The Environmental and Economic Benefits of a Hybrid Renewable Energy System Considering Demand Side Management

T.M. Tawfik [a, ‡], M.A. Badr [a], O.E. Abdellatif [b], H.M. Zakaria [b], M. EL-Bayoumi [a]

[a] Mechanical Engineering Dep., National Research Centre (NRC), El Buhouth street.,Dokki, Cairo,12622, Egypt
[b] Mechanical Engineering Dep., Shoubra Faculty of Engineering, Benha University, Shoubra street, Rod ELFarag, Shoubra Masr ,Cairo, 11672, Egypt

(Tawfik_mohamed1410@yahoo.com, drmabadr@gmail.com, sameh_sohasmr@yahoo.com, zhossam@hotmail.com, el_bayoumi@hotmail.com)

‡Corresponding Author;T.M. Tawfik,El Buhouth street.,Dokki, Cairo,12622, Egypt, Tel: +201007695733, Tawfik_mohamed1410@yahoo.com

Received: 09.05.2022 Accepted: 13.06.2022

Abstract- Renewable energy resources (RES) and Demand side management (DSM) are considered as main concerns when designing an optimal hybrid renewable energy system (HRES). DSM strategies have a significant role in declining HRES over sizing, cost of energy (COE), CO_2 emissions and in the same time increase the renewable fraction (RF). In this regard, this study proposes a detailed Techno-Enviro-economic evaluation for HRES considering DSM to cover the required energy for a research farm in Egypt. The optimized HRES has been evaluated under two different control strategies, cycle charging and load following using HOMER. Then DSM is implemented through shifting loads at low power generation and shaving the high peak of load profile. Different hybridization cases of a PV panels, wind turbine, battery storage and diesel generator are configured, evaluated and compared considering DSM to find the most feasible and reliable solution with least Net present cost (NPC), COE and realistic environmental impacts. The results of considering DSM showed a reduction in CO_2 emissions by 25%, NPC by 14.8 %, and COE by14%, as well as an increase in RF by 8.5%. For technical and economical evaluation of DSM benefits, two basic indicators are used which are DSM quality index for the technical benefits and the DSM appreciation index for economic benefits.

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

Nomenclature:

AF: Animal fodder
BS: Battery system
CC: Cyclic charging
CL: Curtailable loads
CNV: Converter
COE: Cost of energy
DS: Distribution pump
DSM: Demand side management
DU: Desalination unit
FF: Fossil fuels
FP: Feed pump
GHG: Greenhouse gas
HCF: Horizontal cooling fan
HG: Hydrogel
MFU: Mixing feed unit
HHP: High pressure pump
LF: load following
NPC: Net Present Cost
NRC: National Research Centre
LF: Load factor
LFR: Load factor
RF: Renewable fraction
SOC: State of charge
$HRES_{WDSM}$: HRES with DMS
STC: Standard testing condition
SVL: Shiftable volume load
HPP: High-pressure pump
$HRES_{WODSM}$: HRES without DSM

HRES: Hybrid renewable energy system
RES: Renewable energy sources
WT: Wind Turbine
SPL: Shiftable profile load

1. Introduction

The growing population and economic development increased the global demand of energy by 120 million tons of oil in 2019 according to IEA report 2020 [1]. Most of these energy (around 86%) was generated from fossil fuels (FF) which are limited to cover the increasing in global energy demand [2].

The COVID-19 pandemic has affected energy utilization, technologies and markets. This pandemic has led to a significant reduction in FF consumption as a reason of the downturn in the transportation industries and global manufacturing [3]. It will increase the dependence on RES such as wind and solar energy which have been widely well-known as functional ways to control the environmental impacts connected with conventional resources [4-8].

Recently, Egypt is developing various renewable energy projects for rising the percentage of the clean energy in the overall generated power. The share of RES in total electricity generation increased to around 28% until the end of 2019 [9] and it is expected to reach 42% by 2035 [10].

Single standalone systems such as WT or PV systems have difficulty to keep balance between the generated and required energy because of its unpredictable nature and dependence on weather changes. It can be partially overcome this problem by hybridization of renewable energy configuration with/without battery system (BS) to achieve system reliability [11].

Standalone hybrid renewable energy system (HRES) has been widely established for various purposes especially for remote areas. Among these, Maleki et al.[12] investigated a stand-alone HRES consisted of WT /PV /fuel cell to cover the required load for remote area in Iran. Similarly, Ifedayo et al. [13] focused on analysis of different configuration of RES off-grid to cover the demanded energy. the main objective was finding the lowest NPC and COE. The results showed that the HRES had lower NPC and COE than DG only system

In another studies, Mayur et al., [14]; Hannan et al., [15] proposed HRES PV/WT HRES which integrated with BS to improve the system reliability. Also, the techno-economic feasibility for standalone batteryless HRES which consisted of PV-DG to cover the electrical load for a remote area in Burkina Faso by Tsuanyo et al.[16]. The determination of the economic system was based on the lowest COE which was 0.284 €/kWh for batteryless HRES and 0.32 €/kWh for standalone DG system.

On the other hand, Tawfik et al. [17] presented hybrid standalone PV/WT/BS with DG as a backup system. The HRES proposed to supply power in a rural area. The results showed that BS was the main cost of NPC which was around 23%. The BS oversizing indicated that the demanded energy doesn't match the RES generations. Also, it can be observed that the greenhouse gas (GHG) had not taking into consideration.

As an important means of DSM, it can improve the balance between generated and required energy through utilizing load flexibility rather than only modifying generated power or oversizing HRES configuration [18]. Many researchers evaluated the optimal sizing of HRES without considering the effect of DSM [19–23]. However, Jafari et al. [24] presented an optimal HRES o`f PV/WT/DG as a backup system with considering DSM. The results of the study highlighted the impact of the RES on the COE, GHG emissions and system reliability.

El-Houari et al. [25] presented a design of stand-alone HRES PV/BS to electrify a rural district in Morocco and decrease the pollution from GHG. The results showed that the integration between PV/BS with DG system was the optimum configuration with the lowest COE which was about 0.356 $/kWh. The proposed HRES can cover 79.1% of the required energy from the solar generated energy while the DG can cover the rest of the required energy. Most recent attempts similar to previous investigations can be found in [26-28].

In the same manner, Ari Laitinen et al. [29] presented HRES consisted of WT/PV to satisfy the demanded energy of the Kalasatama district in Finland. The results showed that the optimal HRES required very high capital cost while the main asset should be made in WT, due to its higher rate compared to PV. Arabi-Nowdeh et al. [30] compared between PV/WT/BS and WT/BS hybrid systems with off and on grid. The main aim of the study is to cover the required load with the lowest COE taking into consideration environmental emissions cost. The results showed the PV/WT/BS HRES was the most techno-economic configuration and the HRES reliability can be improved by purchasing energy from the main grid and considering minimization of GHG.

In our previous study, [31] focused on optimizing hybrid energy system which consisted of PV,WT,DG,BS and then implementing DSM to minimize the NPC, COE and GHG. However, different control strategies such as cycle charging and load following which can enhance the performance of the proposed system and decrease the system sizing. Also DSM quality index and DSM appreciation index had not been taken into account.

Accordingly, a comparison between on and off grid operation had been performed with cycle charging (CC) and load Following (LF) for HRES in India by Jeslin et al. [32]. The results showed that the HRES on-grid system with LF control strategy was the optimum selection. Another comparison between hybrid PV/BS system, PV/DG system and DG system had been presented by Halabi LM et al. [33].

