of the generated energy from RES, decrease the BBS and the realistic environmental impacts as well as an increase in the RF of HES. Finally, a sensitivity analysis will be performed for the fluctuation of energy demand, fuel price and RES to determine the benefits of DSM.

2. Methodology

2.1. System Description

Different HES configurations consisting of RE components such as PV, WT, BBS and DG; as a buck up system, are investigated to cover the demanded energy for National Research Centre (NRC) Farm in Noubarya, Egypt as shown in Fig. 1. The selection of the optimal HES system that can cover the required load considering the system constraints can be performed according to the scheme rank.

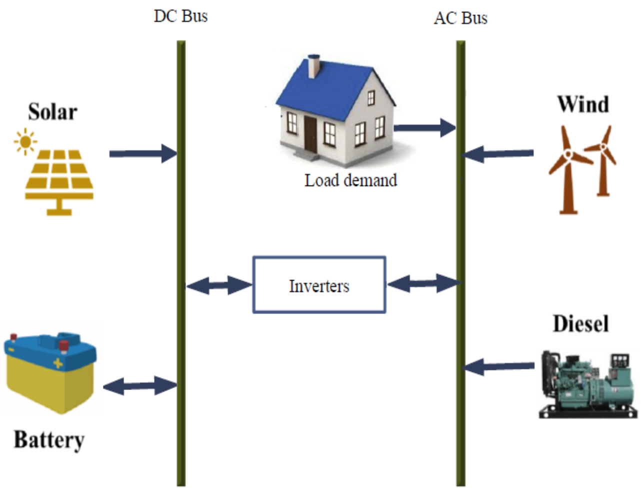

Fig. 1. The Proposed HES configuration

2.2. Resources Assessment

The selected area is National Research Centre-farm in Noubarya, Egypt that is situated at 30°40'0" N and 30°4'0" E. This farm is considered as a research pilot plant for water desalination, agriculture, fish and animal production as shown in Fig. 2. The selected area suffers from frequent shortage of electricity because of instability of the utility grid.

Fig. 2. The selected farm

Wind speed and solar irradiation for the area under study have been obtained from the National Aeronautics and Space Administration (NASA) Surface meteorology and Solar Energy database [31]. The monthly average solar radiation and wind speed are presented in Fig. 3 and 4 respectively.

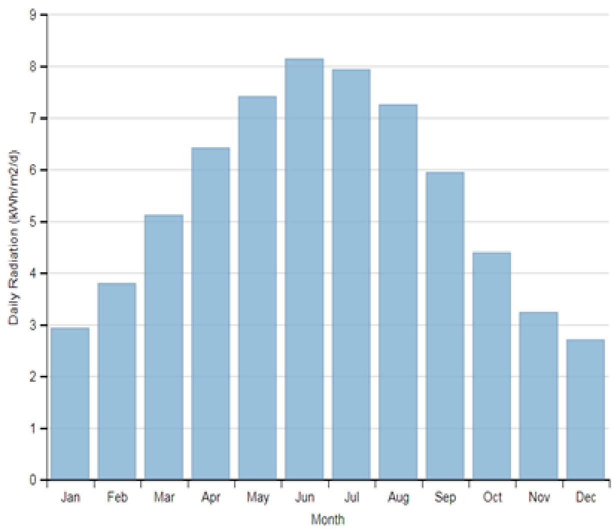

Fig. 3. The monthly average solar radiation

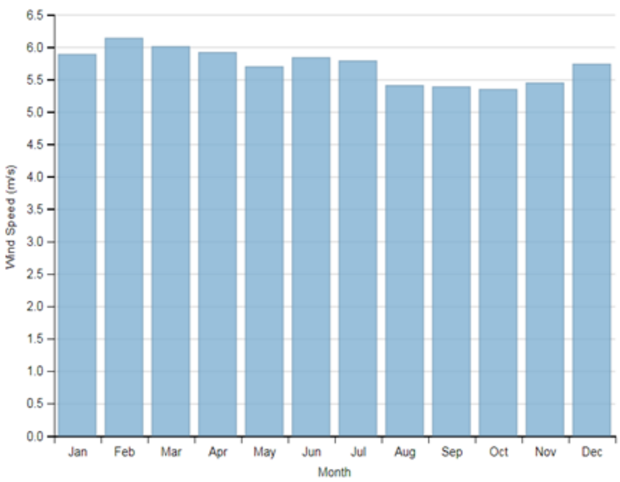

Fig. 4. The monthly average wind speed

The annual average solar irradiation is around 5.43 kWh/m^2/day, and the clearness index is around 0.65 while the annual average wind speed is 5.71 m/s as presented in Fig. 3 and 4.

