# Design and Optimization of Wind Energy System installed in Rehab Gas Power Station Combined with Thermal Energy Grid Storage Multi-Junction Photovoltaics Mean in Mafraq, Jordan

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**Abstract-** The Rehab gas turbine power plant is located 70 km north of Amman, the capital of Jordan. Rehab power station has an overall capacity of 357 MW. However, the Rehab power plant takes in a high quantity of fossil fuels. The overall Rehab power station efficiency is just roughly 39.5%. This paper discusses the feasibility study for designing a wind farm that is combined with thermal energy grid storage – multi-junction Photovoltaics (TEGS-MPV). Thermal energy grid storage is a very cheap energy storage method and can help save carbon emissions. HOMER® software was utilized for this purpose via optimization and sensitivity analysis to calculate the Levelized cost of energy (LCOE) values. The major components of the configuration tested in HOMER® are wind turbines, electrical load, inverter, and CAES. A load of the wind energy system was defined as 60 MW. A large capacity of wind turbines was selected with four MW each, to generate a larger amount of electricity within the provided area in the Rehab location. It was found that there were 5 scenarios for generating and/or storing electricity, and the most effective scenario was number (1) as illustrated in this work, having a Levelized cost of energy (LCOE) of was 0.04252 USD/kWh. This scenario consists of wind turbines, inverters, and TEGS-MPV. This scenario is also the most effective in terms of environmental aspects, as it has no negative influence on the environment including greenhouse gases (GHG) emissions, which would save 293,764 tons of carbon emissions per annum.

**Keywords** CAES, Energy Storage, Jordan, PHES, Rehab Gas Station Power Plant, Renewable Energy, TEGS-MPV, Wind Energy.

## 1. Introduction

The Rehab gas power plant is considered one of the prime power stations used by Jordan central electrical generating company (CEGCO), which provides the Kingdom with 9% of overall electricity generated in Jordan [1]. Rehab is located in the northern zone of the Kingdom, approximately 70 km north of Amman, Jordan, location coordinates are: Latitude= 32.3311, Longitude= 36.0506. The Rehab station site is located 835 meters above sea level. Furthermore, the Rehab site is widely covered by agrarian zones. The station comprises two gas turbines, each having 30 MW of generation capacity, additional to more two gas turbines, and each one has an overall capacity of 100 MW. In addition, Rehab power station comprises one turbine that works by steam, having 97 MW as an overall capacity. Summing all these capacities leads to 357 MW. The station consists of the units: GT10, GT11, GT12, GT13, and ST14 [1]. Since the year 2012, the Kingdom has witnessed large construction too small- and large-scale green energy power plants in comparison to other counties in the region. Small-scale solar PV plants were installed by home and property owners for reducing the electrical bills. Moreover, many mosques in Amman installed PV projects for providing free electricity, which helps minimize every expensive electrical bill. Consequently, many large-scale power plants in the Kingdom including solar PV and wind enterprises were installed having 50 MW as a minimum capacity [2]. Though, there was a high increase in the Kingdom's population as a result of migration from other countries in the region the last two decades, which made very high stress on the Kingdom's electricity infrastructure and leads to a high rate of consumption, resulting in very high rates of electrical bills per annum, and making several economic burdens [3]. Moreover, many PV and wind projects from both small- and large-scale, are wasting permanently electricity with no storage and use. This problem is very critical that make solar and wind unreliable in the long term. In the same context, many countries suffer from the same problem in the whole world [4]. This paper studies the economic feasibility of combining TEGS-MPV for storing excess electricity from Rehab wind power plant and preventing any losses or wastage of electricity. Previous research related to wind energy focused on exploring its efficiency value and capacity factor for the wind turbines. Those works explored methods by which wind farm efficiency could be increased. However, low number of researches were associated with storing energy related to Jordanian projects. There is a main knowledge gap presented by lower researches regarding storing energy, particularly the utilization of TEGS-MPV. In accordance with the literature review conducted, it was found that storing energy is a critical subject that is increasingly investigated globally, for providing solutions of intermittency and unreliability of solar and wind energy projects. Jordan has a high potential of installing solar and wind projects; though, unsteady wind speeds cause unreliability to promising wind energy projects in the Kingdom [5].