The HRES optimized to cover the required energy for two different rural villages. The results showed that HRES of

PV/BS with DG system had the optimal NPC in the first location while the DG system was the optimal system in the second but reduction of GHG emission wasn't taken into consideration.

Some researches involved determining the optimal HRES on-grid connections. Asrari et al. [34] evaluated the feasibility of various configurations of DG and RES on and off grid. The results proved the benefits of providing RES to standalone HRES which reduces GHG and operational costs. However, the HRES on-grid connection would reduce COE.

According to the above previous studies, it is found that most of researchers focused on examining the optimal configuration for HRES with minimum COE and NPC. However, there are still some critical problems to be solved such as the mismatch between RES generated power and the required load that results in the relatively over sizing the battery system and the use of DG that have to be curtailed.

Hence, this paper designed a detailed framework of HRES which includes techno-enviro-economic parameters with considering DSM. Different configurations cases of a PV, WT, BS and DG are optimized and evaluated based on the ranking scheme. All the parameters such as CO_2 emissions, renewable fraction (RF), COE, NPC and battery bank requirements are considered under different control strategies. Then implementing DSM can be implemented to increase the RES utilization and decrease CO_2 emissions as well as an increase in the RF of HRES.

2. Methodology

Different hybrid renewable energy components such as WT, PV, BS, converter and DG are investigated to cover the demanded energy for National Research Centre (NRC) research area in Noubarya, Egypt as shown in Fig. 1

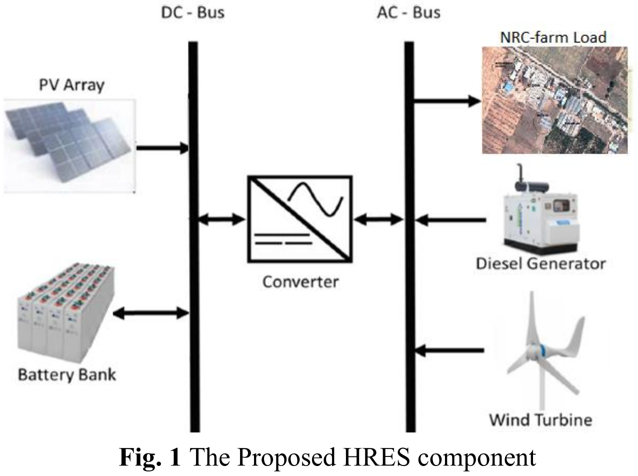

Fig. 1 The Proposed HRES component

During the optimization process, the HRES is optimized using HOMER with the purpose of satisfying the required energy with a minimum environmental impacts, COE and NPC to reach the optimal techno-enviro-economic performance of HRES. Fig. 2 shows the flow chart of HOMER to optimize HRES.

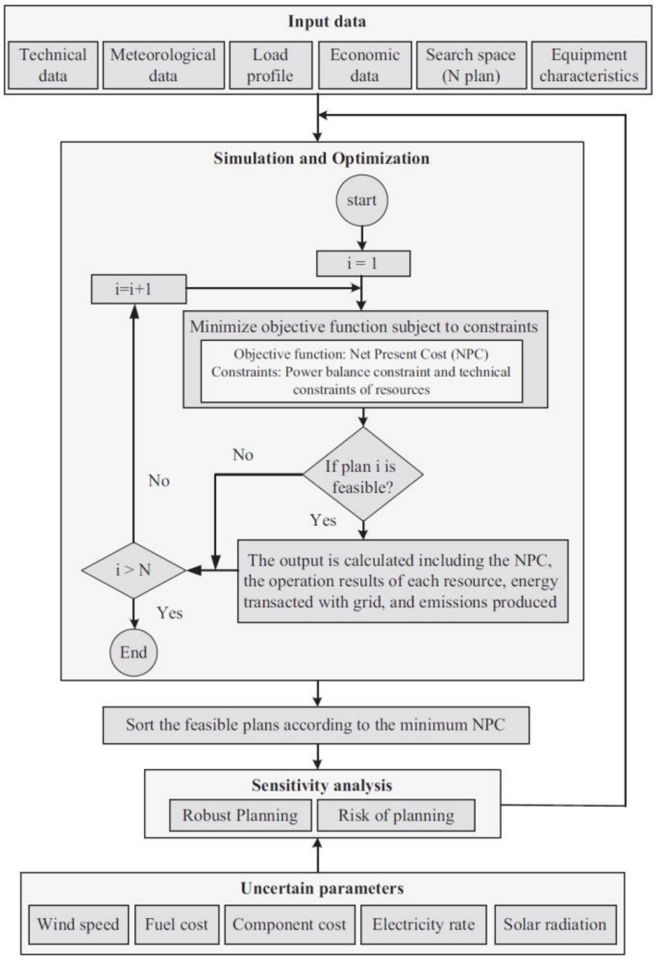

Fig. 2 The flow chart of HOMER optimization.

2.1. The Ranking Scheme

Optimal configurations of the HRES are evaluated according to the ranking scheme [35]. All the factors such as environmental emissions, renewable fraction, NPC, COE and BS requirements are considered to evaluate the optimal system.

The rank is assigned from 1 to 6 according to pros and cons for all considered parameters of the HRES. The pros is ranked by 1 for the maximum value of RF as well as the cons is ranked by 1 based on the minimum value of CO_2 emissions, BS sizing, NPC and COE. Then evaluation of the optimal HRES can be obtained through Eq. (1) [36].

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

Where: R_s: The sum of rank, R_{RF}: The rank of renewable friction, R_{CO2}: The rank of CO_2 emissions, R_{BS}: The rank of battery sizing and R_{NPC}: The rank of NPC, R_{COE}: The rank of COE

2.2. System Components

The current study proposed a 10 kW horizontal axis wind turbine and an array of a 1 kW PV panel which has an efficiency of 19 % at STC and derating factor of 80% [37]. The PV power production was calculated by Eq. (2) [38, 39]:

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

Where f_{PV}: The derating factor for PV panel, I_{STC}: Solar irradiance at STC, I_T: The incident solar radiation on array, Y_{PV}: The peak power of PV array, T_C: PV temperature, α: Temperature coefficient of power and T_{STC}: PV temperature at STC.

While the WT output power can be calculated as a function of turbine specifications and wind speed [40] as in Eq. (3)

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

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

All the techno-economic parameters such as the capacity of each component, its lifetime as well as the capital and replacement costs of HRES component which are presented in table 1.

The NPC and COE of the HRES are important factors for evaluating the economic performance of the system which can be measured through Eq. (4) [44, 45] and Eq. (5) [46] respectively:

$$C_{NPC} = \frac{C_{AT}}{CRF\,(i, R_p)} \quad (4)$$

$$COE = \frac{C_{AT}}{L_A} \quad (5)$$

Where: C_{AT} is the annual cost, C_{RF} is the capital recovery factor, R_P is the lifetime of the project *i* is the discount rate and L_A is the annual load consumption.

2.3. HRES Control Strategy:

The proposed HRES consists of three main sources of RES, BS and DG. To achieve the optimal HRES design, different control strategies can be used such as CC and LF. The flow chart for CC and LF control strategy are presented in Fig. 3 and 4 respectively.

2.3.1 CC Control Strategy

First probability: When the RES power output (P_w) and the required load (P_L) are the same, P_L can be covered by (P_w) without using DG and BS.

Second probability: If the P_w is greater than the demanded power, P_L can be satisfied by (P_w) and the excess energy charges BS until the maximum (BS_{SOC}).

