Performance analysis of a microgrid-connected photovoltaic/wind hybrid system's

1st K.Sumalatha
Research Scholor,Department of Electrical & Electronics Engineering,KU College of Engineering & Technology, Kakatiya University Campus,Warangal, India suma.kucet@gmail.com
2nd Dr.K.Cheena
Assistant Professor,Department of Electrical & Electronics Engineering, University College of Engineering, Kakatiya University Campus,Warangal, India.korrachinna@gmail.com

Abstract:

Future power systems are going to need to take microgrids into consideration more and more. In this study, the system under consideration is made up of two energy sources: solar and wind. In a microgrid system, these renewable energy sources are often connected in parallel. The current system has to be changed in order to improve Microgrid performance. The modelling and management of a PV/wind microgrid are presented in this tudy. The research clearly presents the selection of a suitable wind turbine and an AC or DC Microgrid. The microgrid idea combines a significant number of micro sources without interfering with the main utility grid's functioning. For the DC and AC networks of this hybrid microgrid, there are PV and wind energy sources. Systems for storing energy can be connected to AC or DC microgrids. In terms of power management, the system is modelled and simulated, and both its functioning and the effectiveness of the dispatch method are evaluated. The model accurately depicts the microgrid's behaviour, and many changes are recommended. In contrast to DC sources and loads, which are connected to a DC network, AC sources and loads are connected to an AC network. The system model and operation also take into account the irregular and intermittent nature of wind speed, solar irradiation level, ambient temperature, and load.

Keywords: Microgrid, PV Energy, Wind Energy, Wind speed, solar irradiation, and temperature.

I Introduction

The need to fulfil the global community's growing need for energy has become a major global concern. Furthermore, rapid study into renewable energy sources has become necessary due to the conventional power sources' quick depletion and exhaustibility[1]. Photovoltaic and wind energy have received the greatest attention and are the most promising power technology for generating electricity among renewable energy sources. Large generators may be used to create a lot of electricity by harnessing wind energy. Additionally, as it is free, clean, and available everywhere, PV energy has demonstrated tremendous promise as a promising power source to produce electricity[2]. It can also be used without emitting any pollutants. However, as they are irregular in nature and highly reliant on environmental factors like fluctuations in solar irradiation and wind speed, both wind and PV energy have drawbacks of their own. In order to overcome the irregular nature of these renewable energy sources and provide more dependable, higher-quality electricity for the electrical grid and rural regions, a PV/wind hybrid power system can be used[3], [4].

Globally, the low and medium DG network is rapidly improving. They are run by renewable, irregular generators that include solar networks, wind turbines, and power modules[5]. They are frequently used to expand the utility network during peak hour stack, when that period of time is equivalent to an energy shortage. Additionally, they can aid with control if the basic network lattice fails.

Due to the development and usage of renewable DC power sources as well as the benefits of DC loads in commercial, industrial, and residential applications, DC grids are currently seeing a resurgence[6]. DC microgrid has been offered as a way to interact with the many dispersed generators. However, in order to connect AC sources to a DC grid, they must first be converted into DC, therefore standard AC loads need the use of DC/AC inverters. when renewable energy sources can completely meet all of the world's energy needs. It is no longer essential to transmit HV over great distances[7], [8]. AC The use of micrograms is recommended to make it easier to connect AC systems to renewable power sources. However, DC/DC boosters and DC/AC inverters connected to an AC grid are required to convert the DC output power of photovoltaic (PV) panels into AC. In this study, a hybrid AC/DC micro grid is presented to decrease the number of reverse conversion operations in a single AC or DC grid and to make it easier to connect different renewable AC and DC sources and loads to the power grid[9], [10]. The control coordination strategies[11]. When the hybrid grid is operating in both grid-tied and islanding modes, various modes are proposed to maximise the power from renewable energy sources, reduce power transfer between AC and DC networks, and maintain the stable operation of both AC and DC grids under variable supply and demand condition[12,18]s. The use of cutting-edge power electronics and control technology can provide a grid that is considerably smarter in the future. In the upcoming years, every home will have a self-contained, uninterruptible renewable energy system with the capacity to function in both grid-connected and island mode operations[13,22]. By utilising this technique, it will be possible to create a seamless transition between different modes[14], [15]. The algorithmic rule for landing detection and resynchronization would be challenging.[11,24].