## 2. Literature Review and Problem Statement

Utilizing energy storage became highly desired in the last two decades, due to the need for sustainable electrical resources that cannot be interrupted, and can be sustainable and continuous in all seasons. Because fossil fuels will in 2050 run out [6, 7], the reliance on these resources will be no longer considerable. In addition, they are the major contributors to global warming and climate change. For this reason, the USA, China, European Union, and other countries around the world highly depend on renewable energy to generate clean and free energy. However, one of the major renewable energy resources drawbacks is their intermittency and fluctuations, mainly solar energy and wind. Sun and wind are not available 24 hours. Therefore, managing energy storage became significantly an essence for all countries. One of the most effective storage technologies is thermal energy storage. Thermal energy grid storage became highly reliable for many countries as an effective option to store energy for a long period. These systems can store energy from solar (in the summer season) or wind, to be utilized in another season, such as winter [8]. The energy can be stored thermally in a medium till a particular period for later use [9]. Thermal energy storage is characterized by many advantages. These advantages include their lower carbon and GHG emissions footprint, the lower initial capital cost required for installing this system, lower maintenance and operation (O&M) cost, higher flexibility desired for operation, the excellent thermal capacity of storage in comparison to its unit weight [10]. However, thermal energy storage has a number of disadvantages, which can be summarized by its lower efficiency in comparison to other energy storage technologies, and thermal losses that occur between the storage tank and the surrounding atmosphere. Though, these losses can be minimized by the perfect utilization of functional insulation materials [11]. For increasing the lifetime of thermal energy grid storage, certain monitoring actions can be utilized, such as using combined heat and power (CHP), which can reduce the thermal energy grid storage operation in the system [12]. Cold thermal energy grid storage is a type of thermal energy storage technology, which can use refrigeration and conditioning of air to operate a power plant and offer a shifting of loads. This type of thermal energy storage is common in commercial- and large-scale facilities that can achieve effective peak shifting of loads [13]. The effect of the simultaneously cooling for the front surface and rear of the PV module is evaluated in [14]. The results shows that the temperature of the module drop by 23.55◦C by cooling both surfaces. This leads to an improvement of 30.3% in the power output. The potential of wind energy in different scenarios design is explained more in [15-18], while a new control strategy for conversion system based on fuzzy logic is introduced in [19]. Authors in [20] classified three categories related to thermal energy grid storage, which include: (1) sensible heat thermal energy storage, (2) latent heat thermal energy storage, and (3) thermo-chemical thermal energy storage. Another classification that was formulated by [20], is the thermal energy grid storage multi-junction Photovoltaics, which uses PV pipes for converting thermal energy into electricity. Section (2) illustrates in detail the characteristics and working principles of this system. Cost per unit power (CPP) and cost per unit energy (CPE) of TEGS-MPV technology are presented in Fig. 1.

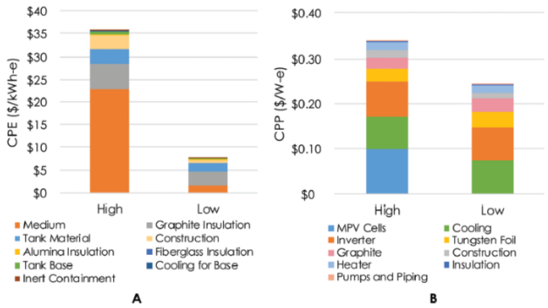


**Fig. 1**. Configuration of: (A) CPE, and (B) CPP of TEGS-MPV technology [21].

As Fig. 1 shows, (A) and (B) present two cases; high-cost and low-cost cases. In a low-cost cases, the storage medium is manufactured using scrap steel, and low-cost graphite is used. Furthermore, cost reduction and higher power density can be attained.