Third probability: If the P_w is less than the required load, there are two cases:

- When BS_{SOC} is greater than the minimum BS_{SOC}, the cost of fulfilling the required load by BS and DG are compared. The required load is cover by the minimum cost selection.
- When BS_{SOC} is equal to the minimum BS_{SOC}, the DG operates at its maximum power capacity to satisfy the required of power that P_w can't satisfy and the excess power charges BS until the maximum BS_{SOC}.

2.3.2. LF Control Strategy:

In case of P_w is equal to or greater than the demanded power, both control strategies are similar. But if BS_{SOC} is equal to the minimum BS_{SOC}, the DG satisfies the rest of load that P_w can't satisfy (without BS charging).

Table 1. Economic parameters of HRES

Component	WT	PV system	BS	DG	Converter
Capacity	10 kW	1 kW	1 kW	1 kW	1 kW
Capital cost	9500 $/kW	650 $/kW	500 $/kW	550 $/kW	300 $/kW
Replacement cost	9000 $/kW	650 $/kW	500 $/kW	500 $/kW	300 $/kW
Lifetime	20 yrs	25 yrs	15 yrs	15,000 hr	15 yrs
Reference	[41]	[37]	[42]	[41]	[43]

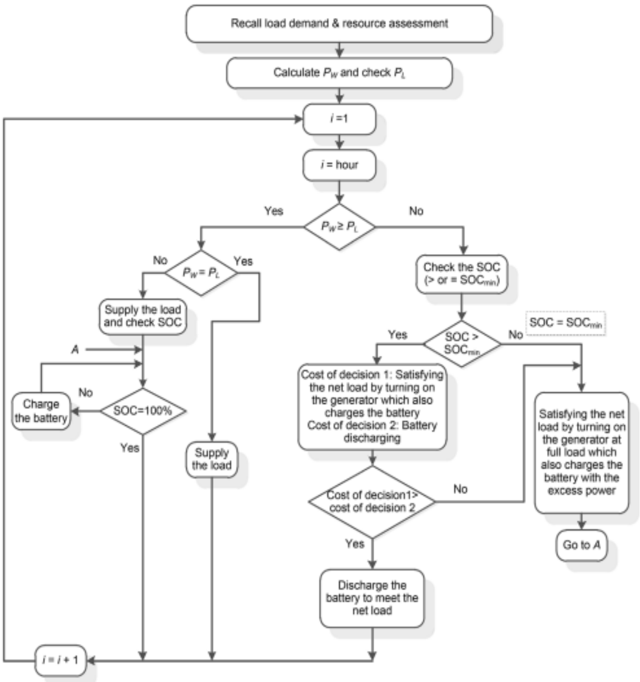

Fig. 3 The flow chart for CC

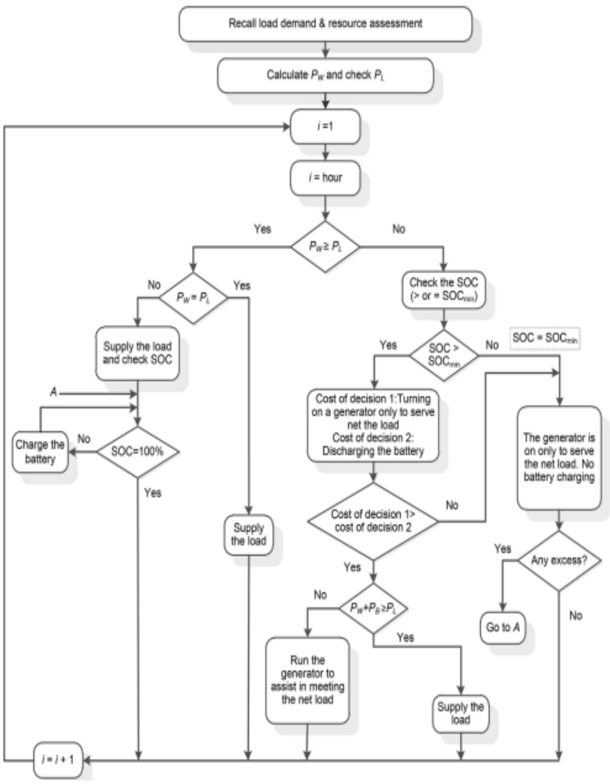

Fig. 4 The flow chart for LF

3. Case Study

The selected area is NRC research plant in Noubarya city, Egypt for animal production, water desalination, fish farming and agriculture. The area suffers from frequent electrical shortage because of instability of the main grid. The location of NRC-Farm is shown in Fig. 5

Fig. 5 The area under study

Wind speed and solar irradiation for the area under study have been obtained from NASA surface meteorology and solar energy database [47]. The annual average wind speed and solar radiation are 5.71 m/s and 5.43 kWh/m^2/day respectively. The monthly average wind speed is presented in Fig. 6 and the solar radiation are presented in Fig. 7. Hence combining of PV panels and WT into a HRES, there is a big chance that the system would be able to cover the required energy under different weather conditions, DG and BS are used as a back-up and storage system.

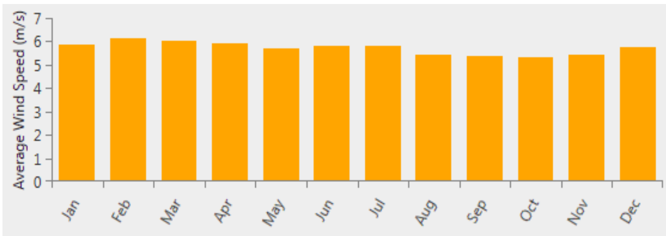

Fig. 6 The monthly average wind speed

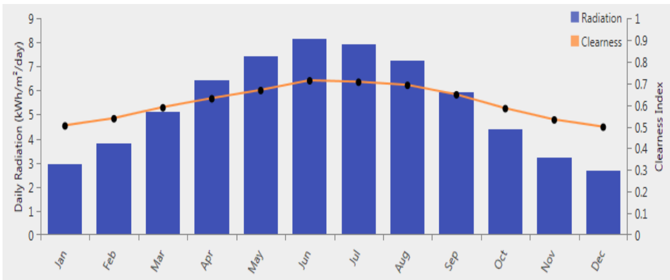

Fig. 7 The monthly average solar radiation

3.1. Load Assessment

The hourly load profile data was collected according to the electricity consumption for NRC-farm. In the present work, the farm consists of:

- Water desalination unit
- Animal fodders (AF) factory
- Hydrogel (HG) factory
- Management building
- lighting system
- Fish farm

The desalination unit system consists of three pumps which are the feed pump (FP), the distribution pump (DS) and the high-pressure pump (HPP). The required power for the FP pump, the HPP pump (5 HP) and the DS pump are about 1.87 kW, 3.73 kW and 1 kW respectively. In the current case, all the pumps work at the same time from 09:00 AM to 12:00 AM, so the average daily consumption and the peak load are about 105.6 kWh/day and 6.6 kW.

The AF factory consists of mixing feed unit (MFU) 5.5 HP, feed piston (FP) 25 HP, horizontal cooling fan (HCF) 5 HP and softener 2 HP. While the HG factory consists of motor (20 HP) and heater (1.5 HP). Monitoring the process operation in each factory, the daily load profile of both of them is estimated; maximum loads are 16 kW for HG factory and 28 kW for AF factory.