2.3. Load Profile (Base Case)

The hourly load profile data was collected based on the electricity consumption for NRC-farm. In the present work, the farm consists of: two small factories (animal fodder and Hydrogel), Water desalination unit for covering the farm daily needs, fish farm, Administration building that consists of 10 rooms and lighting system.

2.3.1 Factories Load Profile:

Two small factories are established one for producing animal fodders and the other for Hydrogel production. Monitoring the process operation in both factories, the daily load profile of each of them is estimated; maximum loads are 28 kW for the fodder factory and 16 kW for Hydrogel factory. The equipment used in the factories and required power are shown in table 1. Defining the load pattern depends on types of equipment, their rated power, and time of operations.

Table 1. The fodder and Hydrogel factories required power

	Equipment	Power (HP)
Fodder factory	Mixing feed unit	5.5
	Feed piston	25
	Horizontal cooling fan	5
	Softener	2
Hydrogel factory	Motor	20
	Electrical heaters	1.5

Desalination based on the use of RE sources is expected to become cost-effective alternative due to continuous declination of renewable technologies costs and the continuously increasing fossil fuels prices [32]. In the desalination process, a membrane is used to separate fresh water from saline water (feed water). Feed-water is passed through the membrane, which selectively passes water and filtration salts. RO desalination is also suited for rural remote areas where there is no other water supply available for drinking or irrigation. The DU system consists of three pumps which are the feed pump (FD), the high-pressure pump (HHP) and the distribution pump (DS). The required power for the HHP pump (5 HP) is around 3.73 kW and the FD pump is about 1.87 kW while the power of the DS pump is about 1 kW. The three pumps work simultaneously, so the peak load is about 6.6 kW from 09:00 AM to 12:00 AM and the average estimation of daily energy consumption is about 105.6 kWh/day [25].

2.3.3 Fish Farm

The freshwater fish farming is one of the most significant fish production systems so two fish ponds are established in NRC-farm for research purposes. Using two paddles of 3 HP for ponds ventilation and the required energy is 4.5 kWh from 09:00 AM until 04:00 PM. The average estimation of daily energy consumption is about 36 kWh/day.

2.3.4 The Administration Building

The Administration building consists of 2 floors 10 rooms which need electricity for lighting, laptops and etc. The average estimation of daily energy consumption is 41.55 kWh/day, respectively. Also there is a night lighting system for the NRC-farm that lights up the entrances for fodder factory, Hydrogel factory, fish ponds and DU also the side gates for the administration building. It's consisted of 16 lamps (50 W- 12 hrs). The net load profile and peak load for the NRC-farm are shown in Fig. 5.

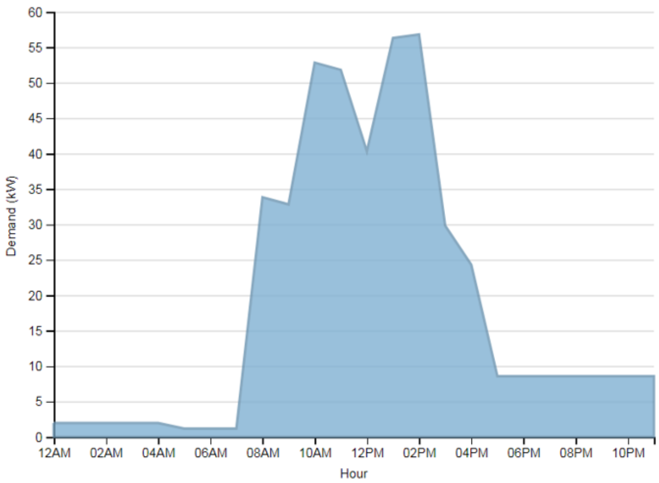

Fig. 5. Load profile for NRC-farm (base case)

2.4. Evaluation of Optimal Configuration

Optimal sizing of the different configurations are selected according to the ranking scheme [33, 34] from the obtained results. All the considerations such as NPC, COE, environmental emissions, BBS requirements and renewable fraction are considered to evaluate the Techno-Enviro-economic characteristics for the optimal system.

The rank is assigned from 1 to 6 according to cons and pros for all considered parameters. The cons is ranked by 1 based on the lowest value of NPC, COE, CO_2 emissions and BBS requirements as well as the pros is ranked by 1 for the highest value of renewable fraction. Then selection of the optimal HES can be obtained through Eq. (1).

$$R_t = Min \sum_{n=1}^{6} (R_{NPC} + R_{COE} + R_{CO2} + R_{BBS} + R_{RF}) \quad (1)$$

Where: R_s: The total of rank, R_{NPC}: The rank of NPC, R_{COE}: The rank of cost of energy R_{CO2}: The rank of CO_2 emissions, R_{BBS}: The rank of BBS requirements and R_{RF}: The rank of renewable friction.

3. Mathematical Modeling of The Proposed HES

The mathematical modeling of each component of the system such as PV, WT, DG, BBS and converter is defined in the next subsections. Also the technical and economic characteristics of each component of the HES are presented.