### *2.1 Contributions and Organization*

TEGS-MPV could effectively obtain a reduction in the values of CPE and CPP raising the efficiency which can exceed 36% [21]. The reason goes back to the fact that TEGS can store a high amount of heat energy and provide effective conversion efficiency. It also allows storing energy heat for long periods. In case the insulation problem in a TEGS-MPV power plant is solved, then the heat can be stored for a number of months, making this energy storage method highly sustainable and reliable and solving the intermittency issues related to solar and wind. This paper comes with several distinct contributions. First and foremost, it aims to investigate the design of an efficient and dynamic renewable power station that is run through winds, due to the fact that most of the old power plants consume much heavy oil, diesel, and natural gas, including the Al-Hussain power station, and south Amman station, which cause higher quantities of a particular matter, higher amount of carbon dioxide, and a considerable reduction in the quality of air. The wind is widely abundant and free, which makes it cost-effective, economic, and safe for the environment. Yet, the issue of power intermittency and fluctuations make wind unreliable. For this reason, a second significant contribution of this paper is using TEGS-MPV technology that proved its effectiveness. TEGS-MPV is an economically feasible energy storage system capable to store electrical energy generated from winds during off-peak times. The storage system can provide electricity if there is critical peak demand on the grid that could not meet Jordanian citizens' demand. The third contribution of this paper is to make this work sufficient to cover a part of overall electrical consumption in Jordan. Figure 2 describes the amount of electrical consumption in Jordan.

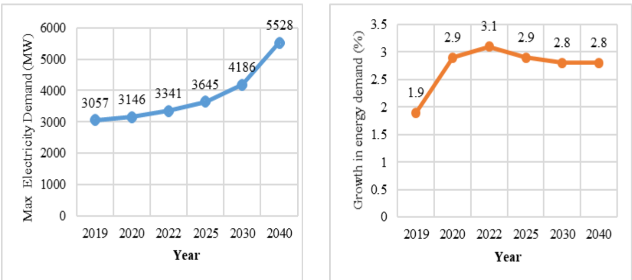


**Fig. 2.** Growth of electricity demand in Jordan – currently and forecasted [1].

The major contributions of this work can be summarized in the following:

1) Use renewable and free winds for generating green electricity.

2) Utilize an efficient energy storage method (TEGS-MPV) for making winds secure and reliable.

3) Try to cover a fraction of overall electrical consumption that is increasing due to the rapid rise of the population in Jordan.

The rest of the paper is organized as the following: The working principle of TEGS-MPV is illustrated in the paragraph below. Thereafter, a mathematical model of the whole configuration is described in Section 4, explaining the major components of the wind energy system integrated with TEGS-MPV. Calculations of TEGS-MPV storage capacity are executed in section 4.

*2.2 Description of TEGS-MPV*

Amy et.al, 2019, point out that one of the main advantages of renewable energy projects is that they can highly minimize the effect of carbon dioxide emissions as well as climate change; however, they have no reliability for providing electrical power continuously. This problem is faced by both small- and large-scale projects. Further, mention that pumped hydro storage (PHES) technology has very high efficiency (between 80% and 90%) [21]. Consequently, compressed air energy storage (CAES) has higher efficiency as well. Though, there are some challenges of PHES and CAES that limit their wide range of use such as their higher initial capital cost, and the geographic constraints. In addition, batteries cannot be exploited for large-scale solar and wind projects, storing 100 percent of overall electricity generated. Thermal energy grid storage (TEGS) can offer an effective solution for storing electricity with lower price, low initial cost, and higher efficiency. TEGS is 10 to 100 cheaper than batteries, relating to the capacity of solar and wind projects. TEGS technology obtains electricity from solar or wind sources, or a fossil fuel plant. Thereafter, it converts electricity to heat energy, which is stored through lower-cost molten salt, mainly silicon dissolved in a fluid, that has a cost of 1.6 US$ for one kilogram, in a number of large energy storage tanks at temperature values that range between 1,900 and 2,400 ºC. These tanks have a lower amount of heat wastage, approximately 1% per day for storing the heat for large-scale projects. In case electricity is required, then the fluid is moved through a pumping force to several tubes that highly give off radiation with higher illumination if hot silicon flows inside them. Utilizing multi-junction PV cells (MPV), this light can be converted to electrical energy. Therefore, TEGS is described as TEGS-MPV, because MPV is used with them. When silicon cools down, due to losing the high amount of heat, it can be pumped to large cold storage tanks, in which it waits for recharging new energy from solar, wind, or fossil fuel plant. This energy storage technology is highly promising due to its lower price and location flexibility [21]. Figure 3 represents the working principle of TEGS-MPV.

