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RESEARCH ARTICLE RENEWABLE ENERGY

The Impact of Loss of Power Supply Probability on Design and Performance of Wind/ Pumped Hydropower Energy Storage Hybrid System

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ABSTRACT

Hybrid renewable energy systems is broadly adopted because they are eco- friendly systems. The general electric grid in Libya has suffered from shortage during the recent years . However , Libya has formidable opportunities for investment in clean energy .Their wind energy resources are promising. The southern region of Libya has demonstrated the viability of utilizing pumped hydroelectric and wind energy for electricity generation, thereby addressing the deficit and strengthening the resilience of the public grid. In this study, hybrid renewable energy system (HRES) consists of 432 MW of wind energy farm and 10782 MWh of pumped hydropower system has been designed, analyzed and optimized to meet a demand of 590,019 MWh. The decision to design these systems is strongly affected by energy prices and pollution. The impact of the Loss Power Supply Probability (LPSP) and the cost of CO_2 emissions on the levelized cost of energy (LCOE) is loss discussed

تأثير احتمالية فقدان مصدر الطاقة على تصميم وأداء منظومة طاقة هجينة (طاقة رياح متصلة بمنظومة تخزين طاقة كهرومائية بالضخ)

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الملخص

انتشرت أنظمة الطاقات المتجددة والهجينة على نطاق واسع كونها أنظمة صديقة للبيئة وعالية الاعتمادية. عانت الشبكة العامة للكهرباء في ليبيا من قصور في امداد الطاقة خلال السنوات الأخيرة، بالرغم من أن ليبيا تمتلك فرص هائلة للاستثمار في الطاقة النظيفة. اثبتت هذه الدراسة جدوى استخدام طاقة الرياح وطاقة الضخ الكهرومائي لتوليد الكهرباء في المنطقة الجنوبية من ليبيا. وبالتالي تعويض العجز في شبكة الكهرباء العامة. في هذه الدراسة، تم تصميم وتحليل وتحسين منظومة طاقة متجددة تتكون من 432 ميجاوات مزرعة توربينات الرياح و 10782 ميجاوات ساعة سعة التخزين لمحطة كهرومائية. تولد المنظومة المقترحة طاقة كافية لتغطية حمل يقدر ب 590.019 ميجاوات ساعة . يتأثر قرار تصميم هذه المنظومات بشدة بأسعار الطاقة والتلوث. تأثير احتمالية فقدان مصدر الطاقة (LPSP) وتكلفة انبعاث ثاني أكسيد الكربون على سعر تكلفة الكهرباء (LCOE)، تم توضيحها .

الكلمات المفتاحية

تخزين الطاقة الكهرومائية
الطاقات المتجددة والهجينة
طاقة الرياح
الحجم المثالي

Introduction

Driven by concerns about climate change and global warming, at the end of 2024; the global renewable energy capacity reaches 4.448 TW, from them 2.085 TW for Photovoltaic (PV) solar energy systems, 1.136 TW for wind energy. This growth in the RE market reflects a global shift towards renewable and sustainable energy technologies [1]. The feasibility and potential of green energy resources as dependable and imperishable electrical energy sources have lately been globally researched by the academic circles and manufacture [1-19] . Nonetheless, sustainable energy systems do not deliver the equal level of load – following pliability in contrast to classical fossil fuel power stations [20,21]. Furthermore, the use of renewable energy systems (RESs), basically PV, reduces active / immediate energy reserves, which are mostly used for preparatory frequency management which subsequent to irregular operating conditions [22]. The deficiency in sustainable energy system could be decreased by establishing effective energy storage system (ESS), which is bidirectional power flow system, allowing excess energy to be stored during periods of generation abundance and supplying the grid during shortcoming periods.in addition, ESS systems , especially PHS, provide the fundamental synchronous inertia level required to execute controlling the frequency [21]. In this respect, lots of studies inspect many amalgamations of hybrid renewable energy systems merged with different power storage techniques, such as: PV – Battery [23], PV - Generator – Battery [24], PV – Battery – Fuel Cell [25], PV-Wind – PHS – Battery [26], CSP – Wind – PHS [27], Wind - Battery [28], Wind – PHS , Wind – H2, PV – Wind – Battery [29], PV- Wind – Battery [30], PV – Wind – PHS [31], PV –