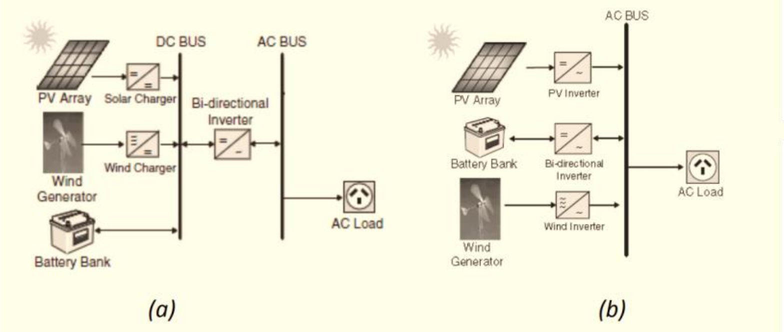

Fig 1. Parallel configuration of (a) a DC and (b) an AC coupled microgrid.

Motivation of research

In order to ascertain the viability and advantages of microgrids, several research organisations have invested a great deal of time and effort in their analysis.

Although the fundamentals of microgrids are widely understood, system execution is not always fully grasped.

Aim and Purpose

The goal of the study is to redesign and alter the photovoltaic system in the micro grid. The choice of wind turbines is based on the microgrid's needs and the control strategies employed for the various types of connectivity. The goal of the task is to analyse the hypothesis that is suggested by the study's historical context and to make sure that its conclusions can shed light on new ideas and support the revision of standards[16,21,23].

II Photovoltaics

Depending on the purpose of the task, the method used, the area of focus for the research, and many other considerations, there are several approaches to model a system and the photovoltaics that make up its components. The same is true when simulating a solar photovoltaic system. Two of the six approaches for modelling a solar cell that are described in are primarily concerned with creating voltage and current as outputs. Here, however, the focus is on the solar array's electricity generation. Real datasheets from the manufacturers have been utilised for all calculations and parameter selection for both the solar panel and the power electronics.

Initially, equation (1) is used to determine the power produced by one solar panel, P1pv:

$$P_{1pv} = f_v * P_{STC}\frac{G}{G_{STC}}\left[1 + k_p\left(T_{emp} - T_{STC}\right)\right]$$

Where,

$\mathcal{F}_v$: A derating factor of about 0.9 to take into consideration various system losses like shading, ageing, or wire losses

P_{STC} : Rated power under standard test circumstances = 255W

G : Immediate Solar Irradiance

G_{STC} : Standard Test Conditions Solar Irradiance = 1000 W/m^2

K_p : For the Canadian Solar CS6P-255 | 260P solar panel, temperature coefficient linked to power = -0.43 % / ^{0}C

T_{emp} : Current temperature

T_{STC} : Temperature for Standard Test Conditions = 25 ^{0}C

To achieve an installed output of around 40 kW, 156 photovoltaic panels are used in total. The solar panels are divided into two distinct teams and linked to two different converters and inverters, each of which has a nominal power of 20kW. Additionally, the open circuit voltage and short circuit current of the solar panels are also taken into consideration.

Thus, each photovoltaic array's power output is as follows: $P_{1ph.a.} = \frac{N_P}{2} P_{1pv}$

The converter and subsequently the inverter get this electricity. The ratio of the power that the power electronics transfer $P_{1ph.a.}$ over the specified power P_{inv_rated} determines how efficient they are. This dependency is provided by the Sunny Tripower Inverter from SMA Solar Technology, and the efficiency varies with the output power ratio $\frac{P_{1ph.a}}{P_{inv\_rated}}$. Through a look-up table, the model incorporates this.

