Performance Analysis of a Hybrid Micro-Energy System for SA Data Centers

Sempe Thom Leholo[1], *Pius* Adewale Owolawi[1], *Kayode* Timothy Akindeji[2]

[1]Tshwane University of Technology, Department of Computer Systems Engineering, Pretoria, South Africa
[2]Durban University of Technology, Department of Electrical Power Engineering, Durban, South Africa

Abstract. The integration of hybridized renewable energy sources (RES) with AC/DC converters has become the focus of the 21st century for green Information Communication Technology (ICT) applications such as the data center. As the data traffic grows exponentially, the corresponding demand for energy to drive the growth becomes a great challenge and considering the environmental impact, a hybrid renewable energy system is favored for eco-sustainability and economic reasons. This is especially true for data centers which represent a dominant share of the total power in cellular networks. This paper evaluates the actual performance of a fuel cell in a renewable energy hybrid system considering the hybridization of photovoltaic (PV), Wind, Fuel Cell, and battery storage system with a choice of a half-grid mode. The reduction and the absence of available PV power by shading and rainy conditions will be easily reduced by the compensation of the other renewable sources. The modeling and simulations are performed using HOMER software. The results show the effectiveness of the proposed system as the energy supply is less intermittent and more stable.

1 Introduction

Most hybrid power systems today utilize wind, hydro and solar energy sources. Solar energy makes the majority of renewable energy utilized on earth today in multiple forms because photovoltaic panels are easily accessible and affordable in addition to the abundance of solar irradiance across the globe [1]. A Hybrid system combining all these different types of power sources has an advantage over PV in terms of balance, stability and satisfied energy outputs [1]. The resources that make-up a data center such as high-level servers, high capacity storage devices, network devices such as routers and switches must be secured with the uninterrupted power supply as this is critical to the business of data centers. It must be noted that most data centers consumed large amounts of energy as the data transaction traffic grows in billions of online users worldwide [2]. In fact, Industrial Development Corporation reports that server's energy consumption is growing by 9% per year globally attributed to the rise of performance which pushes demand for energy [3]. Data centers energy efficiency must, therefore, be improved upon to realize significant tangible energy savings improvements [4]. In South Africa, the rise in big data and Internet-of-Things (IoT) industries in recent years have spurred the continued construction of more data centers [5]. It has been confirmed that the carbon emissions emanating from ICT infrastructure are estimated to be within the range of two to four percent of the global accumulative carbon emissions [6].

Considering the operation of the data center it is observed that the aforementioned percent (2-4) would increase by 40-60 percent [7]. This is further predicted that by 2020 this exponential increase percentage of emission will be double. A huge part of this emission's, one-sixth of that will be attributed to telecommunication networks [7]. Fossil fuel resources have a finite future because of their increasing depletion rate combined with the environmental damage done atmospherically, like global warming, this has started to change the world's perspective on a global warming and it has driven the world economies to dwell more on technologies of renewable energy sources that are safe for humans and do not damage the environment. One of the concerns with this paper is to investigate the costs in line with the inclusion of hydrogen in the proposed hybrid system. The investigation revealed what configuration of PV and wind systems couple with the electrolyzer is feasible in order to produce power that's adequate to sustain constant power supplies to a data center.

The debate on the addition of fuel cell may not be seen as ideal for the short run of the project. Hence, the long run of the combination confirmed a reduction of fuel cell prices by at least 45% of their current capital cost, which shows the competitiveness for the remote data center system deployment and implementation. In most of data centers, the supply of electricity is erratic due to multiple factors such as environmental constraints, inaccessibility by developers and financial constraint as a result of high cost of installation over long-distance from the grid [8].

The data, air and power flow, as well as the interconnection of all components in a typical data center, are shown in Figure. 1. The cooling system is assumed to be based on chilled water. No matter what architecture a data center might have, it only has two types of connections with the outer world – electrical power and internet connections. The data load determines server utilization and the total power demand changes based on the data load. How do the interconnections of the components in a data center affect the total power consumption? To answer this question, there is a need to develop detailed models for all components and their interconnections.