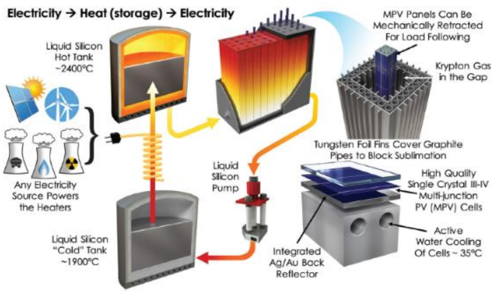


**Fig. (3).** Schematic of TEGS technology working principle [21].

## 3. The Aim and Objectives

This work aims to find the economic feasibility and the value of the levelized cost of energy (LCOE) related to Rehab wind farm project. The LCOE value takes into account integrating mainly thermal energy grid storage – multi-junction Photovoltaics (TEGS-MPV) system to make wind energy viable and reliable in the long term, and allow storing excess electricity during off-peak intervals, to be utilized by Jordanian homes during peak times. Additionally, this work is conducted to achieve the following objectives:

- Design a hybrid off-grid system that comprises wind turbines, and inverters.
- Integrate this wind system with TEGS-MPV.
- Conduct a sensitivity analysis and optimization of several systems through modeling Rehab power plant on HOMER® software.
- Calculate the amount of carbon emissions that can be saved by Rehab wind power plant, by using a special case that exploits only diesel generator for electricity generation without any storage.

## 4. Mathematical modeling of Wind Power Plant with TEGS-MPV

Modeling of the wind energy system was conducted via hybrid optimization and modeling of electric renewables (HOMER®) software, which can make simulation, optimization, and sensitivity analysis of renewable energy systems. In simulation HOMER® makes hundreds and in some complex cases thousands of times, of simulations for the system, which is investigated and modeled. In addition, it tries to select and simulate the most suitable configuration of the system depending on the inputs and constraints that are defined by the user. In optimization, HOMER® optimizes overall simulations created in the simulation step. Thereafter, it sorts and filters these simulations depending on certain criteria that can be defined by the user, including a budget, and storage system. In sensitivity analysis. HOMER® demands correlating the overall components related to the system, to certain variables such as fuel cost, wind speeds, the quantity of carbon emissions, and particulate matter produced or saved. When it comes to designing the system configuration, HOMER® can allow us to utilize two or more of the following components: Photovoltaic (PV) energy, hydroelectric power, electrical utility-grid, diesel generators, bio-gas energy, wind turbines, inverters, and hydrogen fuel cells. In the storage section, the software offers batteries, hydrogen, and flywheels. Figure 4 illustrates the configuration of this work modeled in HOMER® software.