Table 1: Efficiency profile of the Photovoltaics inverters:

Output Power Ratio %	**Efficiency %**
5	94.0
10	96.6
20	97.8
30	98.0
40	98.1
60	98.2
80	98.4
100	98.1

Consequently, the photovoltaic system's total power output is equal to $P_{PV} = 2 * \eta_{p.e.} * P_{1ph.a.}$ In this instance, Figure 2 serves as an illustrative representation of how the model mentioned above was implemented in Simulink.

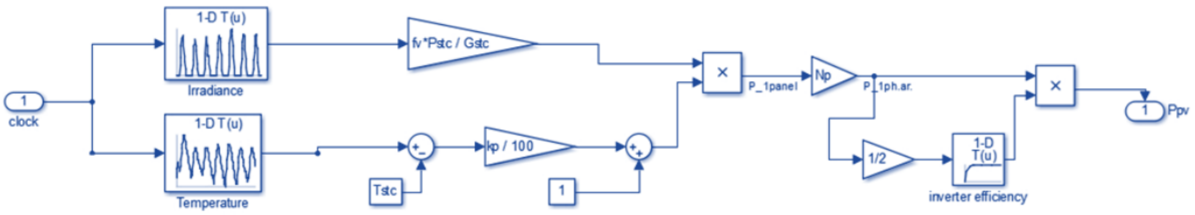

Fig 2. The P_{pv} calculations at the Simulink model

III Wind Turbine

The wind turbine power output is estimated and added to the model using a similar logic as before. The wind turbine was designed with affordability and robustness in mind. It features a horizontal axis, a nominal output of 10 kW, and a permanent magnet synchronous generator. The model employed in this study as a data source is the SW-1O kW tiny wind turbines. Figure 3 provides the power curve for this wind turbine as it appears in the datasheet. Small wind turbines typically have this type of curve, where the rated power is reached at a somewhat higher value at 11 m/s of wind speed. However, in this model, the power of the wind turbine is taken into account to be stable for wind speeds greater than the nominal.

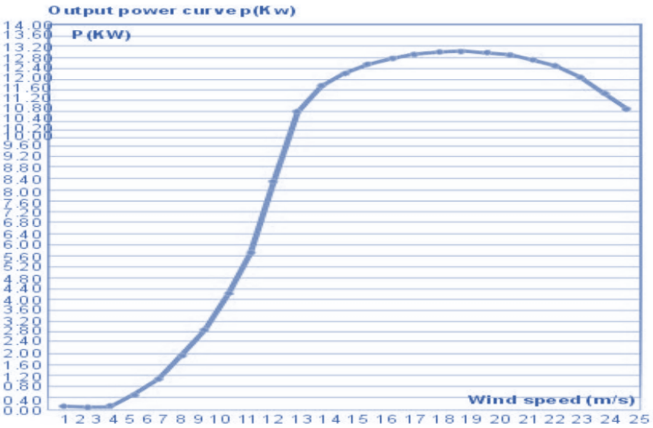

Fig 3. Power source curve of SW-10 KW according to the datasheet.

$$P_{wt} = 0 \qquad \text{when} \quad V_w < V_{cut-in}$$

$$P_{wt} = \frac{1}{2} c_p(\lambda, \beta) * \rho(z) * A * {V_w}^3 - P_{in} \qquad \text{when} \quad V_{cut-in} \leq V_w \leq V_{rated}$$

$$P_{wt} = P_{wt\_rated} \qquad \text{when} \quad V_{rated} \leq V_w$$

$$P_{wt} = 0 \qquad \text{when} \quad V_{cut-out} \leq V_w$$

Where,

V_w : Instantaneous wind speed

V_{cut-in} : Cut-in wind speed, = 3 m/sec

V_{rated} : Rated wind speed, = 10 m/sec

$V_{cut-out}$: Cut-out wind speed, = 3 m/sec

ƛ : Tip speed ratio

when

$$ƛ = \frac{w_{rotor} * R_{ad}}{V_w} = \frac{2\pi * n_{rotor} * R_{ad}}{60 * V_w}$$