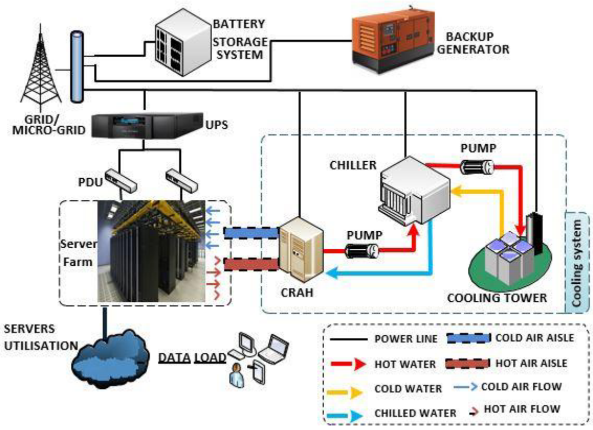

Fig. 1. The interconnection of components in a typical data center.

Comparative economic analyses on a power generating hybrid systems is one of HOMER software capabilities [9]. The chosen parameters serve as inputs to HOMER software to simulate every possible combination of chosen RES and rank in order of best performance. The analysis tests such as capital costs or cost of energy will be parameters of interest in making choice of the suitability of RES. The impact on the Levelized cost of energy (COE) by the cost of fuel like diesel or hydrogen can be done by "HOMER sensitivity analyses" which is often achieved when the input parameters of the renewable resources are optimized. This simulation test is further used to determine any economic feasibility study of energy production and comparability test of electricity generation systems and technologies adopted to achieve the chosen configuration [10]. In addition to the required input parameters to estimate COE, fuel cost, capital cost, operation, and maintenance cost coupled with other basic financing costs play a key role in the estimation [11].

In this work, the datasheet of the chosen systems and the available natural data from solar irradiance, wind speed, and other measurable parameters are used as the input parameters for the simulation to estimate the present, future performance and costs, and efficiencies of the chosen hybrid system.

2 Data collection

2.1 Topographical data

Modelling a system requires input data that is based on the site where the data center is located. These data is inserted into the HOMER software for modelling and analysis. The renewable energy resources amount available to support the system load are determined and estimated by using input data. Data like solar irradiance and wind speed are sampled and processed, before input into the HOMER Software.

Solar resources like solar irradiance data are required for our photovoltaic system. In the certain locations, particularly remote areas in South Africa where the data center will be located, it is important to determine the amount of sunlight available at a certain time, be hourly or daily. In the same vein, wind speed and other relevant data of the location where the wind turbine is to be installed must be obtained. Table 1 below displays the monthly average data for solar irradiances, clearness index and wind speed for the selected Cape Town data center location.

Table 1. Topographical Data

Month	solar irradiances kWh/m^2	Clearness index data	Wind speed m/s
Jan	3.96	0.394	4
Feb	5.1	0.491	4.5
Mar	6.1	0.581	4.9
April	7.02	0.688	5
May	7.68	0.795	5
Jun	8.33	0.895	4.9
July	8.19	0.868	4.7
Aug	7.59	0.765	4.5
Sep	6.78	0.656	4.4
Oct	5.7	0.55	4.3
Nov	4.32	0.428	3.9
Dec	3.59	0.362	4
Avg	6.197	0.623	4.51

2.2 Energy consumption: data center

Having a good understanding of data center energy consumption is critical to implementing a hybrid RES. In this analysis, a data center in a defined and chosen location of interest (typical area of 465 m2) is to be modelled. The modelled data center has a total energy consumption of 215.86 kWh/day and the energy use is classified as either demand aspect or supply aspect. The demand-side system includes is the server power supplies, processors, communication equipment, storage and other server components and accounts for 53% of the sum of consumption. Included in the supply-side systems is the UPS, cooling, power distribution, building switchgear and lighting all account for 47% of total consumption. In addition, it must be noted that a

 https://doi.org/10.1051/e3sconf/20186401003

substantial energy is needed to remove the generated heat from the data center.

