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FEASIBILITY AND OPTIMIZATION ANALYSIS OF A STAND-ALONE WIND-PV HYBRID ENERGY SYSTEM WITH OMNI- DIRECTION-GUIDE-VANE IN MALAYSIA; AN APPLICATION OF HOMER

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***Abstract*— The prospect of utilizing wind energy for electricity generation in urban areas seems to be inefficient, owing to low wind speeds and the turbulence caused by surrounding obstacles. However, these challenges can be overcome by integrating a power augmentation device called an omni-direction-guide -vane (ODGV) to further increase the oncoming wind speed for better performance of wind turbines. This study aims to investigate the influence of the ODGV in the feasibility and optimization of a stand-alone hybrid renewable energy system in a low wind speed area in Malaysia. The HOMER (Hybrid Optimization Model for Electric Renewable) software package was used for the analysis of the simulation. Two case scenarios were analyzed, case 1, is using Wind-PV-Diesel-Battery system with the presence of the ODGV and case 2 is the Wind-PV-Diesel-Battery system without the presence of ODGV. Thousands of simulations were carried out to achieve optimal autonomous system configurations. Four scenarios were evaluated in both cases. The assessment criteria comprises of the Net Present Cost (NPC), Cost of Energy (COE), amount of CO2 emitted and the Renewable Fraction (RF). Comparison was made between the best scenarios in case 1 and case 2. The results indicate that scenario 1, in case 1 (WT-PV-DG- Battery) system is the most feasible, optimized, cost effective and environmental friendly system among other configurations . The economics analysis reveals that with case 1 scenario 1, $4,795 of the total NPC and $0.021/kWh of the COE can be saved respectively. Moreover, the results of the environmental analysis indicates that 438kg/yr (2.3%) of CO2 emitted could be reduced by the system in case 1 scenario 1 and 25% of renewable fraction is achieved.**

***Index Terms*— HOMER; ODGV; Hybrid system; wind turbine; solar PV; Renewable energy**

I. INTRODUCTION

.

Malaysia has sufficient renewable energy resources such as biomass, hydro, wind, and solar, energy [1]. The recognized prospective source of clean energy is wind and solar energy [2]. Wind and solar energy are abundant, untapped and environmentally friendly [3]. But their unpredictable nature and their dependency on weather and climate are their common setback. However, this setback can be overcome by their daily and seasonal complementary relationships. Thus the strength of one source can be used to overcome the weakness of the other by integrating wind and solar energy together [2]. Malaysia is blessed with abundant solar energy due to its location in the equatorial region [4]. On the other hand, wind energy in Malaysia is not very promising. Malaysia experiences low wind speeds, however, some areas facing the South China sea and the east coast of peninsular Malaysia experience strong wind [5]. The power of the wind is known to be proportional to the cubic power of the wind velocity approaching wind turbines [6]. This means that any slight increase in wind speed that approaches the wind turbine can lead to a substantial increase in power output [7]. Therefore, enclosing a wind turbine in a specially designed shroud will increase its output power [8, 9].

2.0 Omni- Direction -Guide –Vane (ODGV)

The omni-direction -guide-vane (ODGV) is a device which consists of several guide vanes (fig 1). The guide -vanes are designed to guide and improve the oncoming wind speed from every direction to a better angle of attack. This improves the performance of the vertical axis wind turbine (VAWT). Moreover, the problem of noise pollution is minimized and hazard due to turbine blade failure is completely addressed since the vertical axis wind turbine is surrounded by the ODGV [10].