Where

W_{rotor} : Angular spped of rotor, rad/sec

n_{rotor} : Rotational spped of rotor, rpm

R_{ad} : Radius of rotor, = 3.5 m

A : Area swept by the rotor, $A = R_{ad}^2$

B : Pitch angle, here it is steady and equal to zero.

C_p : Aerodynamics power coefficient.

$$C_p = 0.73 * \left(\frac{151}{\lambda_i} - 0.58 * \beta - 0.002 * \beta^{2.14} - 13.2\right) * \exp\left[\frac{-18.4}{\lambda_i}\right]$$

Where

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^2 + 1}}$$

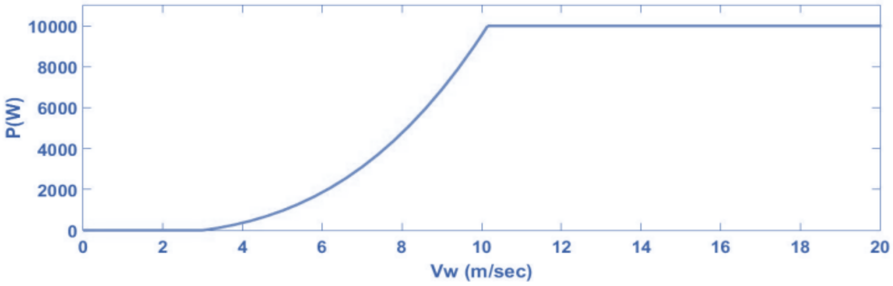

Fig 4. Power output curve of Wind turbine acc to Eq 4.

The power electronics, which operate as the link between the wind turbine and the microgrid's main bus, multiply this power by the generator's efficiency factor Ƞwg=0.9 and then by the efficiency factor of the power electronics. The wind turbine's output is first corrected, and then it is inverted once more. In Table 2, where Ƞgint is the efficiency of the interface between the generator and the inverter, whose efficiency is Ƞinv, their efficiency factors are determined based on their datasheets as well.

Table 2. Efficiency profile of the wind turbine's power electronics

Ƞgint %	**Ƞinv %**	**Loading percentages**
96	94	0.05
96.6	95.3	0.1
97.8	95.4	0.2
98.2	96.2	0.25
98.1	96.4	0.3
98.3	96.3	0.5
98.4	96.2	0.75
98.1	97	1

The part of the model that calculates the power generated by the wind turbine is shown in Figure 5.

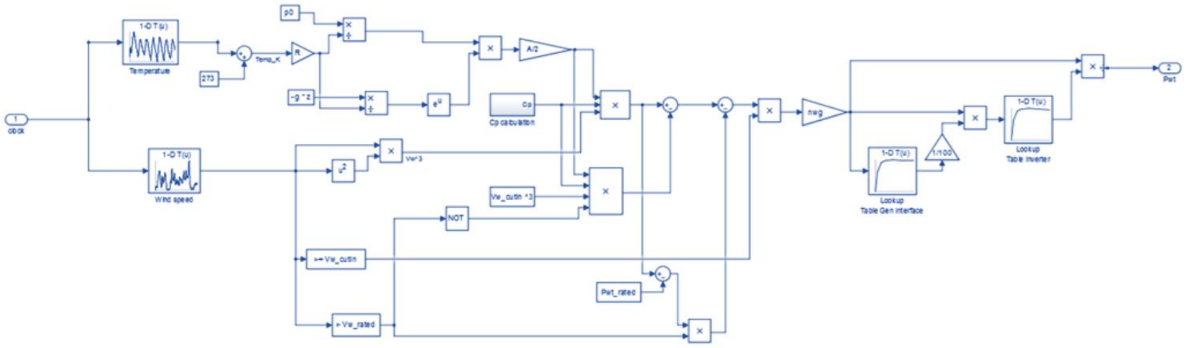

Fig 5. The Pwt is calculated at the Simulink model.

