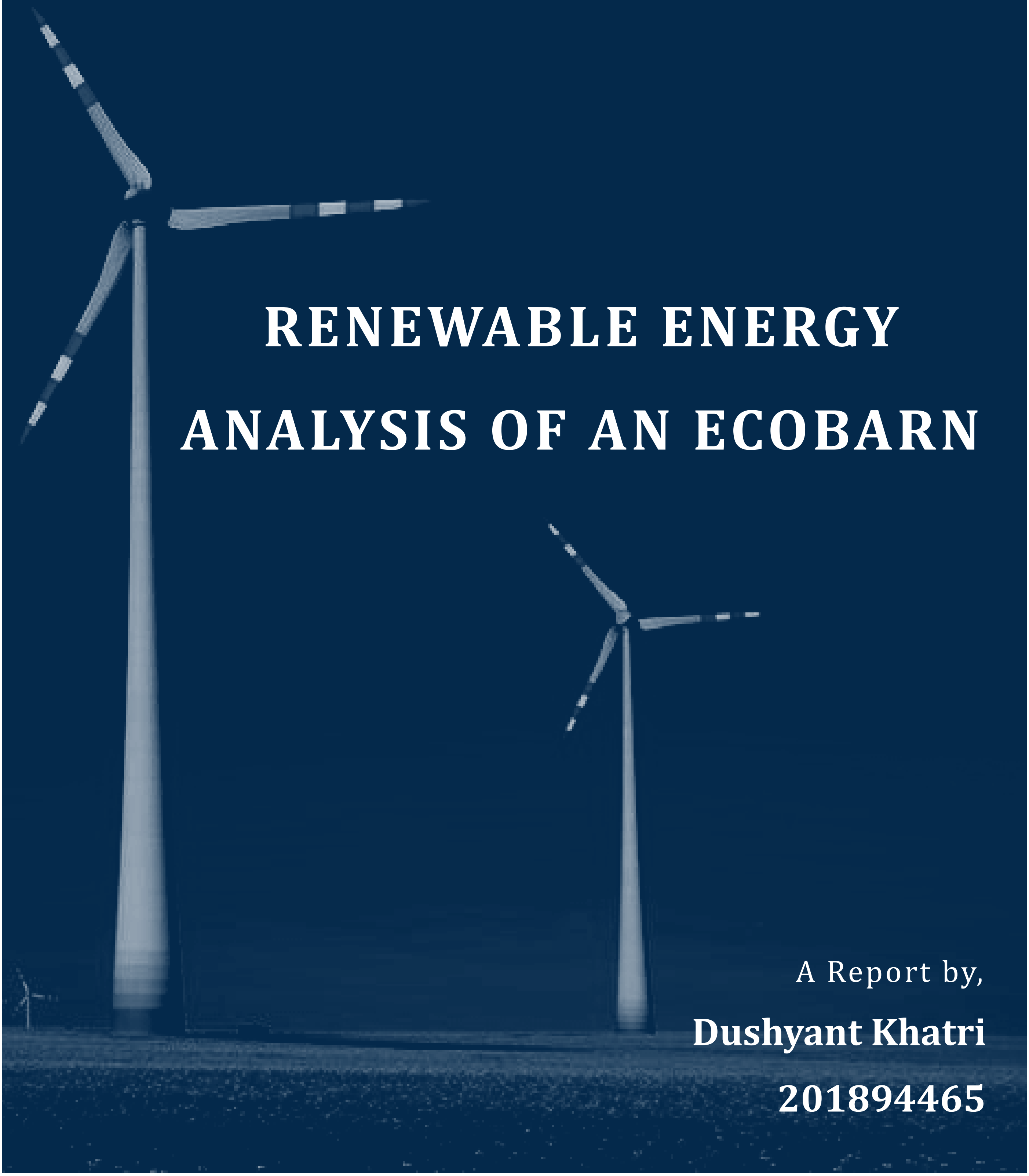
ME930: Energy Modelling and Monitoring



RENEWABLE ENERGY ANALYSIS OF AN ECOBARN

A Report by,

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INTRODUCTION

A renewable energy system uses natural resources such as sunlight, wind, tides, geothermal heat, which are naturally replenished (National Energy Foundation, 2018). Since the story of modern renewables began in the 1970s, they have grown much faster than mainstream energy analysts have predicted (Aklin, 2018). Over the years, renewable energy resources have been investigated in comparison to the present energy generation technologies in recognition of reducing the carbon footprint from the planet (Kaltschmitt, Streicher and Wiese, 2007), however, there were drawbacks discovered of these technologies (Bgo, 2010). In the present day, the main drawbacks – low intensity and intermittent nature – have been eliminated (Bgo, 2010). By considering all the above, it can be anticipated that the growth of renewable energy generation worldwide is near the time. In fact, some countries of the world have already moved towards this change, for instance, the wind energy resource contributed in the first quarter of 2018 was 44 per cent more than what was generated in 2017 for the same period, and further indicates that by 2020, the country will rely 100 per cent for its energy supplies (Frangoul, 2018).

There are various resources of renewable energy – wind, photo-voltaic (PV) solar, fuel cells and hydrogen technology, geothermal, and ocean energy (Sayigh, 2012). In this report, the wind and solar energy systems are explored and analysed. Therefore, this report restricts description and analysis to these two resources. The exploitation of wind energy may be determined as an environmentally friendly approach to covering energy needs, than conventional energy sources such as nuclear, coal, and oil (Kaldellis, 2012). Kaldellis and Kapsali (2012) observe the past statistics of wind energy growth worldwide and analyse future projections to indicate that the target set of achieving 1 TW of wind power installations by 2030 seems feasible. This signifies that wind energy systems can potentially substitute the current energy generation technologies in the future.

The solar power (PV) has become better and cheaper over the years, and this is evident by observing the statistics of annual PV production to be consistently increasing from 1990 to 2010 (van Sark, 2012). Lamont (2012) states that 119 countries worldwide embraced solar energy in 2011 and concludes her study by indicating that mankind should aim for solar power to be a primary fuel of the future and not an 'alternative'. Along with its future anticipation, it is important to mention its features on generating adequate energy and environmental-friendliness. The International Energy Agency (2011) mentions solar energy as ubiquitous, sustainable, inexhaustible, less polluting, and having an edge over fossil-fuel price volatility. Along with other renewables, it can drastically reduce energy-related GHG (Greenhouse Gas) emissions (International Energy Agency, 2011).