The total hourly data center power requirement is 8.994 kW, therefore, the total power requirement for the data center annually is 78.79 MW.

2.3 Load profile data

The load profile of the modelled data center is shown in Figure 2. In order to get a clear power demand of the data centers, the energy demand management concept and corrector factor will be used. Calculations in kWh for Energy produced is in relation to the hybrid power system in a daily allowance situation. Demand factor is used to scale down real daily energy demand to help with actual sizing of the RES in order to cover the data center energy needs. With the utilization of HOMER software and hourly load data, in turn, the data center load profile is obtained as displayed in Figure 2. From the profile, the scaled average for the day is 215kWh/d and the peak is 9.96kW with a load factor of 0.438. The electrical load factor explained as the ratio of the average load, or efficiency of electrical energy usage, in other words, it is the ratio of total energy (kWh) consumed in a certain billing period of hours to the maximum demand which happened at a certain period.

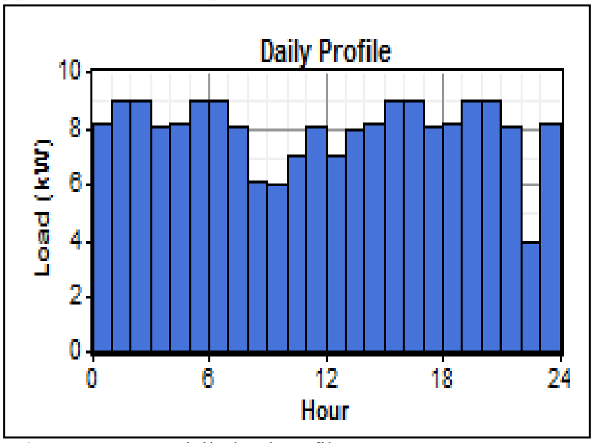

Fig. 2. Data centers daily load profile

2.4 Architectural design of hybrid power system

An RES consisting of solar PV, wind turbines, and a fuel cell integrated with AC–DC converter, electrolyzer, hydrogen tank and a storage battery bank is simulated using the HOMER software. Simulation of the different multivalent system to maximize the available RES and minimize total operation cost. The preferred mode for this work is non-grid-connected with an energy storage device (battery) that automatically and seamlessly connect to the load when RES is not enough to power the load. The schematic diagram of the RES used for the simulation is shown in Figure 3. In order to determine the optimal value of each RES, in order to reach the goal of the optimization process, component variables are considered. These variables can be chosen to determine the sizes of equipment needed to model the system and then HOMER can show multiple possible designs in its optimization process.

There are two goals for the simulation process. Determining the feasibility of the RES is the first step. If the hybrid system can adequately accommodate the data centers load and mitigate any constraint that arises during the selection of systems configurations. Secondly, the cost of the life-cycle of the RES is estimated, in which the installation costs and the lifetime operation costs of the RES are combined [12]. Comparing the economics of various system configurations is a convenient metric which is called the life-cycle cost [13].

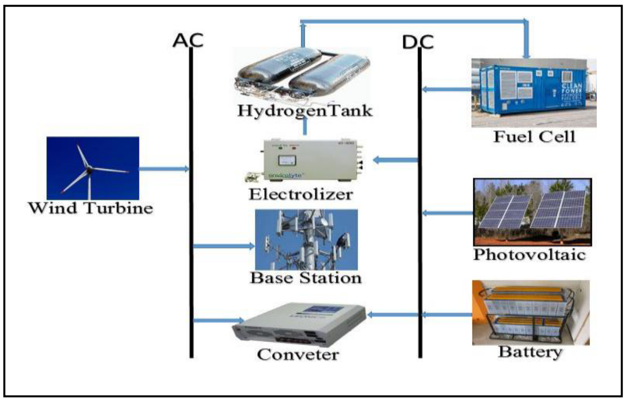

Figure 3. Architectural Design of Hybrid Power System.