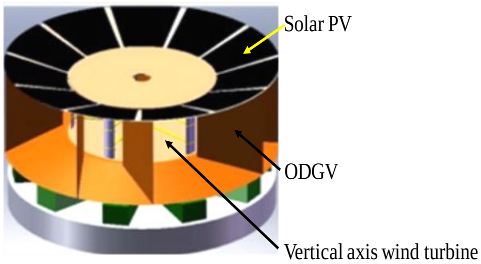


Fig.1. The Omni Direction Guide-Vane ODGV [10]

Many studies have been conducted on modeling, simulation, optimization, economic analysis and component sizing of hybrid energy systems using HOMER software [11-13]. HOMER helps in the design of micro power optimization systems and simplifies the contrast of power generation technologies across an extensive range of applications. The feasibility study of a stand-alone hybrid solar-wind battery system for remote island was reported by Tao et al [14]. Khan and Iqbal [15] presented a study on the pre-feasibility study of a stand-alone hybrid energy system for application in Newfoundland. The present study investigates the feasibility and optimization of wind-solar hybrid energy system in low wind speed areas in Malaysia. The study aims to optimize the hybrid systems through reducing the NPC, CO_2 and COE and also improve the renewable energy penetration by using an innovative device called ODGV.

3.0 Methodology

3.1 System description

Hybrid Wind-PV-DG-Battery power generation systems can effectively improve the system usage factor. In this regard, many researches has been conducted on this area of hybrid energy system, the various studies conducted show that the system is economically and technically viable for remote area application.

3.1.1 System configuration

The system architecture and energy flow for the proposed hybrid Wind-PV-DG-Battery system is shown in fig. 2. The system mainly consists of a vertical axis wind turbine (WT), PV array (PV), Diesel Generator (DG), a Battery and converter. The converter converts the DC power of the PV array into AC from the supply based load. The excess energy available will be fed to the battery bank which will later be used to power the load in the absence of the renewable energy output to supply the load. The diesel generator (DG) will be used as a backup system during odd times when the renewable system is limited. The converter is the main power distribution component where the AC and DC buses are connected.

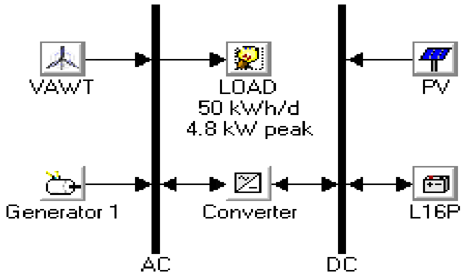


Fig.2. HOMER diagram for the hybrid system

3.2 Modeling of the System

A reliable load consumption profile is crucial for designing a renewable energy system. In designing a hybrid energy system, one of the most important steps is deciding on the load profile. In this study, the daily load requirement is carefully estimated for five households. The estimated load for the five households is 50 kWh/day at 4.8 kW peak. The load was synthesized by adding some randomness for different days and months, and the hourly load profile during different months is as shown in the figures below

3.3 Resources assessment

3.3.1 Wind Resource

One year wind resource for the year 2008 for Malaysia was obtained from the Malaysian Meteorological Department (MMD). The site for the wind resource is located at latitude 2º 44ˡ N and longitude 101º 42ˡ E. The height of the anemometer above the ground is 10m. Meanwhile the rotor of modern wind turbines is place at height above the ground which varies between 40 m and 110 m. This wind speed data was extrapolated to 40 m height by using the equation below,

$$V(z) = Vr\left(\frac{z}{z_r}\right)^{\alpha} \quad \text{.....(1)}$$

[16]

Where;

V(z) is the speed at extrapolated height, Vr is the wind speed at reference height, z is the extrapolated height, Z_r is the reference height and α is a constant given by 0.31. Two scenarios was evaluated for the wind speed; the first case scenario (case 1) was with the presence of the ODGV and the second case scenario (case 2) was without the ODGV as shown in figure 3.

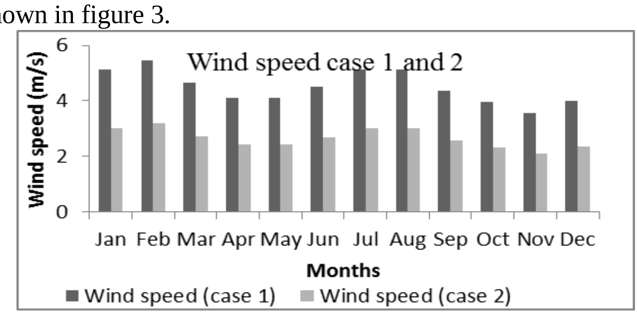


Fig.3. Wind resource of the site for case 1 and case 2

From fig. 3, it can be observed that case 1 has higher wind speed than case 2. This is as a result of the presence of the ODGV in case 1 which further increases the wind speeds through the venturi effect.