With the above description of wind and solar energy, their features, and anticipating their future potential, these renewable sources are anticipated to be promising future energy systems to be adopted worldwide in the coming years. Considering its potential, this report involves analysing and evaluating these energy systems in fulfilling the energy demands of a sustainable building. This is performed by the use of software called 'Merit', developed by the Energy Systems Research Unit (ESRU) at the University of Strathclyde (Energy Systems Research Unit, 2018). The software supports the development of new and renewable energy schemes by searching for matches between user-specified demand profiles and possible supply technologies when deployed separately and in any combination, with an in-built knowledge about typical energy demands and the different possible supplies (Merit, 2018).

> 'MERIT has been designed to be as flexible and generic as possible, so that it can be easily applied to varying size and local energy resources throughout the world.'
>
> \- (Smith *et al.*, 2001)

DESCRIPTION OF THE PROJECT

The project involves on the construction of a sustainable building or an Ecobarn, which relies on energy supply by an off-grid wind/solar hybrid energy system. As the building would be situated near the Scottish borders, the most appropriate climate data from the database could be selected as 'Dundee'. The energy demand profile is a pre-defined data named as 'ecobarn' from the database. The energy systems used in the analysis are tabulated in Table 1.

Table 1 - Energy System Particulars

Wind Energy		Solar Energy	
Model	Power (KW)	Model	Power (kW)
WT600	0.6	SM100	1
WT2500	2.5	SM100-24	1
WT6000	6	SM110	1.1
WT15000	15	SM110-24	1.1

Objectives

The project is categorised into two achievable objectives, listed as follows:

1. To investigate the specification of energy generation and reserve equipment required within the hybrid energy system proposed for the Ecobarn building.
2. Further to achieving the results, to evaluate the energy systems in terms of:
   (a) Providing a reliable all-year round energy supply,
   (b) Minimising capital costs of the system,
   (c) Accommodating any future increases in energy demand, and
   (d) Minimising energy wastage caused due to excess energy generation.