2.5 Cost formulation and calculations

The Optimization by HOMER software gives detailed reports which include a range of scopes from the renewable penetration to the present net capital cost of the RES. It permits the inputs of RES (such as sun irradiances, wind speeds), battery information, load demand information, capital and value related to in operation and maintaining costs(O&MC) prices among others, again analytic sensitivity modelling the impact on the RES to varieties in any input. For the generator, the O&MC is entered as an hourly value while for other components, the annual value of O&MC is entered in the HOMER software and that value is then multiplied by the yearly operation hours of the components. This helps to get annual O&MC of the RES [14].

The total operating cost is the annualized value of all costs and revenues other than initial capital costs of the RES is determined by using the following equation [15]:

$$C_{opt,tt} = C_{anl,tt} - C_{anl,cc} \quad (1)$$

where:

$C_{anl,tt}$ = the total annual cost $[R/yr]$

$C_{anl,cc}$ = the total capital cost annually $[R/yr]$

The COE is determined using the following formula below:

$$COE = \frac{C_{anl,tt}}{E_{prim} E_{dfr} E_{grid,sls}} \quad (2)$$

where:

$C_{anl,tt}$ is the total annualized value, E_{drf} is the total deferrable energy quantity of the load and E_{prim} is the primary energy that the system serves annually.

$E_{grid,sls}$ is the annual quantity of energy oversubscribed to the grid.

$C_{NPC,tot}$ (Total present net cost) is calculated by utilizing the subsequent equation:

$$C_{NPC,tot} = \frac{C_{anl,tt}}{CRF(i_{dr}, Rpjt)} \quad (3)$$

i_{dr} = actual discounted rate annually [%]

R_{pjt} = lifetime of the project $[yr]$

CRF = is the capital recovery factor given by the equation:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (4)$$

where i is the annual real interest rate and N is the number of years.

2.6 Component cost breakdown

The details of the components utilized to design the hybrid power system are shown in Table 2.Table 3 shows the costs of the components for the hybrid power system.

Table 2. Component details of Hybrid Power System.

Component	O&MC (R/yr)	Lifetime
PV	0	25 yrs
Wind Turbine	360	25 yrs
Batteries	7.92	10 yrs
Fuel cell	0.24	47,000 hrs
Electrolyzer	240	25 yrs
Hydrogen tank	0	25 yrs
AC/DC Converter	0	15 yrs

Table 3. Component cost details of Hybrid Power System.

Component	Size	Capital Cost (R)	Replacement cost (R)
PV	40 kW	23 098.80	0
Wind Turbine	25 kW	250 000.00	180 000.00
Batteries	1156 Ah	300 000.00	250 000.00
Fuel cell	10 kW	115 560.00	115 560.00
Electrolyzer	10 kW	30 720.00	30 720.00
Hydrogen tank	10 kg	16 024.00	16 024.00
AC/DC Converter	10 kW	21 080.00	19 800.00

3 Hybrid system composition

3.1 Solar components

To model the PV system for the selected hybrid system, the clearness index and the average solar irradiation of the data center location are considered for the HOMER simulation. The Standard Conditions (STC) test of solar panels where average solar irradiation is 6.197 $kWh/m^2/day$ and clearness index is 0.623 by data taken from Southern African Universities Radiometric Network in table 1.

The number of panels also have an important role in the cost and feasibleness analysis. The determining of the number of panels needed for the hybrid system, equation 5 is used and for this case, it is considered to be 12 panels:

$$N = \frac{P_{pv/day}}{E} \quad (5)$$

where P_{pv} is the energy produced daily and E is the power supply for one PV panel[15].

3.2 Wind turbine components

Any style of a turbine includes a theoretical maximum power potency of 58% (extracted energy carried out by a wind turbine cannot be more than 59% of wind passing through)[16]. Power coefficient is the phenomenon of the above statement and is defined as $C_{Pmax} = 0.58$. Wind turbines is not able to operate at its peak C_p. Each wind turbine type has a unique C_p and it represents the wind speed function that the turbine is operating in.