The management building consists of 10 offices which need electricity for laptops, lighting and etc. The average energy consumption per day is 41.55 kWh/day. Also there is a night lighting system for the NRC-farm that lights up the entrances for the management building fish ponds, desalination unit, HG factory and AF factory also the side gates for NRC farm. It's consisted of 16 lamps (50 W- 12 hrs).

Two fish ponds are established in NRC-farm for research purposes so two paddles of 3 HP for fish ponds ventilation from 09:00 AM until 04:00 PM and the required energy is 4.5 kWh. The average estimation of daily energy consumption is about 36 kWh/day. The peak load and net load profile for the NRC-farm without considering DSM are shown in Fig. 8.

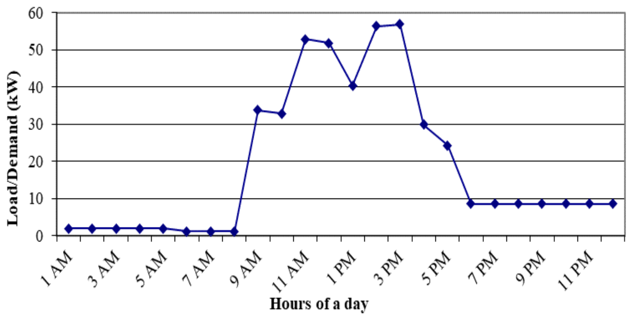

Fig. 8 Load profile for NRC-farm

4. Demand Side Management (DSM)

Balancing the generated energy with the load requirements had been targeted through DSM techniques which can be obtained through load shaving at high peak period, recompensing them at off-peaks periods to avoid the over sizing of the system configuration and maximize the renewable energy utilization [48].

Load flexibility can be categorized according to whether they are sheddable or not [49]. Sheddable loads are flexible to reduce or modify without affecting the nature and comfort in the process. 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 [50].

Load profiles 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: 1- Shiftable profile load (SPL) is the load with a fixed profile while can be rescheduled and moved in time. 2- 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) [51]. Fig. 9 shows the visualization of DSM classifications. 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.

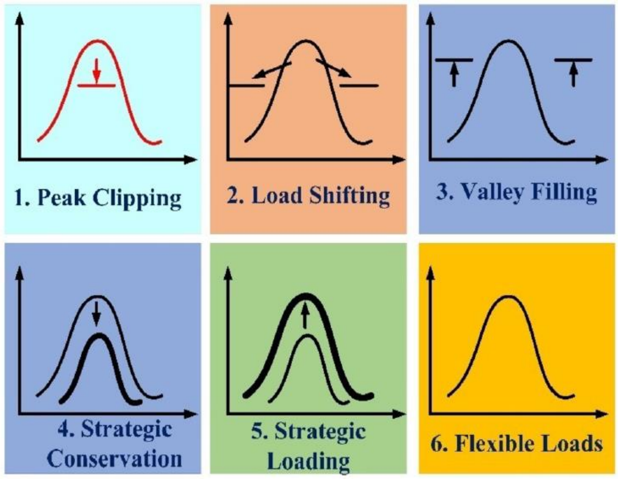

Fig. 9 Visualization of DSM classifications

4.1. DSM Indicators

For technical and economical evaluation of DSM benefits, two basic indicators are used which are DSM quality index (DSMQI) for the technical benefits and the DSM appreciation index (DSMAI) for economic effects [52,53].

DSMQI can be calculated through Eq. (6)

$$DSMQI = \frac{kW_{WODSM}}{kW_{WDSM}} \tag{6}$$

Where kW_{WODSM} is kW used without considering DSM and kW_{WDSM} is kW used with considering DSM.

DSMAI can be calculated through Eq. (7)

$$DSMAI = \frac{COE_{WODSM}}{COE_{WDSM}} \tag{7}$$

Where COE_{WODSM} is cost of energy without considering DSM and COE_{WDSM} is cost of energy with considering DSM.

Load factor (LF) can measure the efficiency of energy usage as the high value of LF express that the load is using energy more efficiently and low LF means the energy used insufficiently compared to the peak load over that period [54].

It is the ratio of the average demanded energy over a specific period to the peak load within that period [54] and it can be calculated using Eq. (8).

$$LFR = \frac{AV_L}{P_L} \quad (8)$$

Where: LFR 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)

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 which represented as LF quality index (LFQI) which can be calculated through Eq. (9)

$$LFQI = \frac{LFR_{WDSM}}{LFR_{WODSM}} \quad (9)$$

Where: LFR_{WDSM} is load factor without considering DSM and LFR_{WDSM} is load factor with considering DSM.

5. Results and Discussion

There are many configurations that have been obtained for WT, PV, BS and DG to select the optimal HERS that covers the required energy for NRC-farm. Different feasible HRES configurations have been simulated using HOMER, the results are compared; economically, environmentally and technically for the HRES without DSM ($HRES_{WODSM}$) and also HRES with considering DSM ($HRES_{WDSM}$).

5.1. The optimal $HRES_{WODMS}$

The configuration with minimum total scheme rank is selected as an optimal configuration $HRES_{WODSM}$ considering the techo-enviro-economic parameters. The $HRES_{WODSM}$ had been examined with both CC and LF control strategies. The $HRES_{WODSM}$ configurations based on the ranking status are presented in Table 2.

Table 2 showed that the most optimal feasible configuration $HRES_{WODSM}$ with minimum R_s was WT/PV/BS/DG with NPC of $336,563, COE of 0.157 $/kWh, with LF control strategy while $HRES_{WODSM}$ with CC control strategy had NPC of $338,247, COE 0.158 $/kWh.

The comparison between LF and CC control strategies showed a slight reduction in NPC and COE but RF% increased from 75% to 78% for LF. The cost of $HRES_{WODSM}$ components for CC and LF control strategies are presented in Fig. 10.

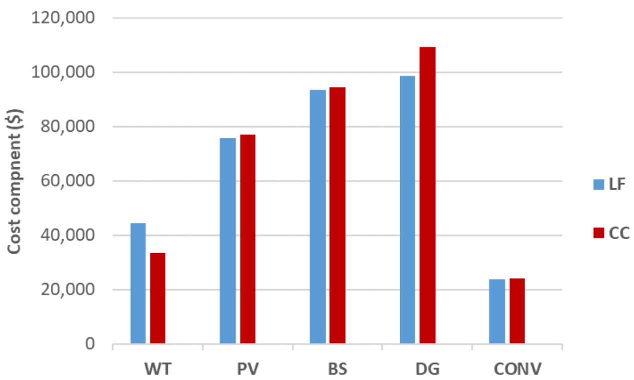

Fig. 10 The optimal $HRES_{WODSM}$ component costs for LF and CC

Fig. 10 highlighted that the major costs of the optimal $HRES_{WODSM}$ are DG and BS which are about 60% (CC) and 57% (LF) from NPC. However, the RES power output for $HRES_{WODSM}$ in both strategies remained largely unmet at peak demanded energy so there was a high need to increase the BS sizing.

The DG consumed around 11,707 L/yr of fuel for LF strategy and 13,149 L/yr for CC strategy which cause high GHG emissions of 31,109 kg/yr and 34,935 kg/yr for LF and CC respectively. The $HRES_{WODSM}$ annual GHG for both strategies are presented in table 3.