The overall purpose of this report is to investigate and evaluate the potential and the feasibility of an off-grid hybrid wind/PV renewable energy system to power the Ecobarn building.

Assumptions

The following assumptions are made in order to fulfil the project objectives in the given timeframe and in order to limiting the analysis to the scope of the project:

1. All the resources of renewable energy are not considered in this study, and the analysis is limited to the ones which are deemed to be concurring with environmental and financial factors of the current project. As the project objectives indicate that a wind/PV renewable energy system is employed, the analysis is limited to this consideration.

2. By all the considerations described on the software, it is assumed that Merit is a suitable software for performing the analysis/simulation.

3. By all the data stored in the software records and data modified as defined in the project guidelines, these are considered accurate for the purpose of fulfilling the objectives.

4. For capital costs of different wind energy systems that are not explicitly mentioned in the project guidelines, the costs are calculated from known energy systems by linear interpolation considering their Power (kW) as a primary function. Although it is acknowledged that this purely theoretical and does not likely correlate realistic cost figures due to construction material difference, manufacturing and timescale differences, or any other function that may affect the cost in practice, adopting this assumption would follow fulfilling the project objectives in a simplistic manner. For all the types of PV panels considered for analysis, the costs are assumed the same as given in the

project guidelines for its simplicity. For all types of auxiliary energy systems/storage systems, the costs are assumed the same. All the capital costs are tabulated in Table 2.

Table 2 - Cost Particulars

Wind Energy		Solar Energy		Electrical Storage	
Model	Cost	Model	Cost	Model	Cost
WT600	£1,250	SM100	£180	105/12	£300
WT2500	£7,008	SM100-24	£180	120/12	£300
WT6000	£16,820	SM110	£180	130/12	£300
WT15000	£42,050	SM110-24	£180	145/12	£300

METHODOLOGY

Objective One

In order to fulfil this objective, the following cases (Table 3) are considered, where the PV panels are of the format <Power_Voltage> and the storage systems (auxiliary) are in the format <Storage Capacity/Voltage>. The number outside the brackets indicating the energy systems are the number of systems used for analysis. The first term is the wind/solar energy system and the second term is the storage system.

Table 3 - Combinations considered for each case in analysing the energy systems

Case 1	Case 2	Case 3	Case 4	Case 5
$[10 \times (100\_12)] + [3 \times (145/12)]$	$[9 \times (110\_12)] + [3 \times (105/12)]$	$[8 \times (100\_24)] + [3 \times (120/12)]$	$\begin{pmatrix} 2 \times (100\_12) \\ 2 \times (100\_24) \\ 2 \times (110\_12) \\ 2 \times (110\_24) \end{pmatrix} + \begin{pmatrix} 105/12 \\ 120/12 \\ 130/12 \end{pmatrix}$	$\begin{pmatrix} (100\_12) \\ 2 \times (100\_24) \\ 2 \times (110\_12) \\ 2 \times (110\_24) \end{pmatrix} + \begin{pmatrix} 105/12 \\ 120/12 \\ 130/12 \end{pmatrix}$
Case 6	**Case 7**	**Case 8**	**Case 9**	**Case 10**
$\begin{pmatrix} 2 \times (100\_12) \\ 2 \times (100\_24) \\ (110\_12) \\ (110\_24) \end{pmatrix} + \begin{pmatrix} 120/12 \\ 130/12 \end{pmatrix}$	$\begin{pmatrix} 3 \times (100\_12) \\ 3 \times (110\_12) \end{pmatrix} + \begin{pmatrix} 105/12 \\ 120/12 \\ 130/12 \\ 145/12 \end{pmatrix}$	$\begin{pmatrix} 4 \times (100\_12) \\ 4 \times (110\_12) \end{pmatrix} + \begin{pmatrix} 105/12 \\ 120/12 \\ 130/12 \end{pmatrix}$	$\text{WT2500} + \begin{pmatrix} 105/12 \\ 120/12 \\ 130/12 \end{pmatrix}$	$\text{WT6000} + \begin{pmatrix} 145/12 \\ 120/12 \\ 130/12 \end{pmatrix}$
Case 11	**Case 12**	**Case 13**	**Case 14**	**Case 15**
$\text{WT15000} + \begin{pmatrix} 105/12 \\ 120/12 \\ 130/12 \end{pmatrix}$	$\text{WT600} + [3 \times (145/12)]$	$\begin{pmatrix} \text{WT600} \\ 4 \times (110\_12) \end{pmatrix} + [3 \times (145/12)]$	$\begin{pmatrix} 3 \times (100\_24) \\ 3 \times (110\_24) \end{pmatrix} + [2 \times (145/12)]$	$\begin{pmatrix} \text{WT600} \\ 5 \times (110\_24) \end{pmatrix} + [2 \times (335/6)]$