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Biomass – Fuel Cell [32], PV – Grid [33,34], PV – Wind [35], Grid-PHS [36]. Extra literature is epitomized in Table A1, which reveals the energy supply system, the storage system, the grid connection manner, and the key findings of the study .A record 117 GW of new wind energy capacity was installed across the world in 2024 , resulting in a cumulative installed capacity of 1200 GW. Looking ahead, Africa and the Middle East are anticipated to introduce 17 GW of new capacities in the next five years (2023-2027),with specific projections including 5.3 GW in South Africa, 3.6 GW in Egypt, 2.4 GW in Saudi Arabia, and 2.2 GW in Morocco [37]. While, the installed capacity reached 188.1 GW for PHS by the end of 2023. This growth in the RE market reflects a global shift towards renewable and sustainable energy technologies [38]. The universal power storage market accomplished considerable increase, with around 175000Mwh of available capacity added during 2024 [39]. There are various tactics to store electrical energy such as: Kinetic [40], Potential [41], Electrical [42], Chemical [43] and Thermal [44] energy storages which are characterized in literature. The ESS systems tend to provide numerous advantages, such as more effectively renewable energy system dependability and safety in both on-grid and off-grid operating modes, higher consistency margins, less operating costs for power grid distribution systems, smoothing switching from classical grids to smart grids. Lots of ESS techniques are illustrated in Figure 1, which is replicated here to assert on the many impediments and constraints while Elucidating the promise of assorted technologies. In the middle East and North Africa (MENA) zone, there are appreciably fewer assured PHS constructions. Even though formidable MENA's potential for sustainable energy sources, the regions distinguished geography and the implication of PHS might result in major benefits. State of Libya, as an eminent MENA representative, has improved an aspirant strategy to amalgamate PHS into its national power framework, especially in its southern metropolitan areas. The national grid is sensitive to fluctuations in voltage, voltage dips, and instability in general, which is a common issue.

Integrate PHS into its national energy framework, particularly in its southern metropolitan regions. The national grid is sensitive to voltage fluctuations, power sags, and general instability, which is a common problem. Considering Libya's abundant solar and wind energy resources, the integration of RESs without a reliable energy storage method may escalate these concerns. As a result, the deployment of a durable and economically feasible Energy Storage System (ESS) is critical. Fortunately, Libya's geographical characteristics allow for the reduction of capital expenditures associated with PHS initiatives.

For the target of consummate Brack City, Libya's electricity demands, in this article, a configuration model for an isolated Wind/PHS, is optimized. To identify the (HRES) optimal size, objective function and constraints were performed. To preserve costs which are equivalent to those of fossil fuel power stations while assuring the security and the stability of the system, this tactic picks out objective function (OF) which is minimum Levelized Cost of Energy (LCOE) , while the constraints are selecting the best fitted percentage value for Loss Power Supply Probability (LPSP);which gives the lowest (LCOE) value. In addition, determination the answer stability concept. The System Advisor Model (SAM) is used to estimate the real productivity of wind turbine under real time climatic data, which provided as hourly time series data by the renewable energy laboratory in Wadi Alshatti University for the year 2023.

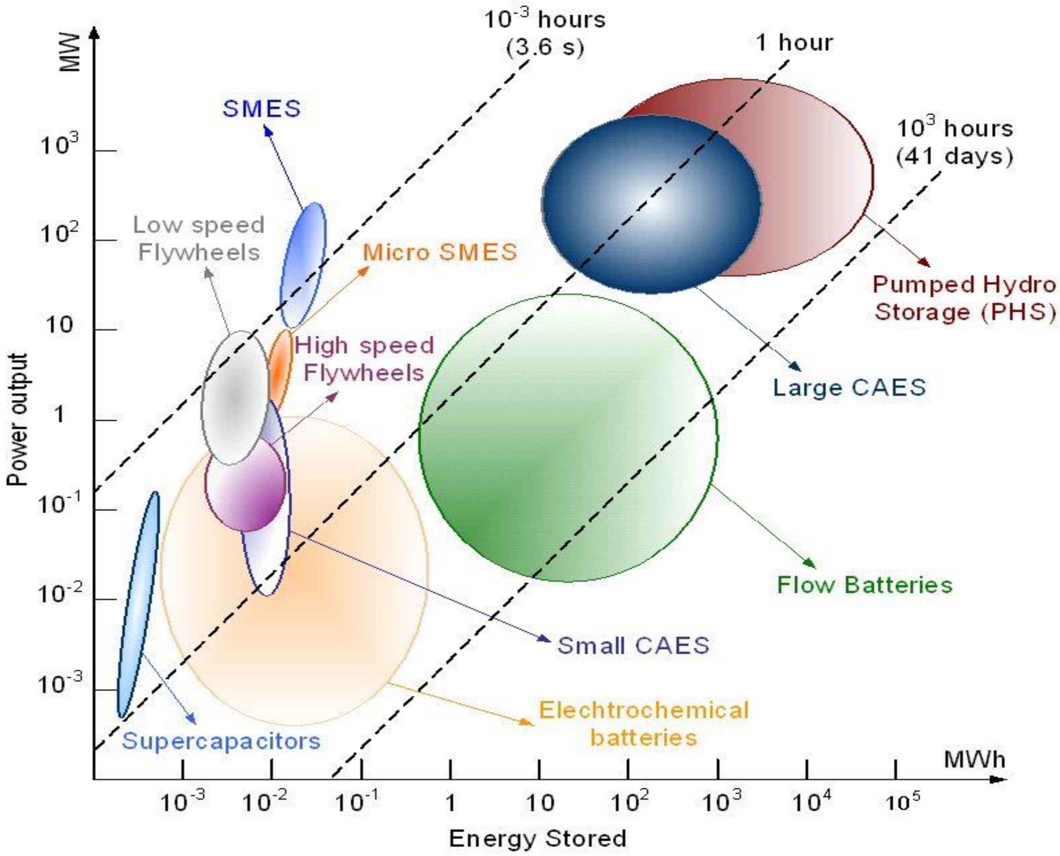

Fig.1: Rated energy capacity versus power rating at different discharge times for different ESS
[Source: https://www.intechopen.com/chapters/42273]

The remainder of this paper is structured as the following: Section 2: The discussion of methodology and attributes of the study location, including its geographic orientation, latitude, and climatological data. Moreover, outlines the unpredictable optimization procedure and presents the study hypothesis. Section3: Presents the results and discussion. Finally, the main conclusion is given in section 4.