IV Results and Discussions

Different scenarios can be simulated to better understand how the system behaves in various situations. In this section, many instances are defined in a way that covers a variety of circumstances with various potentials for the generation of electricity from renewable sources. The temperature, irradiance, and wind speed throughout the year are all represented by a variety of meteorological data. The case studies may be defined using this data as a foundation as shown in below figures 6 and 7.

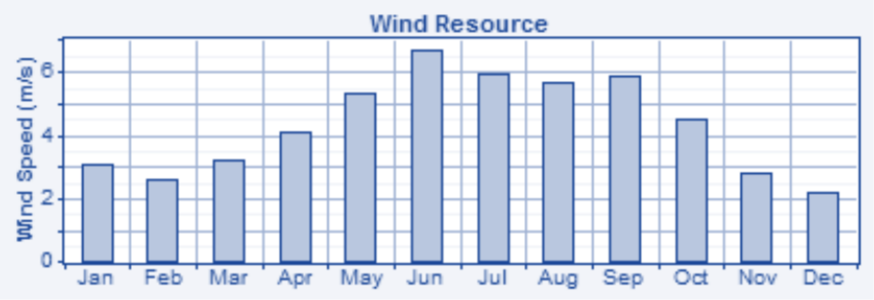

Fig 6. Average monthly values of wind speeds

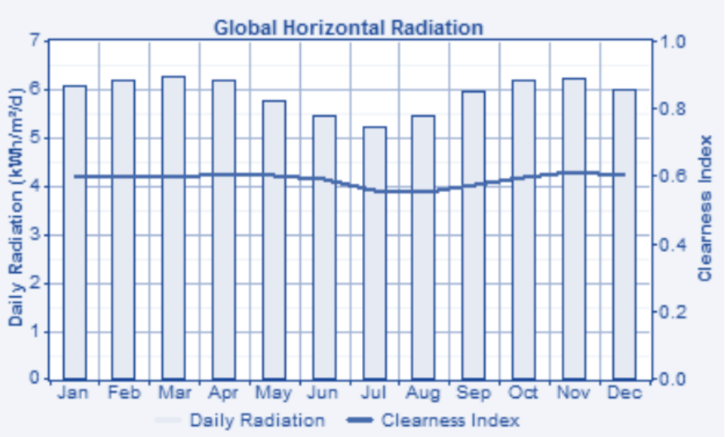

Fig 7. The average daily irradiation readings for each month.

When comparing the two graphs, it can be seen that the solar energy fluctuates far more than the wind speed over the course of a year, indicating that the electrical power supplied by wind turbines varies significantly more than that from solar photovoltaics.

The simulation will run for two days (48 hours), with varying inputs for irradiance, temperature, wind speed, and primary load. But because of how it has been defined, the latter one does not fluctuate significantly throughout the course of the year.

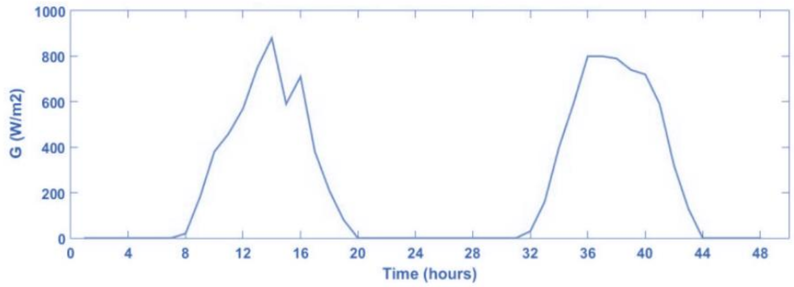

Fig 8. Solar irradiance at case 1.