Table 2. $HRES_{WODSM}$ configurations for CC and LF

	CC						LF					
$HRES_{WODSM}$ configurations	NPC $	RF %	COE $/kWh	BS kW	CO_2 kg/yr	Rs	NPC $	RF %	COE $/kWh	BS kW	CO_2 (kg/yr)	Rs
PV/WT/BBS/DG	338,247	75	0.158	128	34,935	9	336,563	78	0.157	127	31,109	9
PV/WT/BBS	577,996	100	0.271	361	0	12	577,996	100	0.271	361	0	13
PV/BBS/DG	388,238	69	0.182	164	50,462	14	412,517	72	0.193	171	45,006	14
PV/BBS	869,142	100	0.408	559	0	17	869,142	100	0.408	559	0	17
WT/BBS/DG	591,819	59	0.277	272	67,082	22	747,344	70	0.35	569	49,220	22

Table 3. The annual GHG of $HRES_{WODSM}$ for both strategies

Emissions	Control strategy CC	Control strategy LF
Carbon Dioxide	34,422	30,647
Carbon Monoxide	215	191
Nitrogen Oxides	202	180
Sulfur Dioxide	84.3	75

Unburned Hydrocarbons	9.47	8.43
Unburned Hydrocarbons	9.47	8.43

Applying DSM rises the RES utilization that can reduce the DG fuel consumption CO_2 emissions from DG and decline the BS over sizing through load shifting and shedding.

5.2. The optimal $HRES_{WODSM}$

Particularly critical scenarios would be applied during high demanded energy with low RES generated energy or low demand energy during high RES generated energy. At these scenarios, it would be possible to implement DSM through shaving high peaks of demanded energy at low RES generated energy and shifting load to increase the consumption during low peak periods. The DSM rescheduling process is according to the shedding priority which is ranked based on the degree of flexibility. The case under study is arranged as follow:

The demanded energy for HG factory is estimated to be a shiftable profile load (SPL) as the required energy can't be reformed but it's possible to shift it in another period of time. While the fish pond load profile is considered to be a shiftable volume load which is possible to be moved to another time with a fixed volume but it can't be modified since its paddles have to work for 8 hrs/day. For desalination unit, the demanded energy is estimated to be a combination between SVL/SPL as part of load can be reformed. The desalination unit pumps can be rescheduled at the periods of high RES Generation and low demanded energy. The management building and the lighting system can be reduced at the high peak periods so it's considered to be a CL. Lighting can't be shifted but it can be decreased which achieved by shedding half of the lights. While the required energy for the AF factory is estimated to be a non-sheddable (NS) load as it's not possible to be shifted or reformed because the production process mainly related to the presence of workers at the daily working time. Table 4 is presented the distribution for $HRES_{WODSM}$ and $HRES_{WDSM}$ while the load profile for both is also presented in Fig. 11.

The results of implementing DSM showed different $HRES_{WDSM}$ configurations which are illustrated in table 5 while the Techno-Enviro-economic evaluation for the optimal $HRES_{WDSM}$ is also based on the minimum scheme ranking.

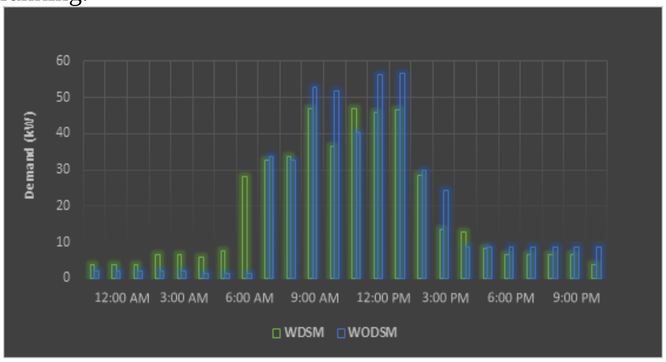

Fig. 11 Load profile for $HRES_{WODSM}$ and $HRES_{WDSM}$

Table 4. The load profile for $HRES_{WODSM}$ and $HRES_{WDSM}$

Application	Classification	Component	WODSM	WDSM
Fish farm	SVL	Fish paddles	9AM-5PM	7AM-11AM,4PM-6PM
DU	SPL/SVL	FD pump	9AM-12AM	12AM-3AM,7AM-2PM,4PM-7PM
		HPP/DS pump	9AM-12AM	4AM-10AM,12PM,4PM-11PM
HG factory	SPL	Motor	9AM-12PM,2PM-5PM	7AM-10AM,12PM-3PM
		Heaters	9AM,11AM,2PM,4PM	7AM,9AM,12PM,2PM
Lighting system	CL	Outdoor Lighting	1AM-5AM 6PM-12AM	3AM-5AM reduce 6PM-10AM reduce
Manag. Building	CL	Indoor Lighting	12AM-12PM	9AM-5PM reduce
AF factory	NS	MFU	9AM-3PM	9AM-3PM
		FP	11AM-3PM	11AM-3PM
		CF	1PM-3PM	1PM-3PM
		Softener	3PM	3PM

Table 5. $HRES_{WDSM}$ optimal configurations for both strategies

	CC						LF					
$HRES_{WDSM}$ configurations	NPC $	RF %	COE $/kWh	BS kW	CO_2 kg/yr	Rs	NPC $	RF %	COE $/kWh	BS kW	CO_2 (kg/yr)	Rs
PV/WT/BBS/DG	286,096	84.6	0.135	58	26,950	9	286,593	86.5	0.135	56	23,136	9

PV/WT/BBS	552,019	100	0.261	341	0	11	552,019	100	0.261	341	0	11
PV/BBS/DG	349,969	74.7	0.182	88	43,274	14	375,596	77.3	0.177	105	39,060	14
PV/BBS	913,490	100	0.431	622	0	17	913,490	100	0.431	622	0	17
WT/BBS/DG	501,701	59.9	0.237	179	69,576	22	656,100	69	0.310	569	54638	22

The above table showed that the optimal $HRES_{WDSM}$ configuration was PV/WT/BBS/DG for both strategies which had NPC of $286,096 and COE of 0.135 $/kWh with CC control strategy. While $HRES_{WDSM}$ with LF control strategy had NPC of $286,593 and COE of 0.135 $/kWh. It could be observed that $HRES_{WDSM}$ PV/WT/BBS/DG with LF was the optimal economic, environmental and technical option. It showed a relatively reduction in CO_2 emissions by14% and BS sizing by 3.4% comparing to CC control strategy.

5.3. Comparison Between $HRES_{WODSM}$ and $HRES_{WDSM}$

The results of the $HRES_{WODSM}$ and $HRES_{WDSM}$ are compared based on technical, environmental and economical parameters. Fig. 12 exhibits NPC, capital cost and running cost for $HRES_{WODSM}$ and $HRES_{WDSM}$.

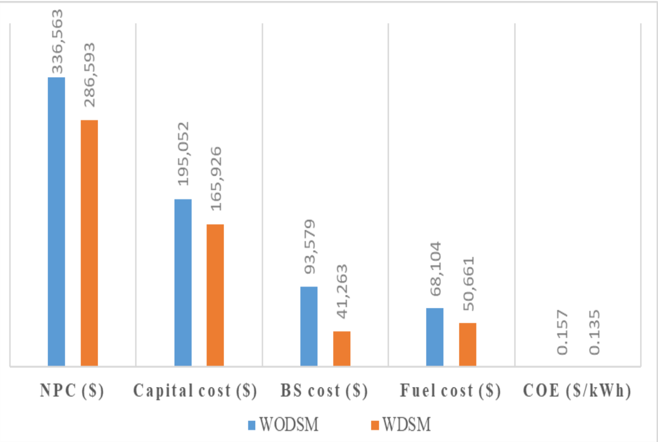

Fig. 12 Economical evaluation for $HRES_{WODSM}$ and $HRES_{WDSM}$

Fig. 12 showed that $HRES_{WDSM}$ had a significant reduction in NPC, capital cost, BS cost and fuel cost and COE by 14.8 %, 14.9 %, 55.9%, 25.6% and 14% respectively. The technical evaluation for $HRES_{WODSM}$ and $HRES_{WDSM}$ is presented in fig 13.