Methodology

Essential data on the study site

Geographical information

The study site has been selected near a 70-meter-high mountain and near the local electricity grid in Brack City, Libya (27°32′N, 14°17′E). In the near future, this site is a good choice for constructing the proper power plant. An illustration of this location is shown in Figure 2.

Energy Situation

The hourly electrical load for the year of 2023 is presented in Figure 3. Behavioral analysis of the Alshatti district sub- grid for the year 2024 reveals that the whole yearly available power was 605,879.5 MWh, while the load was 590,018.7 MWh.That means there is a surplus in energy .However, outage of energy hours account of 1573 hours, this is due load mismatch.

Climatic parameters

Hourly climate data for wind speed $V_o(t)$, were attained from the meteorological weather station at Center for Renewable Energy and Sustainable Development Studies (RCRESDS), Wadi Alshatti Universitty, Brack City, over the years 2023-2024. The demonstration of hourly wind speed gauged at 10 m above the ground level is as in Figure 4 . The average hourly wind speed in Brack experiences noteworthy cyclic changes throughout the year. The average value of wind velocity is more than 4.5 m/s. May is The windiest month of the year, with an average hourly value of 4.9 m/s. The trtranquile time of year lasts for 6.4 months, it starts from August 31 to March 12. The calmest month of the year in Brack is December, with approximately 3.6 m/s. The preponderant wind direction is marginally low the north-east direction.

Fig.2: Map of the site under consideration

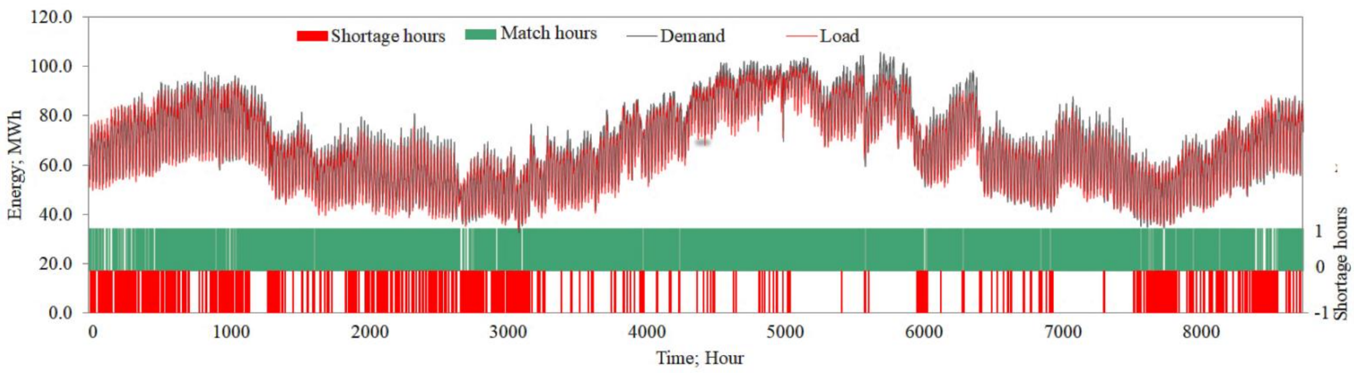

Fig.3: Hourly generated electricity, demand, hours of deficit, coincidence and excess power in the sub-grid - Alshatti

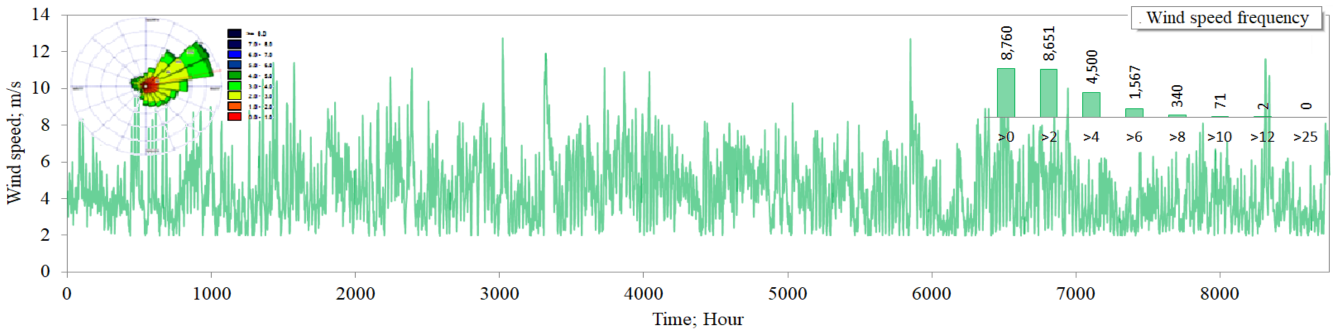

Fig.4: Hourly wind speed at 10m from ground level $V_o(t)$ in m\s and wind speed frequency