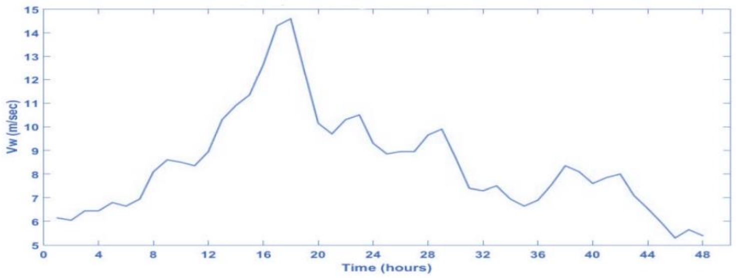

Fig 9. Wind speed at case 1.

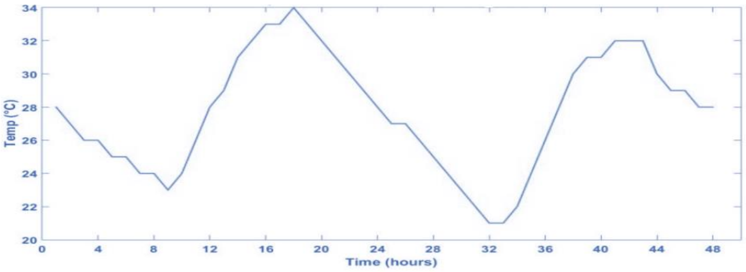

Fig 10. Ambient temperature at case 1.

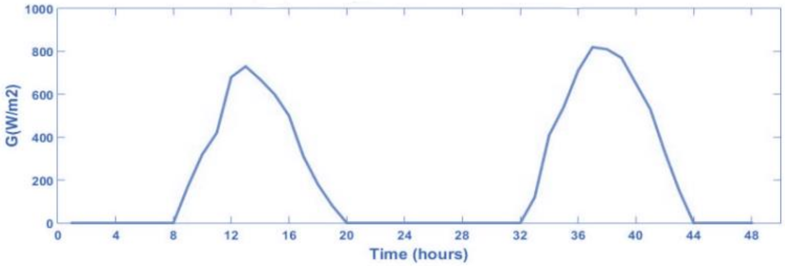

Fig 11. Solar irradiance at case 2.

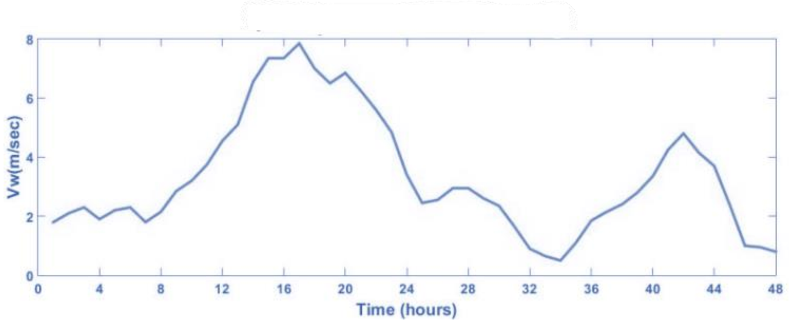

Fig 12. Wind speed at case 2.

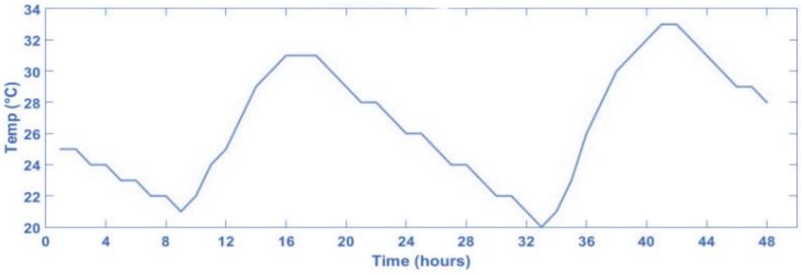

Fig 13. Ambient temperature at case 2.