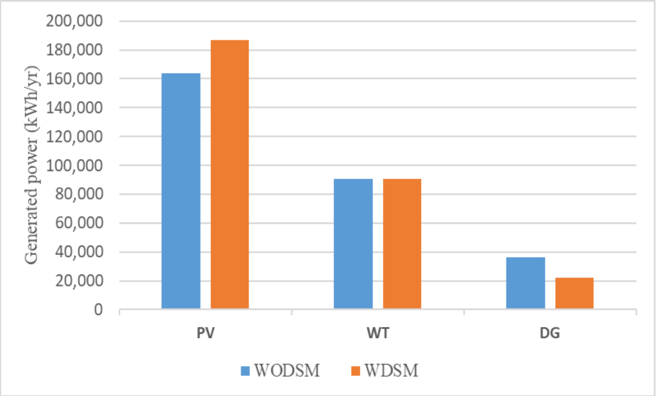

Fig. 13 Power generation for $HRES_{WODSM}$ and $HRES_{WDSM}$

Fig. 13 exhibited that the balance between the peaks of load demand with RES power is increased through $HRES_{WDSM}$ which reduces power output from DG; which was around 36,123 kW/yr and 21,785 kW/yr for $HRES_{WODSM}$ and $HRES_{WDSM}$. BS sizing for both systems is presented in Fig. 14.

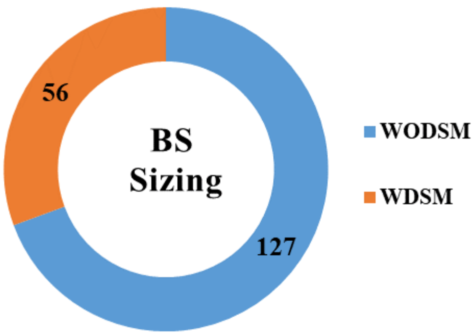

Fig. 14 BS sizing for $HRES_{WODSM}$ and $HRES_{WDSM}$

It could be observed that the matching between the peaks of required load and RES generated power increased through DSM strategy which lead to decrease BS sizing by 57%; which was around 127 kW and 56 kW for $HRES_{WODSM}$ and $HRES_{WDSM}$ respectively as shown in Fig. 14. In addition to the DG fuel consumption decreased by 25.6%; which was about 11,707 L/yr of fuel for $HRES_{WODSM}$ and 8,709 L/yr for $HRES_{WDSM}$. Fig. 15 shows the annual GHG for $HRES_{WODSM}$ and $HRES_{WDSM}$.

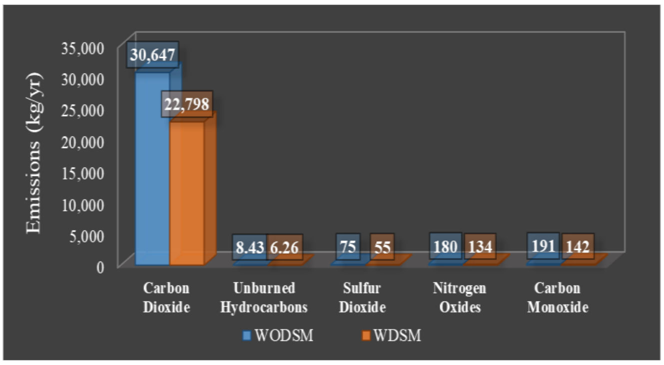

Fig. 15 GHG emissions for $HRES_{WODSM}$ and $HRES_{WDSM}$

Fig. 15 showed a significant reduction in GHG by 25% while the DG power output during one year for $HRES_{WODSM}$ and $HRES_{WDSM}$ are presented in Fig. 16 and 17 respectively.

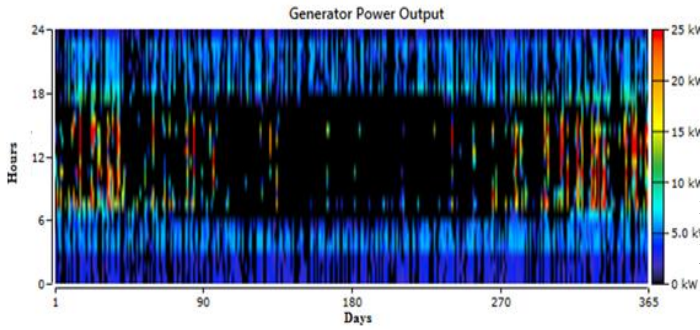

Fig. 16 DG power output for $HRES_{WODSM}$

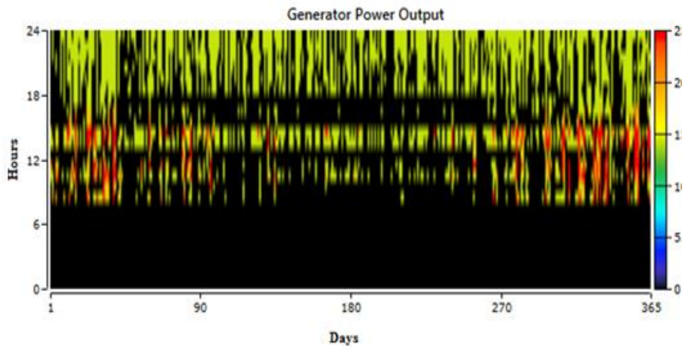

Fig. 17 DG power output for $HRES_{WDSM}$

Fig. 16 showed that the DG power output for $HRES_{WODSM}$ was around 15-20 kW (yellow color) during 12 hours of day while Fig. 17 showed that applying DSM decreased the dependence of DG to be almost 0-5 kW (blue color).

Also $HRES_{WDSM}$ load profile showed a significant reduction in peak load from 58.97 kW to 48.69 kW and rising of load factor from 0.32 to 0.38 which enhance the economic and technical performance of the proposed HRES comparing to $HRES_{WODSM}$ load profile. Fig. 18 exhibits DSM indicators for $HRES_{WDSM}$ such as DSMQI, DSMAI and LFQI.

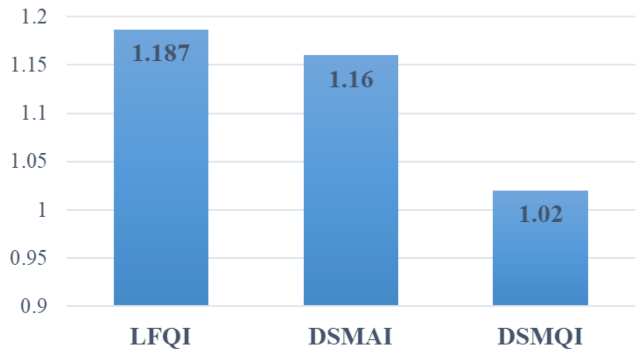

Fig. 18 DSM indicators for $HRES_{WDSM}$

The above Fig. showed a relatively growth in DSMQI which indicated the technical effects and DSMAI for economic effects of DSM.

In a comparison with the previous studies, the results showed a high reduction in COE 70%, 52% and 23% comparing to [14], [16] and [17] without taking into consideration DSM and the CO_2 emissions. However, there are still some major problems to be solved such as the mismatch between the generated and demanded energy that results in the relatively over sizing the battery system and the use of DG that have to be reduced.