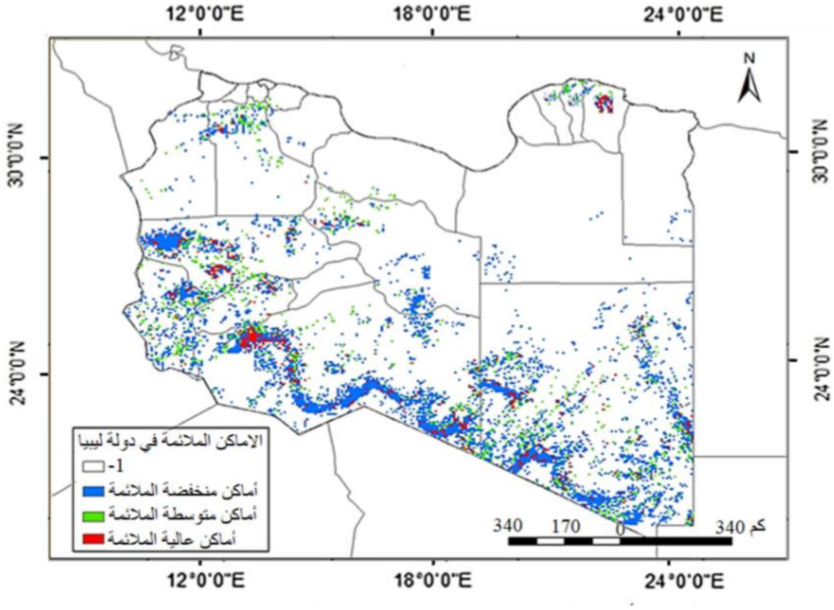

Fig.5: Promising Locations for the Consumption of Pumped Hydro Energy Storage Plants
[Source: https://doi.org/10.51646/jsesd.v14i1.426]

Topographer of the site

Mohammed et al., in [45] disclosed that roughly quarter percent of Libya's territory area is appropriate for establishing hydroelectric power storage stations, as it depicted in Figure 5. The most auspicious locations have been specified all over the country, with Brack Alshatti standing out as a particularly eligible site, one of its mountains (27.54^0 '14.260) rises about 650 meters from its base, making it exemplary for such project ideas.

Design and operating plan

To promote the viability of this work, the analysis is applied for Wind/Grid/PHS system. The arrangement of the proposed system is illustrated in Figure 6. The research's utility has been boosted by investigating a wind turbine system (W) integrated with pumped hydro storage (PHS). The sustainable energy sources have intrinsic intermittency and uncertainty. To transact with these affairs, control systems for wind turbine farm are destined to optimize power generation under changing weather conditions.

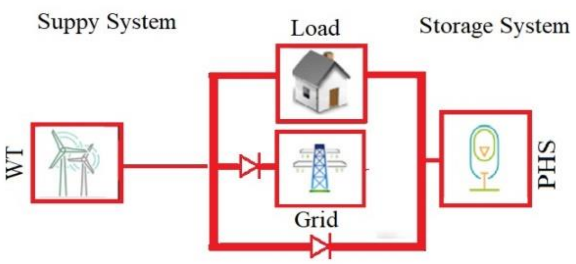

Fig.6: Arrangement of the proposed Wind/Grid/PHS

Pumped Hydroelectric Storage (PHS) system in fact consists of two naturally occurring reservoirs at the study venue. The significance of this geographical benefit is it has the potential to diminish the capital costs of the suggested hybrid energy system.

The PHS operates in three different modes: zero, positive, and negative. The waterpower is transformed into mechanical energy by turbine engines which drive electrical generators in the positive mode. While the power flow reverses, and the generators act as motors; pumping water back into the upper reservoir for storage during the negative mode. The quantity of stored energy is determined by difference in height between reservoirs and the entire volume of water.

Wind Energy

The generated energy by a specified wind turbine may assessed as [46,47]:

$$E_{Wind}(t) = \begin{cases} 0 & V_Z(\mathrm{t}) \leq V_{cut-in} \; OR \; V_Z(\mathrm{t}) \geq V_{cut-off} \\ P_{rat}\left(\dfrac{V_Z(t) - V_{cut-in}}{V_{rat} - V_{cut-in}}\right) & V_{cut-in} < V_Z(\mathrm{t}) < V_{rat} \\ P_{rat} & V_{rat} \leq V_Z(\mathrm{t}) < V_{cut-off} \end{cases} \quad (1)$$

Where: P_{rat} is the rated power of the wind turbine at rated wind speed V_{rat} , V_{cut-in} and $V_{cut-off}$ represent the cut-in and cut-off wind speeds, respectively; and $V_{Z,t}$ is the wind speed at the wind turbine hub height (h_Z) is assessed by the exponent relation as: $V_Z(t) = V_0(t)\left(\frac{h_Z}{h_0}\right)^{\propto}$, where $\propto$ wind shear coefficient which taken as1/7 [48,49]. The characteristics of the suggested wind turbine are tabulated in Table 1.