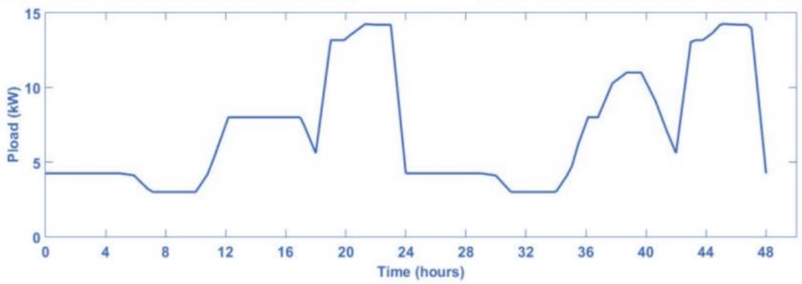

Fig 14. Primary load at case 1.

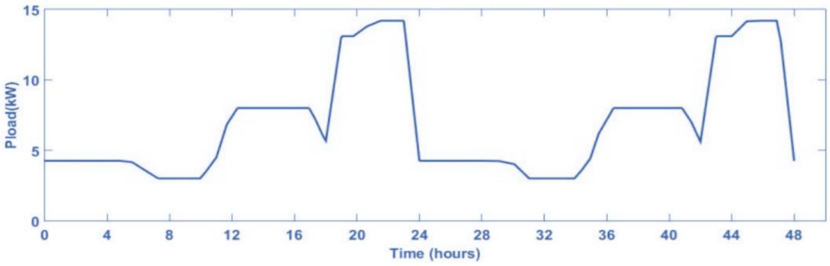

Fig 14. Primary load at case 2.

Case (i) comprises two days (48 hours), when the year's peak level of electrical power output is attained. The storage bank is at 80% of its nominal capacity at time t = 0 hours, the diesel generator is not running, and the deferrable load is not engaged.

First, Figure 15 contains the graphs relating to electricity generation. It is clear that the photovoltaics have a high output rate and that the wind turbine reaches its peak power (equal to the nominal) about noon on the first day of the experiment. Figure 16 shows the power demand for the primary load P_{load}, whereas Figure 17 plots the signal for the power differential P_{dif}. This parameter shows the discrepancy between the amount of energy generated by renewable sources (P_{pv}+P_{wt}) and the amount of energy needed (P_{load}).

At Figure 17, the light green line crossing y-axis at P=0 'separates' the conditions of power excess and power deficit. When P_{dif} is positive, the produced power is higher than the one consumed by the users. On the contrary, when P_{dif} is negative, then the power produced at that time is not enough to cover their needs. Each one of these conditions triggers a series of different actions, aiming towards the better and stable management of power in the system. Nonetheless, it is visible in Figure 17 that during this month, when the performance of both energy sources is high enough, the magnitude of P_{dif} is significant and potentially problematic in terms of management and stability issues.

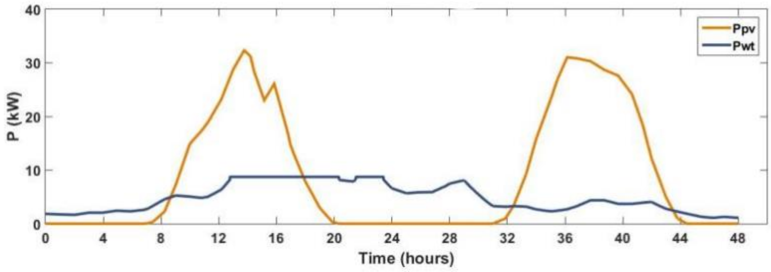

Fig 15. Produced power by Pv and wind turbine at case 1.