3.1. PV Panels

The generated power from PV panels effected to solar irradiance and cell temperature. The case under study proposed an array of a 1 kW PV panel which has an efficiency of 19 % at standard testing condition (STC) and derating factor of 80% [35]. The PV power production was calculated by Eq. (2) [36, 37] and the PV cell temperature can be calculated by Eq. (3) [38]:

$$P_{PV} = Y_{PV} \times f_{PV} \times \frac{I_T}{I_{STC}} \times [1 + \alpha(T_C - T_{STC})] \quad (2)$$

Where Y_{PV}: PV array at peak power (kWp), f_{PV}: The panel derating factor (%), I_T: The incident solar radiation on PV array (kW/m^2), I_{STC}: Solar irradiance at STC (kW/m^2), T_C: Photovoltaic temperature (∘C), α: Temperature coefficient of power (%/∘C) and T_{STC}: PV temperature at STC (25 ∘C).

$$T_c(t) = T_a(t) + \left(\frac{NOCT - 20}{0.8}\right) \times \frac{I_T}{I_{STC}} \quad (3)$$

Where T_a: The ambient temperature (∘C) and NOCT: The nominal operating PV cell temperature (∘C).

3.2. Wind Turbine (WT)

A wind turbine is exploited to convert the dynamic energy of wind to electricity. In the current study, a 10 kW horizontal axis WT is considered and the wind speed is calculated at the height of the hub based on wind speed on the selected site. The output power of WT calculated based on different parameters [39] is presented in Eq. (4)

$$P_W = 0.5 \times \rho \times A \times V^3 \quad (4)$$

Where: ρ is the air density, A is the wind's cross-sectional area and *V* is the wind speed.

Also the WT output power can be expressed as a function of the wind speed and WT specifications [40] as presented in Eq. (5)

$$P_W = \begin{Bmatrix} 0, V_{hub} < V_{in} V_{hub} < V_{out} \\ V_{hub}^3(t)\left(\frac{P_r}{V_r^3 - V_{in}^3}\right) - P_r\left(\frac{V_{cut}^3}{V_r^3 - V_{out}^3}\right), V_{in} \le V_{Hub} \le V_r \\ P_r, V_r \le V_{hub} \le V_{out} \end{Bmatrix}$$

(5)

Where: V_{hub} : The hub speed, V_{in} : The cut-in speed of WT, V_{out} : the WT cut-out speed of WT, V_r : the rated speed of WT and P_r : the rated power of WT.

3.3. Diesel Generator (DG)

In the current study, the DG used as a backup system to cover the required energy at the high peak periods when there is shortage of RE generated power. The fuel cost is 0.45 $/liter and the fuel consumption rate F is defined by Eq. (6) [41].

$$F = F_0 \, Y_{DG} + F_1 P_{DG} \quad (6)$$

Where: P_{DG} is the DG rated power, Y_{DG} is the output power of the DG, F_o is Intercept coefficient, F_1 is Slope of the fuel curve.

3.4. Battery Storage System (BSS)

BSS is a significant component of any HES for storing any excess energy from RE generators. The capacity of the BSS can be computed by Equation (7) [42].

$$B_C = \frac{LD \; A_d}{\eta_e \; DoD \; V_S} \quad (7)$$

Where: L_D is the load demand, A_d is days of autonomy, η_e is the BSS round-trip efficiency, DoD is the depth of discharge and Vs is the nominal system voltage.

While The BSS state of charge (SOC) can be defined by Eq. (8) [43]

$$SOC(t) = SOC(t-1) \int_{t-1}^{t} \frac{P_b(t)\, \eta_e}{V_S} \, dt \quad (8)$$

Where P_b is the power stored in the BSS over a period of time t.

3.5. Converter

The converter is used to maintain the energy flow between DC and AC. The output power from the converter can be calculated by Eq. (9), where P_{in} is the input power and η_{in} is the converter efficiency [41]:

$$P_{out} = P_{in} \times \eta_{in} \quad (9)$$

3.6. System Design and Economic Components

During the optimization process, the HES is optimized using HOMER Pro in order to cover the power demand with a minimum NPC, COE and CO_2 emissions. All the techno-economic considerations such as interest rate and discount rate in addition to the capital and replacement costs of the HES component which are illustrated in table 2.