Table 1: The main parameters of proposed wind turbine [47].

Metric	Value
hub height; m	80.0
Cut-in speed; m/s	2.0
Cut-out speed; m/s	25.0
Rated speed; m/s	12.5
Capital cost; $/kW	1,247
Operational and maintenance expenditures; $/kW	81
Lifespan; year	30
CO2 life cycle emission; g CO_2/kWh	32

Pumped hydropower Storage:

In PHS, the power flow is bidirectional according to the mode of the operation. However, the power, in either the discharging mode P_t or charging mode P_p, depends on the parameters of the PHS system as given by [50]:

$$P_t = \rho\, g\, \dot{V}(H + h_f)\eta_t \quad (2)$$

$$P_p = \frac{\rho\, g\, \dot{V}(H + h_f)}{\eta_p} \quad (3)$$

where ρ is density of the working fluid (1000 kg/m^3), g is the ground gravity (9.81 m/s^2), $\dot{V}$ is the volumetric flow rate (m^3/s), H is the height of the upper reservoir (m), h_f is the head loss (m). The hydrodynamic analysis of the water and penstock design is attached down in the appendixes. The main characteristics of the PHS equipments are tabulated in Table 2.

Table 2: The main parameters of PHS equipments

Metric	Value
Reservoirs; \$/kWh	12.5
Turbine price; \$/kW	140
Pump price; \$/kW	51
Civil works; \$/kW	1000
Investment expenditures regarding to installed capacity, \$/kWh.	775
Operational and maintenance cost,PHS; \$/kWh	0.025
Lifespan; years	60
CO_2 life cycle emission; g CO_2/kWh	35

Sizing of the proposed PHS

To determine the optimum size of the upper reservoir, a real time simulation of the PHS integrated the supply system and the load is necessary for estimating the energy flow through the PHS system and the energy level.

Operation modes of the PHS

The PHS system operates within 3 modes: charging, discharging and standby mode. The following statements describe the atomization regime of the PHS system:

Charging mode:

IF $[\mathrm{W}(t)] > E_{Load}(t)$ and

$$\eta_{p/t}(t) \times [E_{Wind}(t) - E_{load}(t)] + E_s(t-1) < E_{ur} \quad (4)$$

Discharging mode:

IF $[E_{Wind}(t)] < E_{Load}(t)$ and

$$\eta_{p/t}(t) \times E_s(t) > [E_{Wind}(t) - E_{Load}(t)] \quad (5)$$

Standby mode:

IF: $[E_{Wind}(t)] = E_{Load}(t)$ or $E_s(t) = E_{ur}$ (6)

Where: $E_{Wind}(t)$, $E_{Load}(t)$ and $E_s(t)$ are the energy generated by wind turbines farms, the load and the energy level in the upper reservoir in MWh at a certain time (t), respectively, E_{ur} is the upper reservoir capacity in MWh, $\eta_{p/t}(t)$ represents pump and turbine efficiencies.

Instantaneous PHS energy, $E_s(t)$

The instantaneous energy of PHS system $E_s(t)$ is given by,

$$E_s(t) = E_s(t-1) + \eta_{p/t}(t)^M \times [E_{Wind}(t) - E_{Load}(t)]$$

Where: $M = \begin{cases} 1 & \text{For charging mode} \\ -1 & \text{For discharging mode} \end{cases}$ (7)

And $E_s(t) \leq E_{ur}$

Storage Capacity, E_{ur}

The storage capacity, E_{ur} represents the maximum value of energy stored in the upper reservoir, and it is calculated in four steps:

Step 1: Assuming an initial value for the storage capacity

$$E_s(0) = E_{ur} \quad (8)$$

Step 2: Calculating $E_s(t)$ for the 8760 hours of a year.

$$E_s(t) = \begin{cases} E_{ur} & If \quad \eta_{p/t}(t)^M \times [E_{Wind}(t) - E_{Load}(t)] \geq E_{ur} \\ Else & E_s(t-\Delta t) + \eta_{p/t}(t)^M \times [E_{Wind}(t) - E_{Load}(t)] \end{cases} \quad (9)$$

Step 3: Finding out the minimum value of $E_s(t)$ .If the minimum value is less than 0, then there is a shortage in the capacity of the reservoir, and the vice versa. The ideal value is that when the minimum value of $E_s(t)$ is equal to zero. The second iteration for the energy storage capacity will be as:

$$E_{ur} = E_s(0) - Min(E_s(t))_{t=1,8760} \quad (10)$$

Step 4: Check for the answer stability, it satisfies when the value at the end of simulating period $E_s(8760)$ of energy level in the storage equals to the initial value $E_s(0)$. To achieve that it is necessary to increase the capacity of the supply system ($E_{wind}(t)$) and repeat the above mentioned steps again until satisfying the stability.