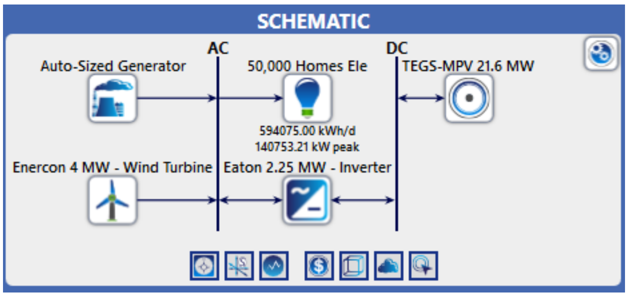


**Fig. 4.** Architecture of Wind energy system configuration in HOMER® software [21].

### *4.1 Electrical Load Definition*

60 MW wind power plant can serve around 50,000 homes not 60,000 homes as European wind energy association European wind energy association (EWEA) states, as load of each Jordanian home is larger than conventional European homes. It is assumed that every house can include 5 individuals (two parents besides an average of three children) for covering ordinary and worse cases of electrical consumption. Table 1 represents typical electrical devices in each Jordanian home.

**Table 1.** Consumption load of typical electrical devices in a Jordanian home.

| # | Home Appliance | Capacity (Watt) | Number of appliances | Total (W) |
|---|---|---|---|---|
| 1 | LED | 3 | 24 | 72 |
| 2 | Electrical Fans | 55 | 5 | 275 |
| 3 | Electric Sockets | 5 | 6 | 30 |
| 4 | LED TV | 17 | 1 | 17 |
| 5 | Refrigerator | 150 | 1 | 150 |
| 6 | Clock Radio | 2 | 1 | 2 |
| 7 | Air Conditioner | 2,000 | 1 | 2,000 |
| 8 | Washing Machine | 500 | 1 | 500 |
| 9 | Water Filter and Cooler | 100 | 1 | 100 |
| 10 | Water Heater/ Kettle | 1,200 | 1 | 1,200 |
| Total Consumption Load | | 4,032 | 42 | 4,346 |

As the Jordanian family individuals leave their home for work or school except foe housewives, the electrical demand may vary and have different load consumption profiles during every season. This profile can have certain peak values, during times when the residents prepare to leave the home to go to their work and school, and after they return back to their home. For example, in summer, it will be higher peak values as AC units are used. It should be noted that Jordanian residents tend to use gas heaters instead of electric heaters as the price of electricity is relatively high.

### *4.2 Wind Energy Definition*

HOMER® allows users to download wind speed data from the NASA database. After the location data (latitude and longitude of Rehab power plant) was defined, the wind speed profile can be downloaded from NASA. Figure 5 presents the mean wind speed profile monthly, which is downloaded from this database.

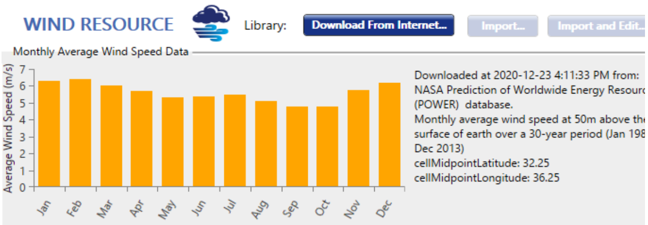


**Fig. 5.** Wind Profile in Rehab, Jordan. Source: (NASA Database, 2020)

After this step, the wind turbine type was determined, which has an overall capacity of 4 MW, from Enercon company. For covering total electricity demand, the number of wind turbines (Enercon - 4 MW) is 15. According to the NREL database [22], the initial capital cost related to this wind turbine equals four million USD. More details regarding the wind turbine in HOMER® can be presented in Table 2.

| **Table 2.** Wind Turbine Specifications. | |
|---|---|
| Rotor Diameter | 127 m |
| Hub Height | 135 m |
| Lifetime | 20 years |
| Replacement cost | 4,000,000 US$ |
| O&M Cost | 176,000 US$/annum (*) |
| (*) Assuming that O&M cost for wind equals to 44,000 for every MW per annum [22]. | |

The Rehab wind power plant has a total capacity of 60 MW, which can indicate that the total amount of generation can equal 367 million kWh/yr. This number was calculated by:

$$P_{a,w} = TC \, . \, CF \, . \, N \, . \, YD \tag{1}$$

Where

| | |
|---|---|
| $P_{a,w}$ | Annual production of wind system |
| $TC$ | Total capacity |
| $CF$ | Capacity factor |
| $N$ | Number of hours per day |
| $YD$ | Year days |

Which can bring $P_{a,w}$ = 60 MW × 0.70 × 24 hrs × 365 days = 367,920 MWh/yr, or $P_{a,w}$ = 367 million kWh/yr. The resulted value is represented based on daily consumption as well: $P_{d,w}$ = 1,008 MWh/day. Authors in [23] report that CF common value equals to 70%.