HRES considering DSM is an impeccable solution in all demand sectors, including residential, agricultural, commercial and industrial sectors as the matching between the required energy profile with the peaks of the generated energy. Implementing DSM for these sectors can enhance of the performance of the system, increase the RES utilization, decrease capital costs and cover the required demand with resendable COE and lower emissions.

6. Conclusion

This paper discussed the optimal design and demand side management for HRES that covers the demanded energy for a research farm in Egypt. The different HRES configurations have been simulated, optimized and evaluated for both CC and LF control strategy using HOMER. The optimal HRES selection was based on the minimum ranking scheme which takes into account all the Techno-Enviro-Economical parameters such as GHG emissions, RF, NPC, COE and the needs of BS.

The results showed that the optimal $HRES_{WODSM}$ was NPC of $336,563 and COE of 0.157 $/kWh with LF control strategy while $HRES_{WODSM}$ with CC had NPC of $338,247 and COE 0.158 $/kWh. The major costs of the optimal $HRES_{WODSM}$ are BS and DG which are about 57% (LF) and 60% (CC) from NPC. However, the RES generation for $HRES_{WODSM}$ in both strategies remained largely unmet at peak demanded energy so there was a high necessity to oversize the BS and frequently use DG. So the DG consumed about 11,707 L/yr with LF and 13,149 L/yr with CC which cause high CO_2 emissions of 31,109 kg/yr and 34,935 kg/yr for LF and CC respectively.

DSM can be implemented through load shifting at low power generation, recompensing them at high peak periods based on the load profile flexibility to minimize the BS sizing and the high consumption of DG. Considering DSM, the optimal $HRES_{WODSM}$ was PV/WT/BBS/DG for both strategies which had NPC of $286,096 and COE of 0.135 $/kWh with CC control strategy. While $HRES_{WDSM}$ with LF control strategy had NPC of $286,593 and COE of 0.135 $/kWh. The results showed that $HRES_{WDSM}$ PV/WT/BBS/DG with LF control strategy was the optimum technical, environmental and economical configuration. It showed a relatively rise in renewable friction, high reduction in GHG emissions and BS sizing.

The matching between the peaks of required energy and RES generation is increased through DSM strategy which lead to decrease BS sizing by 56%; which was around 127 kW for $HRES_{WODSM}$ and 56 kW for $HRES_{WDSM}$ with LF control strategy. Also the DG output power had been reduced by 40%; which was about 36,123 kW/yr for $HRES_{WODSM}$ and 21,785 kW/yr $HRES_{WDSM}$. The results also showed a relatively rise in DSM indicators by 1.02, 1.16 and 1.187 for DSMQI, DSMAI and LFQI which clarifies the economic and technical effects of $HRES_{WDSM}$.

References

[1] IEA. Global energy review 2019. International Energy Agency (IEA) Paris. (2020).

[2] M. Sevgül, Ü. Ağbulutb..: Electricity production based forecasting of greenhouse gas emissions in Turkey with deep learning. Support vector machine and artificial neural network algorithms. J. Clean. Prod. Vol. 285. 2021.

[3] B. Wang, Z. Yang, J. Xuan, K. Jiao.: Crises and opportunities in terms of energy and AI technologies during the COVID-19 pandemic. Energy AI 1. 1. (2020).

[4] Q. Lv, J. Zhang, K. Ding, Z. Zhang, H. Zhu, R. Hou,: The Output Power Smoothing Method and Its Performance Analysis of Hybrid Energy Storage System for Photovoltaic Power Plant. 2021 10th International Conference on Renewable Energy Research and Application. (2021)

[5] M. Longo, W. YaÃ¯ci, F. Foiadelli.: Hybrid Renewable Energy System with Storage for Electrification Case Study of Remote Northern Community in Canada. INTERNATIONAL JOURNAL of SMART GRID, Vol.3. (2019)

[6] M. Colak, S. Balci.: Intelligent Techniques to Connect Renewable Energy Sources to the Grid: A review. 2021 9th International Conference on Smart Grid. 179-185. (2021)

[7] A. Ameri, M. Camara.: Efficient Energy Management for Wind-Battery Hybrid System Based Variable Frequency Approach. 2021 10th International Conference on Renewable Energy Research and Application. (2021)

[8] F. AYADI, I. COLAK, I. GARIP, H. I. BULBUL.: Targets of Countries in Renewable Energy. 2020 9th International Conference on Renewable Energy Research and Application. (2020)

[9] International energy agency.: Global energy review 2020, Analysis–IEA. (2020)

[10]International Renewable Energy Agency: Renewable Energy Outlook: Egypt. (2018).

[11] A. Couto, A. Estanqueiro.: Assessment of wind and solar PV local complementarity for the hybridization of the wind power plants installed in Portugal. J. Clean. Prod. 319. (2021).

[12] A. Malekia, F. Pourfayaza, M. Rosenb.: A novel framework for optimal design of hybrid renewable energy-based autonomous energy systems: A case study for Namin. Iran. Energy. Vol. 98, 168-180. (2016).

[13] I. Mofolorunso, T. Matthew, A. Longe.: Optimal Sizing of Hybrid Renewable Energy System for off-Grid Electrification: A Case Study of University of Ibadan Abdusalam Abubakar Post Graduate Hall of Residence. International Journal of Smart Grid. Vol.4. (2020)

[14] M. Bonkile, V. Ramadesigan.: Effects of sizing on battery life and generation cost in PV–wind battery hybrid systems. J. Clean. Prod. Vol. 340. (2022).

[15] M. Hannan, R. Begum, S. Young, M. Hoque, P. Ker, M. Mansur, K. Alzaareer.: The value of thermal management control strategies for battery energy storage in grid decarbonization: Issues and recommendations. J. Clean. Prod. Vol. 276. (2020).

[16] D. Tsuanyoab, Y. Azoumaha, D. Ausselb, P. Neveub.: Modeling and optimization of batteryless hybrid PV (photovoltaic)/Diesel systems for off-grid applications, energy. Vol. 86, 152-163. (2015).

[17] T.M. Tawfik, M.A. Badr, E.Y. El-Kady, O.E. Abdellatif.: Optimization and energy management of hybrid standalone energy system: a case study. Renewable Energy Focus. Vol.25, 48-56. (2018).

[18] L. Qinliang, T. RuiZhaoa, S. Guc, J. Wangb.: Multi-objective electro-thermal coupling scheduling model for a hybrid energy system comprising wind power plant, conventional gas turbine, and regenerative electric boiler, considering uncertainty and demand response. J. Clean. Prod. Vol. 237. (2019).

[19] D. Bishnoi, H. Chaturvedi.: Techno-Economic Analysis of Hybrid Energy System for Efficient Utilization of Waste Flare Gas from Oil and Gas Fields. 9th IEEE International Conference on Smart Grid. (2021)

[20] D. Icaza, J. R. Espinoza.: Study of a Hybrid System Wind-Photovoltaic on grid for The Self-Supply of Energy to an Area with Bioecological Infrastructure. 2021 9th International Conference on Smart Grid. (2021)

[21] D. Icaza, J. R. Espinoza, D. Valarezo.: Scenarios of Operation of an Energy Production System of a Hybrid

WT/PV System of a Bioecological Infrastructure. 2021 9th International Conference on Smart Grid. (2021)

[22] B. Zafar, Design of a Renewable hybrid photovoltaic-Electrolyze-PEM/Fuel Cell System using Hydrogen Gas. International Journal of Smart Grid, Vol 3, 2019.