It can be noted that Case 15 has an unusual storage system than the rest of the cases. This is employed to verify the impact of adopting a storage system with different technical feature on the overall design. The results for the analysis performed are discussed further in the report, where the parameters percentage match, total supply (in kWh), total demand (in kWh), surplus (in kWh), deficit (in kWh), and capital costs (in £) are achieved by using the software. All the power unit parameters are calculated over a period of one calendar year.

Objective Two

Once the results for the first objective are tabulated, the scope of the project remains restricted to the combinations analysed, and therefore, these are evaluated for each of the four criteria defined in the Objectives section, earlier in this report. It is to be noted that not all the cases are discussed in detail and plotted in the form of a graph, and only the cases that are deemed to align with criteria are interpreted further.

RESULTS

Objective One

Table 4 - Result table of the demand/supply match analysis

Case No.	% Match	% Match comment	Total supply (kWh)	Total Demand (kWh)	Surplus (kWh)	Deficit (kWh)	Capital Cost (£)
1	57.73%	Poor	1000.00	815.08	319.36	188.27	£2,700
2	61.91%	Reasonable	986.43	815.08	294.82	210.39	£2,520
3	56.62%	Poor	913.23	815.08	267.62	233.14	£2,340
4	58.59%	Poor	902.34	815.08	246.14	230.59	£2,340
5	60.43%	Reasonable	802.27	815.08	177.70	255.33	£2,160
6	62.42%	Reasonable	665.39	815.08	102.26	290.07	£1,680
7	63.33%	Reasonable	629.02	815.08	62.76	302.57	£2,280
8	61.63%	Reasonable	838.69	815.08	192.92	234.00	£2,340
9	15.40%	Almost no match	7330.00	815.08	6460.00	4.42	£7,308
10	6.25%	No match	20130.00	815.08	19250.00	1.04	£17,720
11	2.56%	No match	50090.00	815.08	49180.00	1.54	£42,950
12	42.93%	Very poor	2160.00	815.08	1320.00	21.09	£2,150
13	39.43%	Bad match	2600.00	815.08	1750.00	2.64	£9,320
14	50.50%	Poor	582.17	815.08	257.66	484.78	£1,320
15	40.21%	Very poor	2800.00	815.08	1900	8.73	£2,750

From Table 4, specific cases are taken further in analysis, in evaluating the criteria, as a part of the second objective, as given in the next section. Conclusions are drawn from this section further in the report.

Objective Two

The first criterion – Providing a reliable all-year round energy supply

The cases that fulfil the first criterion are where the energy deficit is minimum and the total supply is more than the total demand. These are achieved by cases 1, 2, 3, 4, 9, 10, 11, 12, 13, and 15. The supply/demand graphs achieved for these cases are similar to that shown in Figure 1.