$$E_s(8760) = E_s(0) \quad (11)$$

Pump capacity, $\boldsymbol{E_{Pump}}$

The energy required to pump the water from the lower reservoir to the upper one is calculated by,

$$E_{Pump} = min(E_s(t))_{\,t=1-8760} \quad (12)$$

Turbine capacity, $\boldsymbol{E_{Turbine}}$

The PHS system supplies electrical energy to the power grid to meet load demands during periods of supply deficiency. In accordance with the principle of energy balance, the energy generated is equal to the energy used for pumping.

$$E_{Turbine} = max(E_s(t))_{\,t=1-8760} \quad (13)$$

Assumptions, limitations, of the study and uncertainties of the results

To simplify the analysis in this study, the following assumptions are deemed:

- The upper reservoir is considered initially full.
- The PHS system is deemed to be lossless, without leaks or evaporation.
- The head calculates neglects to take into account the water level in the upper reservoir.
- The flow of water through the penstock is presumed turbulent.
- Turbine and pump efficiencies are supposed to be constant, regardless of flow rate.

The principal limitation of this study is neglecting the weather influences (evaporation and precipitation) on upper reservoir water levels .

The primary causes of uncertainty are data availability, model selection, and parameter estimation. For example, the availability of renewable energy resources (such as wind) is heavily influenced by climatic conditions, which can have a considerable impact on the power production profile of associated facilities. The cost of renewable energy projects is also a source of uncertainty. According to Fathi and Alsadi [51], Water turbine costs ranged from \$353 to \$2,216 per kW. PHS facilities' maintenance costs vary, ranging from \$2.12/kW to \$5.64/kW per year.

Optimization process

Objective function

This study intents to determine the optimal configuration of a W/PHS for Brack City, while minimizing the Levelized Cost of Energy (LCOE) [52-54].

The objective function (OF) is expressed in Eqn. (14).

$$OF = \min\ (LCOE) \tag{14}$$

Where:

$$LCOE = \frac{\left[\frac{r(1+r)^{\mathrm{n}\text{wind}}}{(1+r)^{\mathrm{n}\text{wind}}-1}(C_{wind}) + \frac{r(1+r)^{n_{PHS}}}{(1+r)^{n_{PHS}}-1}C_{PHS} + (O_{wind}+O_{PHS}) + C_{CO_2LCA} - C_{CO_2}\right]}{\sum_{t=1}^{8760} E_{Load}(t) + \sum_{t=1}^{8760}\mathrm{Grid}(t)} \tag{15}$$

where C_{wind} and C_{PHS} are the capital costs of the wind and PHS system; O_{wind} and O_{PHS} are wind and PHS operation & maintenance costs respectively. r represents the discount rate (2.5%). n_{w} and n_{PHS} are the wind and PHS system lifespans.

Constraints

The suggested hybrid renewable energy system must be dependable and able of sustaining an autonomous energy supply, as it acts as the lone source for meeting the location's load demand. Thence, the objective function in Equation (14) is subject to the Loss of Power Supply Probability (LPSP) constraint.

$$LPSP = \frac{\sum_{t=1}^{8760}[E_L(t) - (E_{Wind}(t) + (-1)^m E_{PHS}(t))]}{\sum_{t=1}^{8760} E_L(t)} \tag{17}$$

where $E_L(t)$, $E_{\mathrm{wind}}(t)$, $E_{PHS}(t)$ are instantaneous load, wind and PHS energy respectively. The accepted LPSP For the system under consideration, the LPSP is set at 1%, balancing high dependability with power supply security in the suggested hybrid system. LPSP of zero requires a significantly costly renewable power system. Set LPSP to 1% achieves the lowest value of LCOE and ensuring full load accomplishment.

Results and discussion

Sizing the wind turbines farm

The variation in results considering the answer stability constraint is depicted in Figure 7. It illustrates that the PHS size which satisfies the answer stability condition is 10782 MWh and this is the optimum size . Figure 8 displays the change in supply system size (Wind turbine) and storage system size(PHS). It is obvious from the figure that highest the percentage of LPSP, the lower supply and storage systems capacities and vice versa.

The two-way direction of PHS power indicates its technical feasibility since it acts as a source as well as a sink for the load, thus ensuring supply continuity and compliance with the operational constraints of the design.

Cost analysis of the hybrid renewable system.

The cost analysis is carried out for the suggested system, which integrates Wind turbine and PHS, to assure it meets the total load requisites while considering the given constraints. From Figure 9, the Levelized Cost of Energy (LCOE) serves as a dependable economic indicator for comparison investing more in the system impacts no matter much to the LCOE. The overall finding is that a capacity of 432 MW supply and 10872 MWh of storage is the optimum size. This setup insures efficient energy rendering for the proposed system. Figure 10 shows the change in energy level in PHS reservoir with the change in the percentage of Loss of the Power Supply Probability (LPSP).

Sizing PHS for the proposed PV

Based on economic evaluation, the best choice is the one has the minimum Levelized Cost of Energy (LCOE). Referring to Figures 8 and 9, the lowest LCOE is accomplished using a 432 MW Wind turbine farms and 10782 MWh from the PHS system, which is the most cost effective option.