The NPC of the HES is calculated as present value costs of the HES over lifetime minus the NPC of the revenue [46]. It can be calculated according to Eq. (10) [47, 48]:

$$C_{NPC} = \frac{C_{AT}}{CRF\,(i, R_p)} \tag{10}$$

Where: CNPC is the total NPC ($), CAT is the annual cost ($/year), CRF is the capital recovery factor which is measured by Eq. (11), i is the discount rate and RP is the lifetime of the project.

$$CRF(i, N_p) = \frac{i(1+i)^{N_p}}{(1+i)^{N_p}-1} \tag{11}$$

The COE can be calculated by Eq. (12) [49, 50]:

$$COE = \frac{C_{AT}}{L_A} \tag{12}$$

Where: L_A is the annual load consumption

4. Demand Side Management (DSM):

Balancing the generated energy with the load requirements had been targeted through DSM techniques such as load shedding and shifting to ensure the optimal design and operation of HES [51].

4.1. DSM Techniques

The DSM can be obtained through load shaving at high peak period, recompensing them at off-peaks periods according to the flexibility of the load profile to avoid the over sizing of the system configuration as it can also reduce the NPC and COE. Load flexibility can be categorized according to whether they are sheddable or not [52]. Sheddable Loads are flexible to modify or reduce without affecting the productivity and comfort in the farm. Either in case of the required energy can't be rescheduled or shifted from the forecasted energy profile, the load is classified as not sheddable [53].

Sheddable loads can be classified into shiftable loads and curtailable load. If the required energy must be met, but it is acceptable that the shape of the energy profile is either changed or moved in time, the load is classified as shiftable loads can be classified to:

- ➢ Shiftable profile load (SPL) is the load with a fixed profile while can be rescheduled and moved in time
- ➢ Shiftable volume load (SVL) is the load with a fixed volume but the profile can be modified.

Loads that have an energy need which can be reduced without being replaced are called curtailable loads (CL) [54] as presented in Fig. 6. Particularly critical scenarios would be implemented during at high energy demand at the periods of low RE production or high RE generated energy during low demanded energy. At these scenarios it would be possible to apply DSM by allowing increases of consumption during peak periods and reductions at off-peak periods.

4.2. Load Factor (LF)

Load factor is a useful indicator to describe the energy consumption characteristics over a specific time. It is the ratio of the average load used over a specific period to the peak load within that period [55] and it can be calculated using Eq. (13)

$$LF = \frac{AV_L}{P_L} \tag{13}$$

Where: LF is load factor, AV_L is the average load over a specific time (kW/t) and P_L is the peak load over the same period (kW/t)

Table 2. Economic description of HES component

Component	capacity	Capital cost	Replacement cost	Lifetime	Reference
PV system	1 kW	650 $/kW	650 $/kW	25 yrs	[35]
WT	10 kW	9500 $/kW	9000 $/kW	20 yrs	[44]
BBS	1 kW	500 $/kW	500 $/kW	15 yrs	[45]
DG	1 kW	550 $/kW	500 $/kW	15,000 hr	[44]
Converter	1 kW	300 $/kW	300 $/kW	15 yrs	[30]

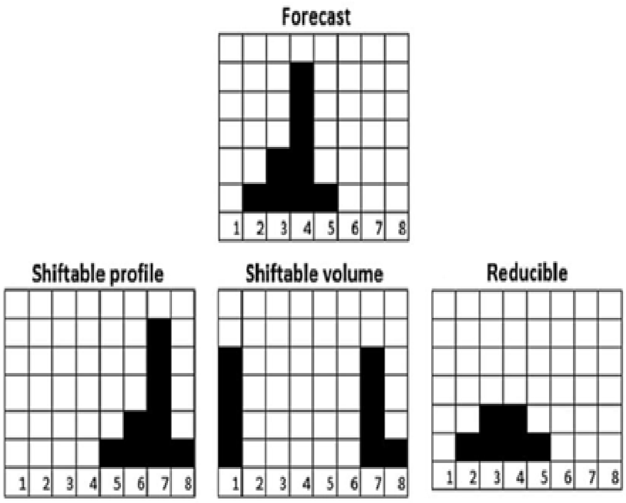

Fig. 6. Visualization of DSM classifications

LF is used to measure the utilization rate which means the efficiency of energy usage. The high value of LF presented that the load is using energy more efficiently; in this case the running time of P_L isn't high which provides more saving in electrical energy and low LF means the energy used insufficiently compared to the peak load over that period [55]. DSM attempts to keep the LF as high as possible through shaving the P_L and shifting to the period which have a low power consumption and high generated energy as shown in Fig. 7.

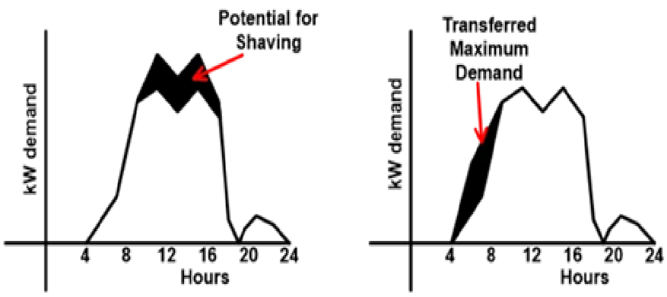

Fig. 7. Peak load shaving

5. Results and Discussion

There are many combinations that have been obtained for PV, WT, BBS, and DG as a backup system to determine the optimal HES for the NRC-farm in Noubarya. The simulation of HES is performed using HOMER where obtained configurations are optimized with 0% energy shortage. Different feasible HES configurations have been simulated, the results are compared; technically, environmentally and economically for the base case (without DSM) and also with considering DSM.