Furthermore, the components inside the wind turbine like the bearing and gearbox also have losses, which means the actual converted wind power into usable electricity is about 10-40%. The factoring of the power coefficient in equation 6 and power from the wind that can be extracted is given by[17]:

$$P = \frac{1}{2}\rho A v^3 C_p \quad (6)$$

where:

ρ is the Air density in kg/m^3, A is the rotor swept area in m^2, C_P is the Coefficient of performance and v is the wind velocity in m/s.

3.3 Fuel Cell components

A fuel cell consists of an electrolyte membrane sandwiched between two catalyst-coated electrodes the anode and the cathode. By redox chemical reaction a fuel cell acts like an electrochemical engine which produces electricity [18]. When hydrogen is passed through the anode electrode and oxygen (air) passed through the cathode electrode, electricity is generated with water, and heat being the byproducts [18].

Hydrogen fuel cells are very efficient but are also expensive to build. On a wide scale, hydrogen will not be used to produce electricity due to safety and huge costs [18]. On the anode side, the hydrogen gas is oxidized then releases electrons and creates H^+ ions as seen in equation 7. As seen in equation 8 on the cathode side, a reaction between the oxygen, electrons from the electrodes and H^+ ions from the electrolyte and water. In this process, water is the waste product and removed from the cell.

Anode side: $$H_2 \rightarrow 2H^+ + 2e^- \quad (7)$$

Cathode side: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow 1H_2O$ (8)

3.4 Electrolyzer components

An electrolyzer uses an electrochemical process called electrolysis which converts electrical energy into chemical energy to produces hydrogen by using electricity to split water into hydrogen and oxygen. In this project, the photovoltaic system generates electricity to power the electrolyzer to create a chemical reaction to produce hydrogen and supply the hydrogen tanks. The equations 9 and 10 show the anode and cathode reactions.

Anode side: $1H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$ (9)

Cathode side: $2H^+ + 2e^- \rightarrow H_2$ (10)

3.5 Battery storage components

For this system, the Surrette 6CS25P 1156Ah with a 6V Deep Cycle is chosen and it should be noted that this battery is a new generation series 5000 which has a very high capacity with features advantages like dual case, exchangeable cells, tiny footprint and an expected lifetime of ten years. The parameters that are associated with the mathematical model of the chosen battery are presented below.

B_{sc} = Battery storage capacity N_B = Number of batteries

E_d = Energy demand D_a = Autonomous operation days

V_S = System voltage Ah_R = Battery Amp-hour rating

$B_{sc_{total}}$ = Total battery storage capacity

The daily watt-hour of the load is multiplied by three (autonomous days) to allow for bad weather when the sun doesn't shine. This provides a buffer, in case the batteries are not recharged on a daily basis.

$$B_{sc} = E_d * D_a \quad (11)$$

The batteries should not discharge below 50%, B_{sc} is multiplied by 2. This will give the total battery capacity the system needs to store to run for three days.

$$B_{sc_{total}} = B_{sc} * 2 \quad (12)$$

The required total amount of battery storage capacity for the chosen system requires 1290000 watt-hours.

$$N_B = \frac{B_{sc/V_S}}{Ah_R} \quad (13)$$

By using the nominal capacity of the battery which is 1156 Ah, the number of batteries required is approximately 186 batteries to support the load of 9.96 kW on autonomous days (days that wind and solar cannot support the system due to lack of wind and sun).