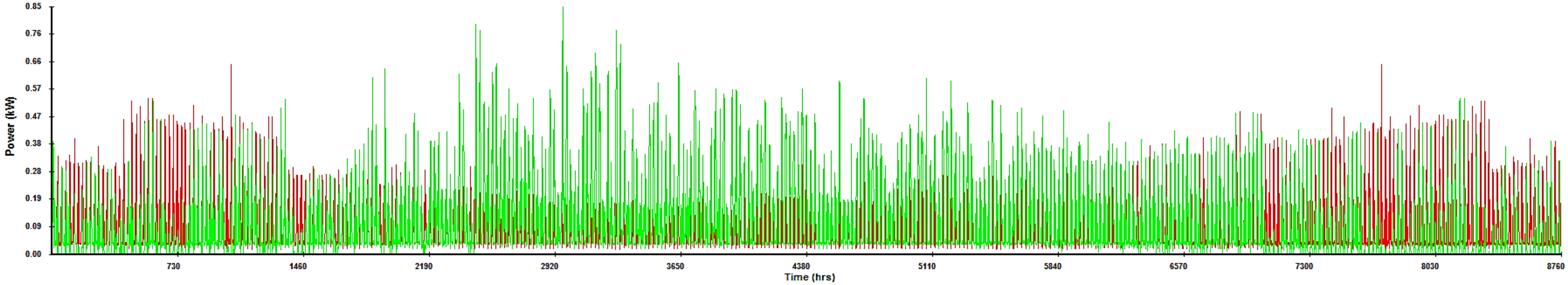

Figure 1 - Graph plotted by the use of Merit software, where green bars indicate the supply and the red bard indicate the demand. This figure is achieved for Case 2

Among these cases, similar graphs are achieved for 1, 2, 3, and 4, where one can interpret that there is a significant rise of supply in the middle of time, ranging from 2000 hrs to 5800 hours (approximately). This is because these cases involve a pure solar renewable energy system. It is apparent that during this period, the solar radiation is significantly high due to the presence of sun (summer time). For cases 9, 10, 11, 12, 13, and 15, there is a fluctuation in the supply, due to the fact that these are wind energy systems, and because wind is an intermittent phenomenon, the supply varies rapidly over time (as shown in Figure 2)

The second criterion – Minimising capital costs of the system

By considering Table 4, the most economic combination is from case 14, however, this does not meet the total demand. The second most economic combination is case 6, however, this does not fulfil the energy demand either. Therefore, the cases that fulfil the first criteria are only considered to further narrow down our choice of energy systems in terms of capital costs. It is a general observation that the wind energy systems are more expensive than the solar panels, therefore, cases 1, 2, 3, and 4 are considered to fulfil this criteria. As an exception, case 15 is also considered due to its costs being similar to the above cases considered.

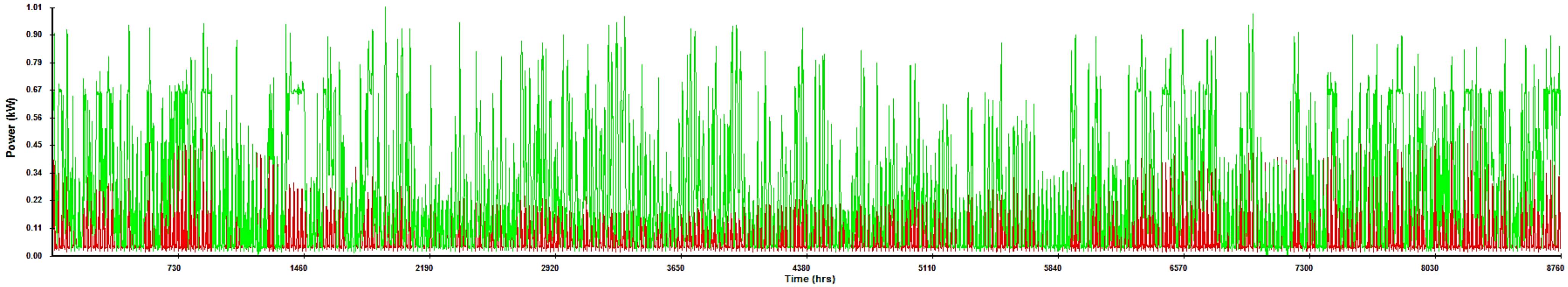

Figure 2 - Case 15: Supply plot of a wind energy system. The green bar denotes supply and the red bar denotes demand

The third criterion – Accommodating any future increases in energy demand

Anticipating the increase in energy demands in the future, it is assumed that the consumption may reach an increase of 20% than the current total demand, which is 978.08 kWh. The cases which facilitate a total supply more than 20% of the total demand increase are cases 1, 2, 9, 10, 11, 12, 13, and 15.