5.1. The Optimal System for Base Case

The configuration with minimum total rank is selected as an optimal configuration HES. According to the ranking status, the HES configurations for base case without considering DSM are given in Table 3.

Table 3. Optimal configurations for base case

Configurations	NPC ($)	COE ($/kWh)	RF %	BBS kW	CO_2 (kg/yr)
PV/WT/BBS/DG	334,452	0.162	78	128	30,929
PV/BBS/DG	397,689	0.187	69	164	43,500
PV/WT/BBS	586,794	0.275	100	326	0
WT/BBS/DG	606,670	0.285	59	272	55,400
PV/BBS	902,226	0.424	100	568	0
DG/BBS	1,115,592	0.523	0	347	151,820

The optimal configuration with minimum total of rank (R_t) was PV/WT/BBS/DG with NPC of $334,452, COE of 0.17 $/kWh, capital cost of $202,537.68, BBS cost of $100,716 and $68,303 of fuel cost while the RF was around 78%. The cost of HES components for the base case (without DSM) is presented in table 4.

This system consisted of 95 kW of PV, 4 WT of 10 kW, 128 kW of BBS and 25 kW of DG. Fig. 8 presented the monthly average generated power. PV, WT and DG provided 56%, 31.4% and 12.5% of the required energy, respectively, while the PV and WT power output during one year presented in Fig. 9 and 10.

Table 4. Component costs of the optimal HES for base case

Cost	PV	WT	BBS	DG	CNV
Total cost ($)	74,535	44,560	100,716	100,147	24,491
% NPC	21%	13%	30%	29%	7%

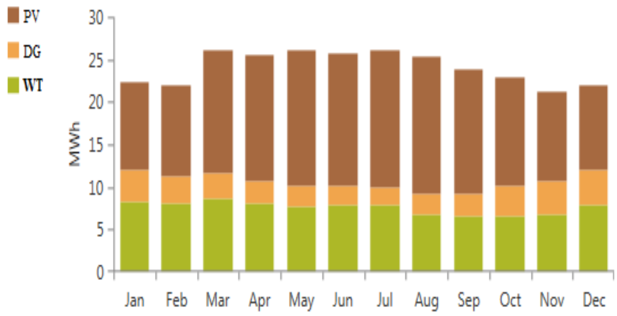

Fig. 8. The monthly average power generation for base case

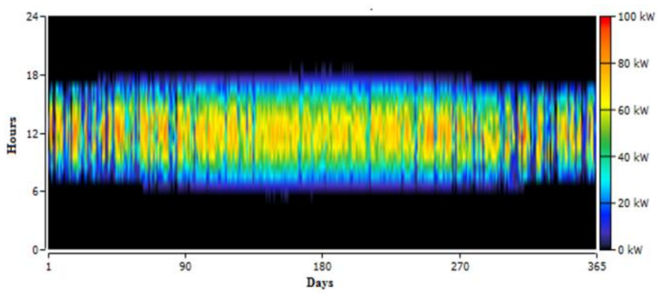

Fig. 9. PV power output for base case.

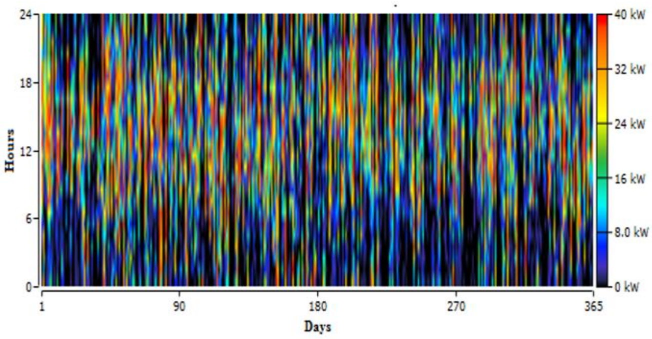

Fig. 10. WT power output for base case.

Table 4 showed that the major costs of the HES are BBS and DG which are about 30% and 29% from NPC. The DG consumed around 11,741 L/yr of fuel which cause high CO_2 emissions of 30,929 kg/yr. However, the RE generation for the base case remained largely unmet at peak demanded energy so there was a high necessity to oversize the BBS. DSM could reduce these values through load shedding and shifting. Applying DSM increases the utilization of RE that can decrease the BBS over sizing and DG fuel consumption CO_2 emissions from DG and. Table 5 the annual CO_2 emissions of base case.