*4.3 Inverter Definition*

The Inverter is the only part of the Rehab wind power plant that is responsible for allowing produced electrical power to be easily utilized by residents. Typically, wind turbines can produce DC electrical power, which may not provide any use for residents. The Inverter can convert DC electrical power into useful AC electricity for easy use. For small- and large-scale renewable power plants, inverter capacity, generally can equal the overall capacity of renewable energy power plants [24]. Therefore, the capacity of the inverter would be 60 MW, as the capacity of the Rehab wind farm equals 60 MW. The inverter used here is a central inverter, as it can be effective for such large and utility projects. More details regarding the selection and design of the Rehab inverter are shown in Table 3.

**Table 3.** Rehab power plant Inverter characteristics.

| | |
|---|---|
| Inverter | Eaton Power Xpert 2.25 MW |
| Project Capacity | 60,000 kW |
| Number of Inverters | 27 |
| Capital Cost | 3,600,000 USD |
| Replacement Cost | 3,600,000 USD |
| O&M Cost | 360,000 USD/yr |
| Efficiency | 98% |
| Lifecycle | 5 years |

NREL 2018 report [24], states that the price of solar and wind inverters equals approximately 0.14 USD/W that are used in small- and residential scales. On the other hand, the cost of inverters used in renewable commercial-scale systems can equal roughly 0.09 USD/W. Moreover, the cost of utility-scale (or central inverters), due to NREL 2018 report [24], is 0.06 USD/W. Hence, the capital and replacement costs are 3,600,000 USD. The O&M cost equals 0.006 USD/W/yr that can equal 360,000 USD for Rehab wind system [24].

*4.4 TEGS-MPV Definition*

The major energy storage method in this paper is TEGS-MPV. The size of the TEGS-MPV system is defined by finding the amount of excess electrical power that can be attained after consumption. 50,000 Jordanian homes can consume approximately 594,075,000 Wh/day. This amount was attained by summing up the amount of consumption through twenty-four hours for every month. Thereafter, it was divided by 12 to obtain the mean value. The calculations related to the capacity of TEGS-MPV are represented through the following equations:

$$DSC = P_{d,w} - E_{cons} \tag{2}$$

DSC = 1,008 MWh/day − 594 MWh/day = 414MWh/day. The safety factor is added, by multiplying the value obtained by 1.25 (25% more) which equals 517.5 MWh/day or approximately **520 MWh/day**. DSC is defined as daily storage capacity. 414 MWh/day is considered as the excess electricity that is not used and requires storage. The size of TEGS-MPV in (MW) is calculated through:

$$P_{comp} = \text{DSC}\left({}^{YD}/_{YH}\right) \quad (3)$$

Where YD and YH are year's days and year's hours, respectively. These values can be substituted into this equation to obtain:

$P_{comp} = 414\left({}^{365}/_{8760}\right) = 17.25$ MW, which is multiplied by a safety factor of 25% (or 1.25) leading to 21.6 MW. According to Amy et.al, 2019, as shown in Fig. 1, the cost per unit power of CPP of TEGS-MPV equals to roughly 0.35 USD per Watt. Therefore, financial data required to be defined in HOMER® can be summarized in Table 4.