In order to design a Pumped Hydro Storage (PHS) system for a wind turbines farm, careful consideration is required for storage capacity and power rating to perform a stable equilibrium of energy production and load demand. The following systemic manner outlines the process for sizing a PHS system for a 432 MW Wind turbines farm with a 10,782 MWh storage capacity. Following the methodology sequence, leads to design a dependable PHS system with taking into consideration power storage demands, system constraints, and operational expenditure.

The established system, which contains 432 MW of wind turbine, 10782 MWh of storage, and minimum(LCOE)\$156.12 per MWh is targeted to supply sufficient energy to totally meet the yearly expected load of 590,019 MWh. While, about 253883.7 MWh is estimated as an energy excess from the HRES, which could be exported to the utility grid to make an extra economic profit to the suggested system. Relying on sustainable energy sources, the

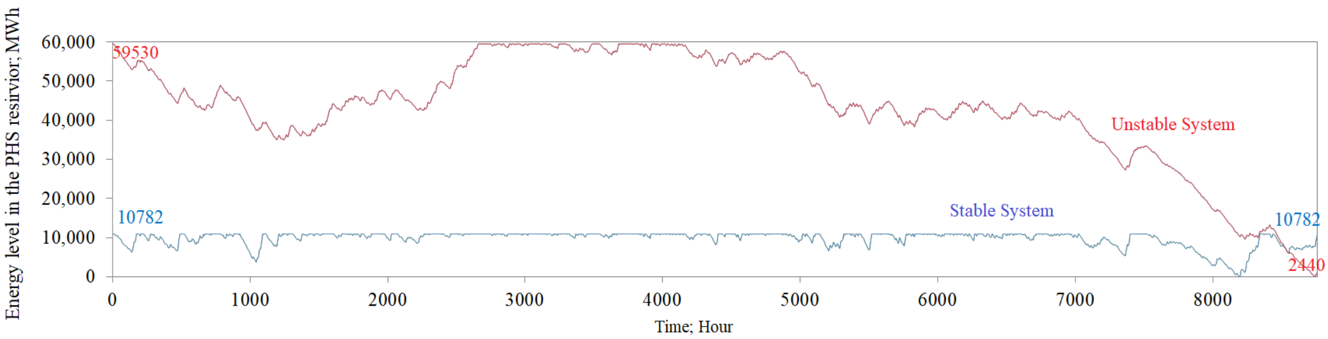

Fig.7: The answer stability concept

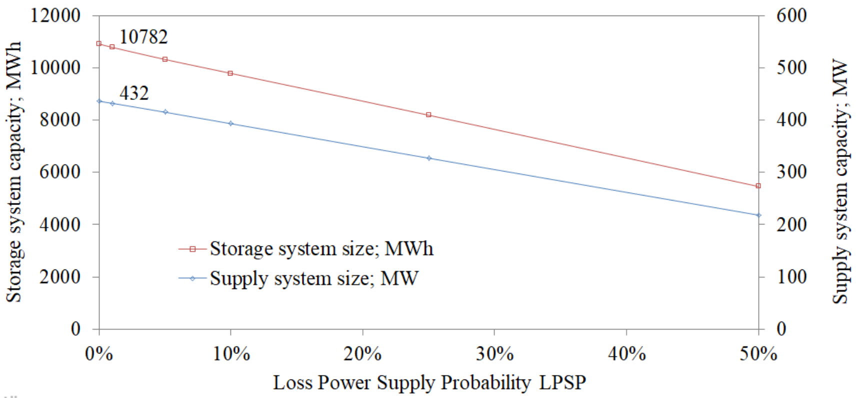

Fig.8: The change in supply and storage system sizes

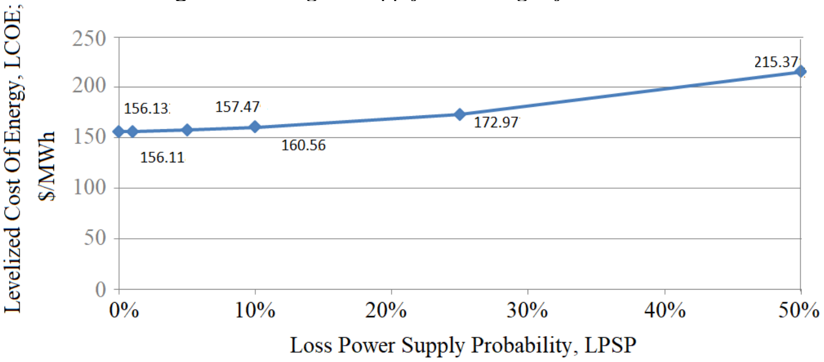

Fig.9: The impact of Loss of Power Supply Probability on (LCOE)