5.2. Optimal System Considering DSM

Particularly critical scenarios would be implemented during low RE production with high energy consumption or high RE production during low consumption. At these scenarios, it would be possible to apply DSM through shifting load to increase the consumption during low peak periods and shaving peaks at low RE production. The DSM rescheduling based on the shedding priority which is ranked according to the degree of flexibility which arranged as follow:

The required energy for fodder unit is considered to be a non-sheddable load as it can't be modified or shifted because the operation process depended mainly on the presence of operators at the daily working time. While the hydro-gel factory is considered to be SPL as the energy profile is fixed but it can be moved in any time. For DU, the load profile is considered to be SPL/SVL as part of energy profile can be modified. The DU pumps can be rescheduled at the periods of high generated energy and low energy consumption. While the required energy for the fish farm can be shifted to anther period with a fixed volume but the energy profile can be modified since its paddles only have to work for 8 hours per day. The administration building and the lighting system can be reduced at the high peak periods so it's considered to be a Curtailable load. Lighting is usually not shiftable since there is an instant need for lighting together with an instant physical behavior of the load. Considering the lighting as one system, it is reducible which achieved by shedding half of all the lights. Table 6 is illustrated the distribution of the load profile before and after applying DSM while the net load profile and peak load considering DSM is shown in Fig. 11.

Table 5. The annual GHG of base case

Emissions	Carbon Dioxide	Carbon Monoxide	Unburned Hydrocarbons	Particulate Matter	Sulfur Dioxide	Nitrogen Oxides
Amount (kg/yr)	30,737	192	8.45	1.15	75.3	180

Table 6. The distribution of the load profile before and after applying DSM

Application	Classification	Component	Before DSM	After DSM
Fodder factory	Non-sheddable	Mixing Feed Unit	9AM-3PM	9AM-3PM
		Feed Piston	11AM-3PM	11AM-3PM
		Cooling Fan	1PM-3PM	1PM-3PM
		Softener	3PM	3PM
Hydrogel factory	SPL	Motor	9AM-12PM,2PM-5PM	7AM-10AM,12PM-3PM
		Electrical Heaters	9AM,11AM,2PM,4PM	7AM,9AM,12PM,2PM
DU	SPL/SVL	FD pump	9AM-12AM	12AM-3AM,7AM-2PM,4PM-7PM
		HPP/DS pump	9AM-12AM	4AM-10AM,12PM,4PM-11PM
Fish farm	SVL	Fish paddles	9AM-5PM	7AM-11AM,4PM-6PM
Adm. Building	CL	Lighting	12AM-12PM	9AM-5PM reduce
Lighting system	CL	Outdoor Lighting	1AM-5AM	3AM-5AM reduce
			6PM-12AM	6PM-10AM reduce

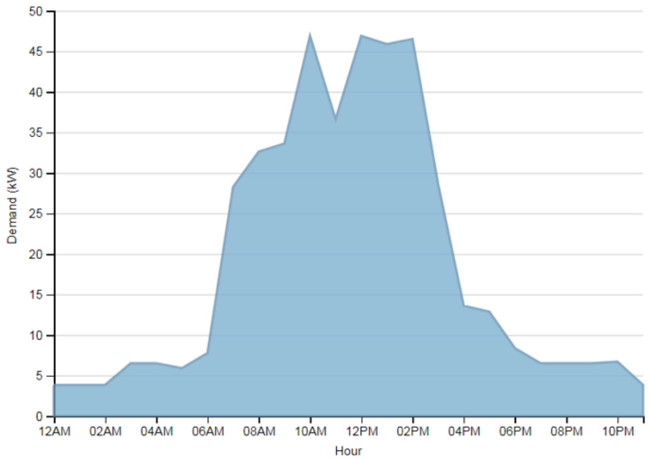

Fig. 11. Load profile for NRC-Farm (DSM)

The results of applying DSM showed different HES configurations which are illustrated in table 7 while the selection and evaluation of the optimal configuration is also based on the scheme ranking status.

Table 7. Optimal configurations with considering DSM

Configurations	NPC ($)	COE ($/kWh)	RF %	BBS kW	CO_2 (kg/yr)
PV/WT/BBS/DG	289,861	0.137	85	55	24,697
PV/BBS/DG	355,620	0.168	75	88	41,402
PV/WT/BBS	422,731	0.200	92	0	15,129
WT/BBS/DG	512,052	0.242	58	179	58,397
PV/BBS	569,605	0.269	100	329	0
PV/DG	847,035	0.400	83	0	28,988
DG/BBS	940,376	0.444	0	203	148,009

The above table showed that the optimal configuration (considering DSM) with minimum sum of rank was PV/WT/BBS/DG where NPC is $289,861, COE is 0.137 $/kWh and the renewable fraction is around 85%.