[23] S. SALAH, D. SAIFAOUI, O. BENZOHRA, A. LEBSIR.: Integration of Decentralized Generations into the Distribution Network- Smart Grid Downstream of the Meter. International Journal of Smart Grid. Wol. 4. (2020)

[24] A. Jafari, T. Khalili, , H. Ganjehlou, A. Bidram.: Optimal integration of renewable energy sources, diesel generators, and demand response program from pollution, financial, and reliability viewpoints: a multi-objective approach. J. Clean. Prod. Vol. 247. (2020).

[25] H. El-houari, A. Allouhi, A. Rehman, M. Buker, T. Kousksou, A. Jamil, B. El Amrani.: Design, Simulation, and Economic Optimization of an Off-Grid Photovoltaic System for Rural Electrification. Energies. Vol. 12. (2019).

[26] R. Ammar, M. AMMAR, A. OUALHA.:Deep Learning and Optimization Algorithms Based PV Power Forecast for an Effective Hybrid System Energy Management. International Journal of Renewable Energy Research. Vol.12. (2022)

[27] I. Grgić, M. Bašić, D. Vukadinović, M. Bubalo.: "Optimal Control of a Standalone Wind-Solar-Battery Power System with a Quasi-Z-Source Inverter. 2020 9th International Conference on Renewable Energy Research and Application. (2020)

[28] S. nasef, A. Hassan, H. Elsayed, M. Zahran, M. El-Shaer, A. Abdelaziz.:Optimal Power Management and Control of Hybrid Photovoltaic-Battery for Grid-Connected Doubly-Fed Induction Generator Based Wind Energy Conversion System. International Journal of Renewable Energy Research. Vol.12. (2022)

[29] A. Laitinen, O. Lindholm, A. Hasan, F. Reda, Å. Hedman.: A techno-economic analysis of an optimal self-sufficient district, Energy Conv. and Manag. Vol. 236. (2021).

[30] S. Nowdeha, S. Nasri.: Multi-criteria optimal design of hybrid clean energy system with battery storage considering off- and on-grid application. J. Clean. Prod.. Vol. 290. (2021).

[31] T.M. Tawfik, M.A. Badr, O.E. Abdellatif, H.M. Zakaria, M. EL-Bayoumi.: Techno-Enviro-Economic Evaluation for Hybrid Energy System Considering Demand Side Management. International Journal of Renewable Energy Research. in press. (2022).

[32] J. Jeslin, S. Suruthi, S. Charles, T. Kartick.: Techno-economic analysis of both on-grid and off-grid hybrid energy system with sensitivity analysis for an educational institution. Energy Conv. and Manag. Vol. 239. (2021).

[33] L. Halabia, S. Mekhilef, L, Olatomiwa, J. Hazelton.: Performance analysis of hybrid PV/diesel/battery system using HOMER: a case study Sabah, Malaysia. Energy Conv. and Manag. Vol. 14. (2017).

[34] A. Asrari, A. Ghasemi, M. Javidi.: Economic evaluation of hybrid renewable energy systems for rural electrification in Iran—A case study. Renewable and sus. Energy Reviews. Vol. 16, 3123-3130 (2012).

[35] A. Chauhan, R. Saini.: Techno-economic feasibility study on integrated renewable energy system for an isolated community of India. Renewable and Sustainable Energy Reviews. Vol. 59, 388-405. (2016)

[36] U. Kumar, P. Manoharan, M. Rajkumar.: Feasibility sensitivity analysis in potential area for standalone hybrid renewable energy in Tamil Nadu, India. Applied Mechanics and Materials. Vol. 573, 757-766. (2014).

[37] Q. Ma , X. Huang, F. Wang, C. Xu, R. Babaei, H. Ahmadian.: Optimal sizing and feasibility analysis of grid-isolated renewable hybrid microgrids: Effects of energy management controllers. Energy. Vol. 240. (2022).

[38] A. Aziz, M. Tajuddin, M. Adzman, M. Ramli, S. Mekhilef.: Energy management and optimization of a PV/diesel/battery hybrid energy system using a combined dispatch strategy. Sustainability. Vol. 11. (2019).

[39] D. Luta, A. Raji. Optimal sizing of hybrid fuel cell-supercapacitor storage system for off-grid renewable applications. Energy. Vol. 40, 530-540. (2019).

[40] M. Jahangir, A. Shahsavari, M. Rad.: Feasibility study of a zero emission PV/Wind turbine/Wave energy converter hybrid system for stand-alone power supply: a case study. J. Clean. Prod. Vol. 262. (2020)

[41] J. Li, P. Liu, Z. Li.: Optimal design and techno-economic analysis of a solar-wind-biomass off-grid hybrid power system for remote rural electrification: a case study of west China. Energy. Vol. 208. (2020)

[42] A. Alsagri, A. Alrobaian, M. Nejlaoui:. Techno-economic evaluation of an off-grid health clinic considering the current and future energy challenges: a rural case study". Renewable Energy. Vol. 169, 34-52. (2021).

[43] M. Akhtaria, M. Baneshib.:Techno-economic assessment and optimization of a hybrid renewable co-supply of electricity, heat and hydrogen system to enhance performance by recovering excess electricity for a large energy consumer. Energy Conv. and Manag. Vol. 188. (2019).

[44] A. Singh, P. Baredar, B. Gupta.: Techno-economic feasibility analysis of hydrogen fuel cell and solar photovoltaic hybrid renewable energy system for academic research building. Energy Conv. and Manag. 145. (2017)

[45] B. Das, Y. Al-Abdeli:. Optimisation of stand-alone hybrid CHP systems meeting electric and heating loads. Energy Conv. and Manag. Vol. 153. (2017).

[46] S. Mandal, B. Das, N. Hoque.: Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh. J. Clean. Prod. Vol. 200, 12-27. (2018).

[47] A NASA POWER Global Meteorology, Surface Solar Energy and Climatology Data Client, (2020)

[48] B. Ampimah, M. Sun, D. Han, X. Wang.: Optimizing sheddable and shiftable residential electricity consumption by incentivized peak and off-peak credit function approach. Applied Energy. Vol. 210, 1299-1309. (2018).

[49] H. Li, Z. Wang, T. Hong, M. Piette.: Energy flexibility of residential buildings: A systematic review of characterization and quantification methods and applications. Advances in Applied Energy. Vol. 3. (2021).

[50] D. Olsen, N. Matson, M. Sohn, C. Rose.: Grid Integration of Aggregated Demand Response. Part 1: Load Availability Profiles and Constraints for the Western Interconnection United States. (2013).

[51] S. Ottesen, A. Tomasgard.: A stochastic model for scheduling energy flexibility in buildings. Energy. Vol. 88, 364-376, (2015).

[52] A. Dharme. A. Ghatol.: Demand Side Management Quality Index for Assessment of DSM Programs. 2006 IEEE PES Power Systems Conference and Exposition. 1718-1721. (2006).

[53] T. Akinbulire, P.Oluseyi, O.Babatunde.: Techno-economic and environmental evaluation of demand side management techniques for rural electrification in Ibadan, Nigeria. Int J Energy Environ Eng. Vol. 5, 375–385. (2014).

[54] E. Hartvigsson, E. Ahlgren.: Comparison of load profiles in a mini-grid: Assessment of performance metrics using measured and interview-based data. Energy for Sustainable Development. Vol. 43, 186-195. (2018).