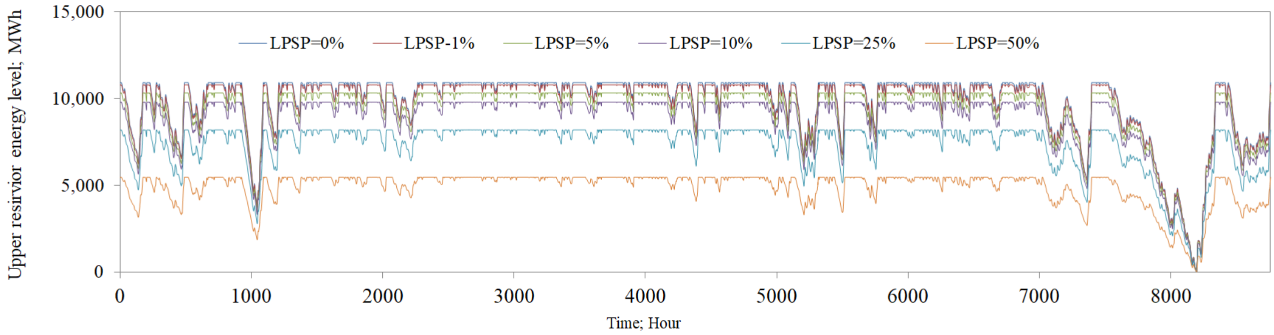

Fig.10: The infeluance of energy level in PHS regarding to LPSP when wind turbe farm capacity of 432 MW

system helps to decrease the emissions of carbon dioxide by about 611,85 tons CO_2 per year (based on the emission factor of the power generation system in Libya is about 1,037 kg CO_2/MWh [55-58], helping to environmental conservation. The annual cost of CO_2 damage was estimated as US$ 42,829,48 (as the cost of CO_2 is $70/ton CO_2 [59- 61]). The impact of renewable energy sources on the environment has been studied in [62]. The successful accomplishment of such efforts shortage an adjuvant environment which involves proper sources of financial support and legal frameworks for associated studies. Moreover, it is indispensable to plan for the transition to environmentally friendly power generation and to encourage private sector to contribute in clean energy projects.

Conclusion

Amelioration technique evolved and implemented to find the suitable capacity of a PHS-incorporated hybrid wind energy system for powering a southern Libyan urban zone. The system's capacity was optimized while preserving the lowest Levelized Cost of Energy (LCOE) and reaching 100% load demand coverage within the specific limits. A hybrid Sustainable Energy System with a 432 MW wind turbines farm and a 10782 MWh PHS was elucidated to be an proper choice for assuring a dependable source of energy to an electric load with a peak power demand of 100.81 MW. The system supports about 55.5% of the energy demand from the hybrid RES, while the remaining 44.5% is absorbed by the PHS.

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Appendix

Table A1: Literature review on the hybrid renewable energy systems

Layout	Storage	Grid	Country	Key findings	Ref.
PV/WT/DG	B	Off	Palestine	A hybrid energy system consists of PV- Wind-Diesel generators , it found that is capable to cover 100% of the load with LCOE of $0.348/KWh	[63]
PV/WT	PHS	Off	Libya	A hybrid RE System contains 1000KW solar PV array and 5000 KW wind turbines farm integrated with PHS of 27954 KWh capacity, was found competent to fulfill the requirements for the sustainable energy supply for an electric load around 1.2 MW peak power and 6.14 GWh yearly energy consumption. The system provides the load with approximately 85% of its energy demand immediately from the HRES and the remaining 15% is covered by the PHS. The avoided CO2 is around 4385 ton/year. The LCOE is $0.132/KWh	[64]
CSP	PHS	Off	Egypt	Yearly energy 131E6KWh, LCOE4.45₵/KWh, Net capital cost $150E6, and capacity of 50 MW	[65]
PV/DG	B	Off	Sudan	The Levelized Cost of Energy is $ 0.328/KWh	[66]
PVT/CSP/HE	FC	Off	Russia	In the present article, a hybrid RES to supply the electricity , heating and fresh water demands of a near zero energy building (NZEB) is suggested.	[67]
PV/WT/HT/BG	-	-	South Korea	The results display that a convolutional neural network could efficiently predict sequential demand electricity (R2 = 98.79%), with respective Bio,solar,hydro, and wind energies optimally provided 45.7 , 34.52 , 14 , and 5.78% under optimal conditions in South Korea.	[68]
PV/W/BG	B	On	Bulgaria	One tonne MSW could potentially produce up to 1000 KWh of electricity . Biogas generator is found to make the most sustainable share of electricity generation (between 60 to 65% of total)	[69]
PV/WT	B/FC	Off	UK	The expenditure of the electricity of the new system was £ 0.776 per kilowatt hour.	[70]
PV/DG	B	On	Lebanon	The optimization technique offers an efficient methodology to evaluate alternative designs in order to choose the best source sizes which minimize the LCOE of the system.	[71]
PV/WT/CSP	TS/B/PHS	Off	Chile	The principal results show that 2050, and considering a baseline scenario defined for 2016, for most of the scenarios studied the renewable electricity generation would be at least a 90% and CO2 emissions would be 75% lower.	[72]

Abbreviations: B- Battery, PV- Photovoltaic solar panel, WT- Wind turbine, BG- Biogas electrical generator, DG- Diesel electrical generator, FC- Fuel cell, HT- Hydro-turbine, PHS- pumped hydro storage system, HE- Hydrogen engine, CSP- concentrated solar power.