5.3. Results of Comparison

The results of the base case and DSM case are compared based on economical, technical and environmental parameters. The load profile of base case has a peak load of 58.97 kW, average load value of 18.82 kW and 0.32 of load factor while the DSM case provided a 48.69 of peak load with an average load of 18.62 and 0.39 load factors. Fig. 12 exhibits the load profile before and after DSM while Table 8 presents the load characteristics of both base case and DSM.

Table 8. Load profile evaluation for base case and DSM case

Items	Base case	DSM	Savings	Increments
Average load (kW)	18.82	18.62	0.2	-
Load factor	0.32	0.38	-	0.06
Peak load (kW)	58.97	48.69	10.28	-

DSM case showed a significant reduction in peak load by 10.28 kW and rising of load factor by 0.07 which enhance the technical and economic performance of the proposed HES. Table 9 exhibits NPC, COE, Capital cost and running cost for base case and DSM.

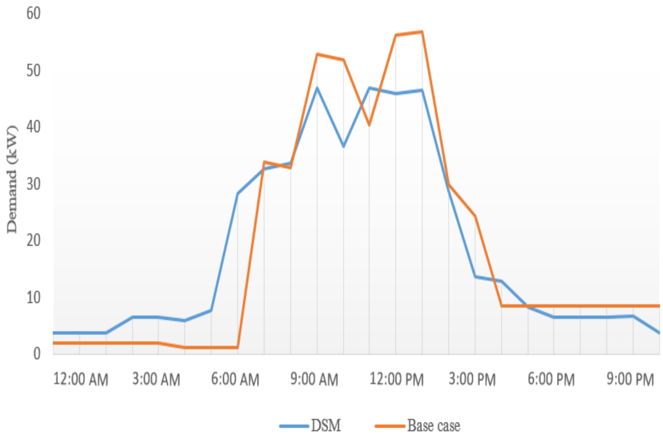

Fig. 12. Load profile for NRC-Farm base case and DSM case

Table 9. The economical evaluation for base case and DSM

Items	Base case	DSM	Savings
NPC ($)	334,452	289,861	44,591
COE ($/kWh)	0.162	0.137	0.025
Capital cost ($)	202,538	164,708	37,830
Running cost ($)	10,978	9681	1,297

The above table showed that using DSM strategy gave better results than the base case. The significant reduction is obtained in NPC, COE, capital and running cost by 13.5%, 15.4%, 18.7% and 11.8% respectively. The technical evaluation of before and after applying DSM is presented in table 10.

Table 10. Technical evaluation of base case and DSM case

Items	Base case	DSM	Savings	Increments
PV (kW)	95	102	-	7
WT (kW)	4	4	-	-
BSS (kW)	128	55	73	-
DG (kW)	25	25	-	-
CNV. (kW)	61	54	7	-
RF %	78	85	-	7

The summarized results in table 10 showed that applying the DSM has a significant effect in decreasing the BBS by 73 kWh; which represented 57% of the BBS base case size. It could also be observed that the balance between the peaks of load demand with generated energy is increased through DSM strategy which leads to decrease the need of storing power in BBS and reduces harmful gases from using DG. Table 11 shows the annual GHG for base case and DSM case and Fig. 13 presented the total GHG emissions for base case and DSM. The results showed a significant reduction in greenhouse gas (GHG) emission by 20%.

Table 11. Environmental evaluation base case and DSM case

Items	Base case	DSM	Reduction
Fuel consumption (L/yr)	11,741	9,376	2,365
Carbon Dioxide (kg/yr)	30,737	24,544	6,193

Carbon Monoxide (kg/yr)	192	153	39
Nitrogen Oxides (kg/yr)	180	144	36
Sulfur Dioxide (kg/yr)	75.3	60.1	15.2

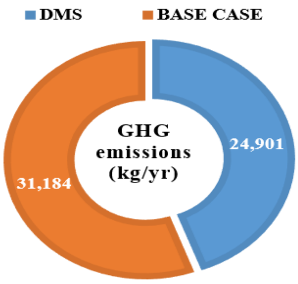

Fig. 13. GHG emissions comparison for base case and DSM

6. Sensitivity Analysis

Sensitivity analysis of the optimal HES with considering DSM is obtained, since the results offer the details behavior of the HES. The range of sensitive parameters is considered for the RES fluctuation, required energy and fuel price are given in Fig. 14, 15 and 16 respectively.