4 System design results and discussion

Figure 6 indicates the total energy required to drive the data center and this is amount to 175601 kWh/yr. In this total, PV takes 51%, Wind is 46% and Fuel Cell (FC) is allocated with 2% of the total renewable energy for the year. In the case of the emission concentration, Figure 7 presents the environmental emissions such as Nitrogen oxides, Sulfur dioxide, Particulate matter, unburned hydrocarbons, carbon monoxide and carbon dioxide using the metric scale respectively. Figure 8 presents the levelized and operating cost of the hybrid system annually for the data center in the chosen region (Cape Town) respectively. The systems performance indicators using levelized and operating cost are cost effective when compared to a diesel generator driven data center which amounts to R2.82/kWh levelized cost and operating cost of R129357/yr.

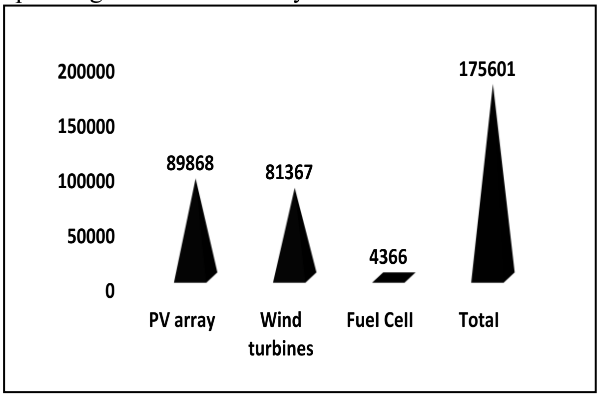

Fig. 6. Total yearly Electricity Production in kWh.

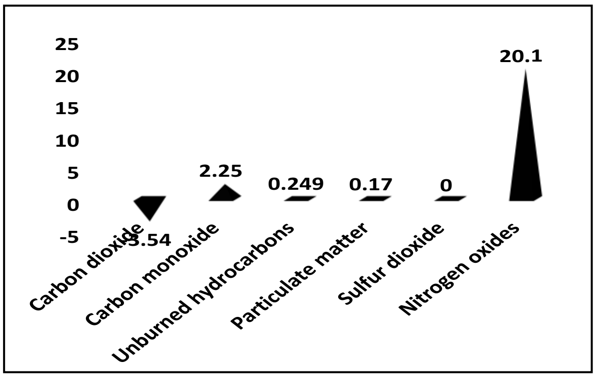

Fig. 7. Yearly Environmental Emissions Quantities

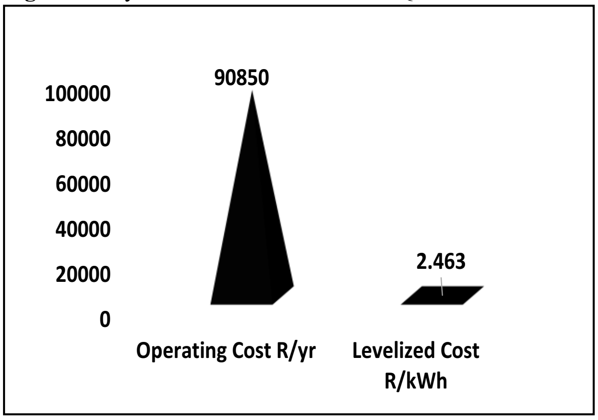

Fig. 8. Annualized Levelized and Operating Costs

5 Conclusion

Rising electricity prices and aging data centers are inflicting several businesses to require an awfully serious look into the energy potency of their computing infrastructure. The alternative sources of energy become the center of the business for the data center. Contained in the paper, is a micro-grid renewable energy system that consists of PV-Wind-FC is chosen. Based on the analysis of the system, the maintenance cost will be far less because the RES system requires less maintenance when compared to diesel generators. As a result of the aforementioned, fuel cell is chosen to acts as a backup power supply for the data center. Moreover, if the hybrid system fails to support the data center, the battery bank will provide the data center load autonomously for three days and twenty-three hours. From the results, the data center could save (885kg/yr) of CO2 emissions annually in Cape Town by removing backup diesel generators used by data centers, and this advantage will reduce the impact of greenhouse gases produced by data centers. Therefore, when RES are utilized in a hybrid system to power data centers, it will decrease the operating cost and will bring down the greenhouse gas emission that damage the environment. The simulation results showed that the solar power system can save 49.6% of the total Net Present Cost (NPC). These results indicate that the solar power system is a good choice for data centers, followed by the wind energy in order to reduce both the operational expenditures and greenhouse gases for any data center applications in other remote locations in the country.