**Table 4.** Fiscal data related to TEGS-MPV

| | |
|---|---|
| Initial Cost | 7,547,000 USD |
| Replacement Cost | 7,547,000 USD |
| O&M Cost | 1,000,000 USD/annum |
| Lifetime | 35 years |

*4.5 Diesel Generator Definition*

The design of the diesel generator highly relies on the amount of power consumed daily. The size of the diesel generator is defined in HOMER® as Auto-Sized allowing the software to choose the most appropriate configuration via sensitivity and optimization analysis. In order to allow HOMER® to make sensitivity and optimization analyses for the overall system, the software can simulate with and without a diesel generator. According to the software, the financial data including initial cost, replacement cost, O&M cost, and fuel cost account equal to 500 USD per kW, 500 USD per kW, 0.030 USD per operational hour, and 1.00 USD per liter. Table 5 presents more details regarding the diesel generator.

**Table 5.** Diesel Generator Specifications.

| | |
|---|---|
| Diesel lower heating value | 43.2 MJ per kg |
| Density | 820 kg per $m^3$ |
| Carbon Content | 88.0 percent |
| Sulfur Content | 0.40 percent |
| Minimum Load Ratio | 25.0 percent |
| Lifetime | 15,000 hrs |

## 5. Results and Analysis

After conducting simulation and optimization analysis it was found that 410 solutions were feasible, and 135 were omitted as shown in the calculation report, see Fig. 6.

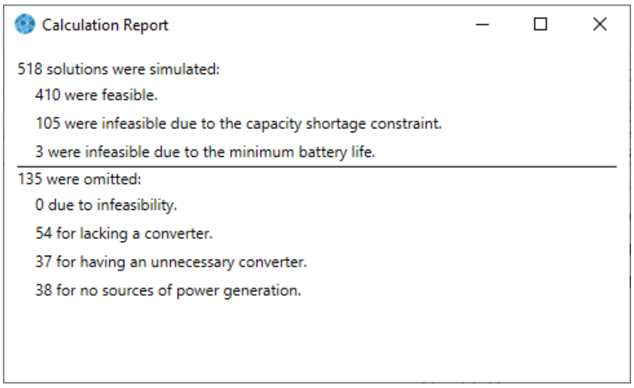


**Fig. 6.** HOMER® calculation report.

**Table 6.** HOMER® Results Summary.

| Scenario | Generation Method | Storage Method | Configuration | The LCOE (USD/kWh) | Total System Cost (USD) | Carbon Dioxide (kg/annum) |
|---|---|---|---|---|---|---|
| 1 | Wind Energy | TEGS-MPV | | 0.04252 | 119,145,105 | 0 |
| 2 | Wind Energy + Diesel Generator | TEGS-MPV | | 0.05277 | 147,925,565 | 1,811,113 |
| 3 | Wind Energy + Diesel Generator | ----- | | 0.2049 | 574,336,326 | 38,968,300 |
| 4 | Diesel Generator | TEGS-MPV | | 0.5359 | 1,502,104,777 | 167,465,420 |
| 5 | Diesel Generator | ----- | | 0.9443 | 2,647,085,270 | 293,763,990 |

In addition, HOMER® found different possible scenarios that can be used for only generating electricity, or generating and storing electricity. Table 6 presents some of these scenarios, and following, the best scenario, in comparison to other scenarios, is discussed in detail

*5.1 Optimal Scenario: Scenario (1)*

In this scenario, it was found that the LCOE was 0.04252 USD/kWh, which is considered to be the least value in comparison to all scenarios. The fiscal results of this scenario are represented in Table 7.