The fourth criterion – Minimising energy wastage caused due to excess energy generation

From the Table 4, it can be interpreted that cases 9, 10, 11, 13, 14, and 15 generate significantly high energy. All of these cases include wind energy systems. Therefore, it could be implied that wind energy systems generate more power, and would result in excess wastage of energy. Considering the percentage match and its comments, along with the residual power graph plotted on the Merit software (as shown in Figure 3), cases 2 and 8 are deemed to be having minimum energy wastage results.

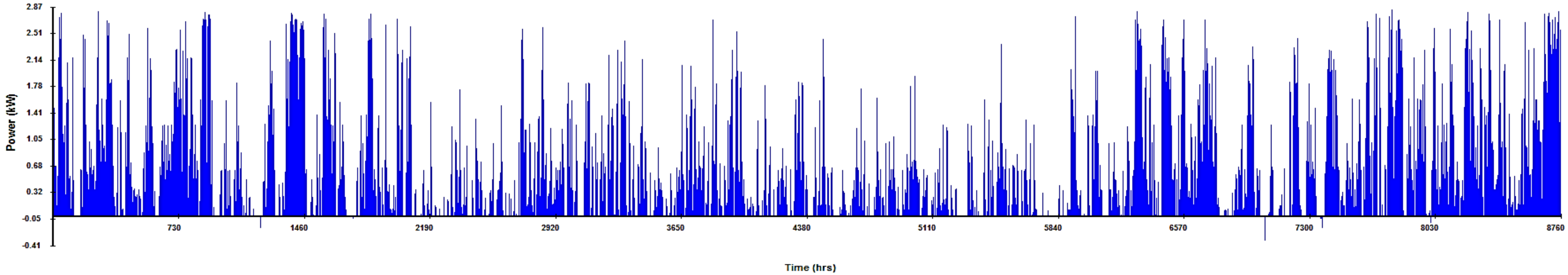

Figure 3 - Residue power for Case 9. It is evident that there is maximum energy wastage due to wind energy systems

INDICATION TO IMPROVEMENT AND FURTHER ANALYSIS

Although every effort was made to perform as many simulations as possible in the give time frame, the combinations accomplished were only 15 in number. Although the project objectives are fulfilled, the analysing different combinations of energy systems is an iterative and an exhaustive process. Although the results that indicate the best hybrid energy system among the 15 cases is achieved, it should also be noted that the analysis performed does not discuss most of the other possible combinations. These could be explored for further improvement and analysis.

CONCLUSION

From the methodology adopted and the results obtained, it is a general observation that wind energy systems are powerful energy generation systems at the analysed location, so much so that most of the energy is wasted due to the demand being very low compared to the supply, however, these systems are not constant, and differ intermittently, due to the nature of wind itself. On the other hand, the solar energy system is seen to experience a significant rise in supply in mid-year (Figure 1), due to the fact that the solar radiation is high in summer. It can also be observed that in such cases, the residual power is high, however, this declines at the start and at the end of the year (Figure 3).

In terms of meeting the four criteria, it can be observed that case 2, which is a combination of 9 solar panels generating 110 W of power with 12 V, and 3 storage systems of 105W/12V configuration is reliable all through the year, is an economic option, accommodates future energy demands, and has minimum energy wastage. As a matter of fact, the match percentage is also found to be 'reasonable' for this case. Therefore, case 2 is recommended among all the 15 cases.

Through the literature study and the analysis, it is apparent that although renewable energy systems retrieve energies that can be replenished, their exploitation can be challenging and expensive to some extent (Bgo, 2010).

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