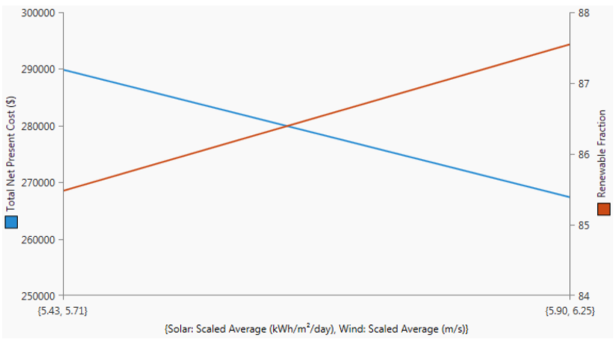

Fig. 14. Sensitivity analysis; effect of increasing RES

Fig. 14 focused on the impact of increasing the solar radiation and wind speed on economic indicators such as NPC which is decreased from $289,861 to $267,322. It also raised RF from 85.5 to 87.5 which decrease the GHG emission of the system.

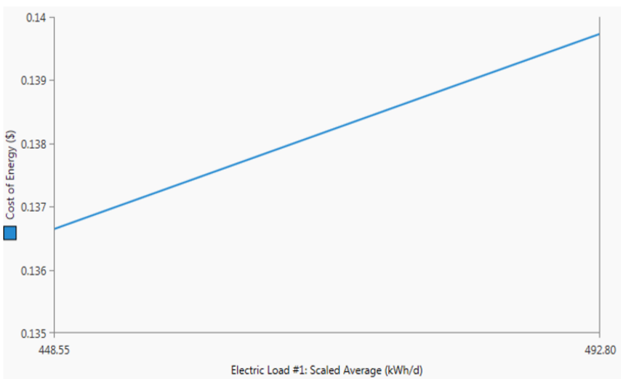

Fig. 15. Sensitivity analysis with increasing energy demand

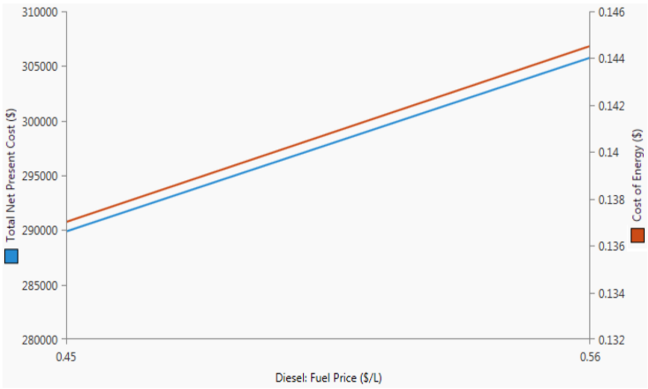

Fig. 16. Sensitivity analysis with increasing fuel price

Fig. 15 showed that raising in the demanded energy by 10%, the COE increased only by 2%. As expected, the increase in fuel prices increases the system COE as shown in Fig. 16. 10% increase in fuel prices raises the system COE from $0.137 to $0.145.

7. Conclusion

This paper discusses optimal design and demand side management for hybrid energy system that covers the required energy for National Research Centre Farm in Noubarya, Egypt. The different feasible HES configurations have been simulated, optimized and evaluated technically, environmentally and economically; first for the estimated load profile (base case) and then considering DSM. The optimal sizing of the different configurations is according to the ranking scheme which considers all the parameters such as NPC, COE, environmental emissions, BBS requirements and renewable fraction to evaluate the Techno-Enviro-economic characteristics for the optimal system. DSM can be applied through load shaving at high peak period, recompensing them at off-peaks periods according to the flexibility of the load profile to avoid the oversizing of the system configuration and high consumption of DG. The results showed that:

- The base case optimal configuration is PV/WT/BBS/DG with NPC of $334,452, COE of 0.17 $/kWh while the RF was around 78%. The major costs of the HES are BBS and DG that represent about 30% and 29% from NPC. The DG consumed around 11,741 L/yr of fuel which cause high CO_2 emissions of 30,929 kg/yr.
- Considering DSM, the optimal system configuration; selected based on the ranking scheme, was PV/WT/BBS/DG with NPC of $289,861, COE of 0.137 $/kWh and the renewable friction was around 85%.
- DSM case showed a significant reduction in peak load by 10.28 kW and rising load factor by 0.07 which enhance the technical and economic performance of the proposed HES.
- The DSM case gave better outcome than the base case. The significant reduction is obtained in NPC, COE, capital and running cost by 13.5%, 15.4%, 18.7% and 11.8% respectively.

- The DSM case decreased the BBS by 57% of that of base case size. Moreover, the matching between the peaks of demand load and generated RE is increased through DSM strategy which lead to decrease the sizing of BBS by 57% in addition to reducing the usage of the DG, consequently harmful gases by 20%.
- The results of the sensitivity analysis showed that the impact of increasing RE resources by 10% can decrease NPC from $289,861 to $267,322. While raising the demanded energy by 10% can increase the COE only by 2% while an increase of 10% in fuel prices cause the COE to rise from $0.137 to $0.145.

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