**Table 7.** Fiscal Data of Scenario (1).

| Component | Capital Cost (CC) (USD) | Replacement Cost (RC) (USD) | O&M Cost (USD/yr) | Fuel Cost (USD) | Salvage Value (USD) | Total |
|---|---|---|---|---|---|---|
| TEGS-MPV | 27,952,927 | 0 | 4,309,338 | 0 | 591,524 | 31,670,741 |
| Inverter | 6,745,867 | 2,862,095 | 8,720,730 | 0 | 538,675 | 17,790,017 |
| Wind Turbine | 40,800,000 | 13,007,340 | 23,207,478 | 0 | 7,330,470 | 69,684,347 |
| Total | 75,498,794 | 15,869,435 | 36,237,546 | 0 | 8,460,669 | 119,145,105 |

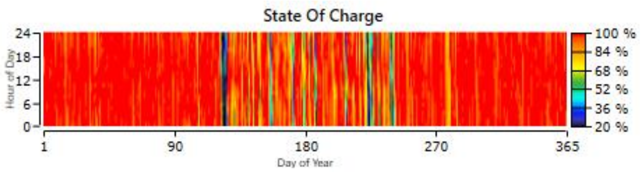


**Fig. 7.** Electrical profile of TEGS-MPV use during the year.

TEGS-MPV profile is represented through Fig. 7. It can be noted from the Fig. 7 that storing electricity would be less during the middle of the year (i.e., in cooling season), at which AC systems are used, therefore, it will be less amount of excess electricity that can be stored. Figure 8 illustrates the generated power from wind turbines throughout the year. Because this case did not use a diesel generator, it will be no emissions from burning fuel.

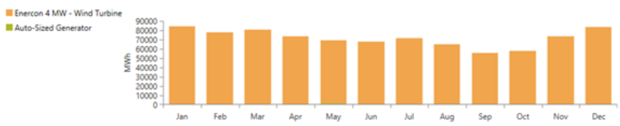

**Fig. 8.** Wind turbine electrical generation profile around the year.

## 6. Discussion of the result

Based on the results found in this work, it can be noted that TEGS-MPV provides an effective solution to the intermittency issue that makes wind energy resources unreliable. Also, it can be noted from comparing scenarios to each other, that despite the fact that diesel generators can be used as a backup resource for providing electricity at high demand or in case the wind is not available, but it is highly harmful to the environment, which can be translated by higher values of all GHG emissions including carbon dioxide, carbon monoxide, unburned hydrocarbons, particulate matter, sulfur dioxide, and nitrogen oxides. Therefore, utilizing TEGS-MPV is more efficient in terms of the LCOE in comparison to conventional fossil fuel electrical resources including diesel generators.

## 7. Conclusion

Following this research, the following conclusions are supported:

1) Utilizing TEGS-MPV to the Rehab wind energy system, which has a capacity of 60 MW, would be sufficient for 50,000 homes in Jordan, and would result in no carbon emissions, whilst the LCOE attained was 0.04252 USD/kWh.
2) Using a diesel generator as a backup with a wind turbine and TEGS-MPV would cost 0.05277 USD/kWh, but it will correspond to several carbon emissions.
3) Exploiting wind turbine and diesel generators in scenario (3), would result in an LCOE value of 0.2049 USD/kWh, which is larger from both scenarios (1) and (2), and cause more pollution as there is no storage method used.
4) Using only diesel generators for providing power, and TEGS-MPV as energy storage would result in an LCOE of 0.5359 USD/kWh, which is very high in comparison to preceded scenarios.
5) Using no any storage methods or any renewable energy resources for generating clean and free electricity would result in an LCOE of 0.9443 USD/kWh, while the GHG emissions would be the largest.

**Nomenclature**

| | |
|---|---|
| LCOE | Levelized cost of energy |
| CEGCO | Central electricity generation company |
| PHES | Pumped Hydroelectric Energy Storage |
| CAES | Compressed air energy storage |
| HOMER | Hybrid optimization model for electric renewables |
| EWEA | European wind energy association |
| CC | Capital cost |
| RC | Replacement cost |
| O&M | Operation and maintenance cost |
| R&D | Research and development |
| CPP | Cost per unit power |
| CPE | Cost per unit energy |
| TEGS-MPV | Thermal energy grid storage with multi-junction PV |
| CF | capacity factor |
| CHP | Combined heat and power |
| GHG | Greenhouse gases |

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