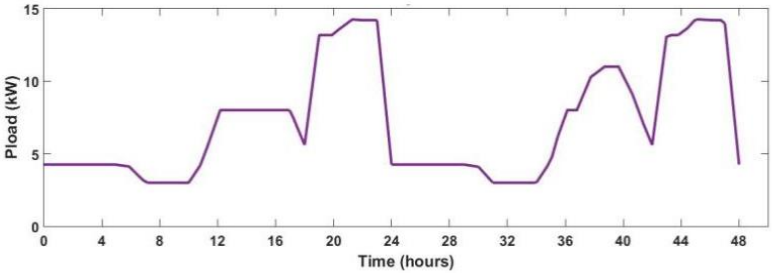

Fig 16. Power demand at case 1.

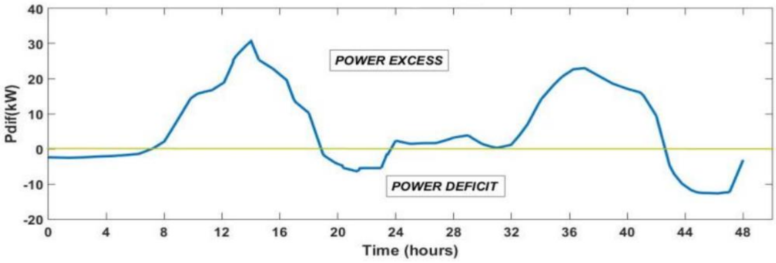

Fig 17. Power difference signal at case 1.

V Conclusion

A hybrid power system with Pv and wind was created, modelled, and tested for this project. It was created with the intention of economically and technologically providing for the fundamental necessities of the locals in terms of electrification and clean water. To have a clearer sense of how it operated and its strengths and shortcomings, it was modelled and simulated. In order to define a representative load curve for the hamlet, which included basic loads for families, streetlight loads, primary school loads, and water pumping and purification loads, literature research was first carried out. A collection of weather information for the area was made, including sun irradiance, temperature, and wind speed. An detailed study was conducted to establish the prices of the basic components of the hybrid system—photovoltaics, and wind turbines. An hybrid microgrid consisting of 40 kWp photovoltaics, 10 kW wind turbine, 9.5 kW diesel genset, batteries with a total capacity of 6.936 kAh, the primary load of the village, and water pumping and purification as the deferrable load was then created using the HOMER software. It became clear during this process how crucial it is and how challenging it may be to get representative and trustworthy information and data in order to estimate the power consumption in a region that had not yet been electrified, as well as locate trustworthy information on the prices and the given equipment.

To demonstrate the consequences of implementing this operational approach in the operation of the system and its performance across several seasons of the year and under various weather conditions, the simulations were extended into time windows of several days. Thus, the three distinct occurrences took place over the course of two days.

A focus was placed on managing power when there was an excess or deficit in the system throughout the results analysis. Various graphs were utilised to show how the various components operated. In the first scenario, the additional power would either be discharged or used to charge the batteries, activate the deferrable load, or both. The issue of electricity being dumped during times of high production existed, and many solutions have been proposed that may increase the microgrid's overall effectiveness. The potential to use the extra electricity in the favour of the locals by adding a wheat mill or pumping additional water was looked into, with promising outcomes. In general, the model implemented the planned approach and gave a realistic impression of the microgrid's performance.

VI Future work

The work that has been completed within the context of this study can serve as the foundation for a variety of upcoming projects.

The mechanism regulating the battery's charge rate can be enhanced further in terms of modelling. Additionally, the way the model is constructed makes it easier to incorporate phasors and to put the fundamentals of droop control into practise (using the inverters' characteristic curves). Reactive power will also be considered if this is done, and further components of control will be looked at.

Moreover, a centralised strategy has been used in terms of the sort of control. However, using a decentralised control strategy like multi agents might be beneficial and lead to some truly intriguing developments in the functioning of the microgrid.

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