References

1. C. Nazir. Coastal power plant: a hybrid solar-hydro renewable energy technology. Clean Energy, 2018.
2. B. Ristic, K. Madani and Z. Makuch, "The Water Footprint of Data Centers", Sustainability, vol. 7, no. 8, pp. 11260-11284, 2015.
3. S. Mishra., N. Mathur.: ‘Load Balancing Optimization in /-A Cellular Networks: A Review’, arXiv preprint arXiv:1412.7273, 2014.
4. M.H Alsharif., , R. Nordin., and M. Ismail.: ‘A review on intelligent Data center cooperation management techniques for greener cellular networks’, Journal of Communications, 2014, 9, (12), pp. 937-945.
5. A. Comninos., S. Esselaar., A. Ndiwalana., and C. Stork.: ‘Airtime to cash: unlocking the potential of Africa's mobile phones for banking the unbanked’, 2009.
6. G. Fettweis., E. Zimmermann.: ‘ICT energy consumption-trends and challenges’, in Editor (Ed.)^(Eds.): ‘Book ICT energy consumption-trends and challenges’ ((Lapland, 2008, edn.), pp. 6.
7. R. Gasch., J. Twele.: ‘Wind power plants: fundamentals, design, construction and operation’ (Springer Science & Business Media, 2011. 2011).
8. M. Khodayar, "Rural electrification and expansion planning of off-grid microgrids", The Electricity Journal, vol. 30, no. 4, pp. 68-74, 2017.
9. S. Sinha., Chandel, S.: ‘Review of software tools for hybrid renewable energy systems’, Renewable and Sustainable Energy Reviews, 2014, 32, pp. 192-205.
10. C.P. Castillo., B.F. e Silva. and C. Lavalle. (2016). An assessment of the regional potential for solar power generation in EU-28. Energy Policy, 88, pp.86-99.
11. S.B. Darling., F. You., T. Veselka., and A. Velosa.: ‘Assumptions and the levelized cost of energy for photovoltaics’, Energy & Environmental Science, 2011, 4, (9), pp. 3133-3139.
12. B. Zakeri., and S. Syri.: ‘Electrical energy storage systems: A comparative life cycle cost analysis’, Renewable and Sustainable Energy Reviews, 2015, 42, pp. 569-596.
13. T. Lambert., P. Gilman., and P. Lilienthal.: ‘Micropower system modeling with HOMER’, Integration of alternative sources of energy, 2006, pp. 379-418.
14. V. Khare, S. Nema. & P. Baredar. (2015) Optimisation of the hybrid renewable energy system by HOMER, PSO, and CPSO for the study area, International Journal of Sustainable Energy, 36:4, 326-343, DOI: 10.1080/14786451.2015.1017500.
15. C. Wang., M.H. Nehrir., and S.R. Shaw.: ‘Dynamic models and model validation for PEM fuel cells using electrical circuits’, IEEE transactions on energy conversion, 2005, 20, (2), pp. 442-451.
16. D.W.R. Thompson.: ‘Incorporating renewable energy in a desalination plant: case study in El Paso, Texas’, 2017.
17. M. Şenol., S. Abbasoğlu., O. Kükrer., and A. Babatunde.: ‘A guide in installing large-scale PV power plant for self-consumption mechanism’, Solar Energy, 2016, 132, pp. 518-537.
18. Z. Xia, S. Wang, L. Jiang, H. Sun, S. Liu, X. Fu, B. Zhang, D. Sheng Su, J. Wang and G. Sun, "Bio-inspired Construction of Advanced Fuel Cell Cathode with Pt Anchored in Ordered Hybrid Polymer Matrix", Scientific Reports, vol. 5, no. 1, 2015.