3.3.2 Solar Resource

The solar radiation data for the site was obtained from NASA surface Meteorology and Solar Energy web site given the location of the site. [17]. The location of the site is Latitude 2° 44`N and Longitude 101° 42`E. From the locations, HOMER generates the solar radiation data which was used as the input for the solar resource as shown in fig 4.

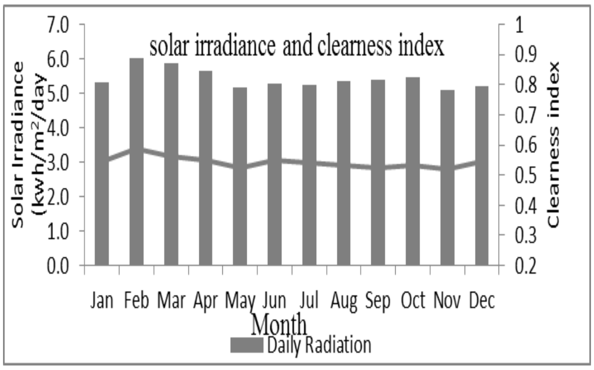


Fig.4. Solar radiation profile for the site obtained from HOMER [17]

4.0 RESULTS AND DISCUSSION

4.1 Simulation results

Two cases were simulated and analyzed. The first case (case1) was a WT-PV-Diesel-Battery system with the presence of the ODGV and the second case (case 2) was without the presence of the ODGV. Based on the meteorological data and load consumption, thousands of combinations were simulated to achieve an optimal system configuration. HOMER estimates their technical feasibility and scales them according to their NPC, COE, amount of CO_2 emitted, and renewable energy penetration.

4.2 Optimization results

4.2. Case 1: Wind-PV-DG-Battery with presence of ODGV

HOMER simulates thousands of combinations and categorized the best four combinations that are feasible, cost effective and environmental friendly. The categorized form of the optimization results for case 1 is presented in table 1. HOMER displays all the possible configurations for the systems and considers the four best feasible scenarios. For case 1, the four best feasible scenarios considered are the WT-PV-DG-Battery, PV-DG-Battery. DG-Battery and WT-DG-Battery systems

4.2.1 Case 1 Scenario 1 WT-PV-DG-Battery system

From the results in table 1, the most optimal combination of all the four categorized hybrid renewable energy technology that is considered cost effective (less expensive) and environmentally friendly is the **Wind- PV-DG-battery** system (scenario 1). The selection is based on the total NPC, COE, CO_2 emission and renewable fraction. From the results, the total NPC, COE is $247,347, $1.060/kWh, respectively. The amount of CO_2 emitted by the system is 13,534 kg with 25% renewable fraction. The electric power produced by case 1 scenario 1 is shown in figure 5.

Table 1 Categorized optimization results for case 1

Scenarios	WT(kW)	PV(kW)	DG(kW)	Battery	Total capital cost ($)	Total NPC ($)	Total O&M ($)	Operating cost ($)	Renewable Fraction (%)	Co2 emission (kg/yr)
WT-PV-DG-Battery	1	3	3	32	24,960	247,347	12,591	1.06	25	13,354
PV-DG-Battery	0	3	3	40	25,700	252,228	12,933	1.08	23	13940
DG-Battery	0	0	3	64	22,520	303,006	16,449	1.29	0	17,747
WT-DG-Battery	1	0	4	16	11,380	312,275	17,436	1.32	0	18,160

4.2.2 Case 1 Scenario 2 PV-DG-Battery system

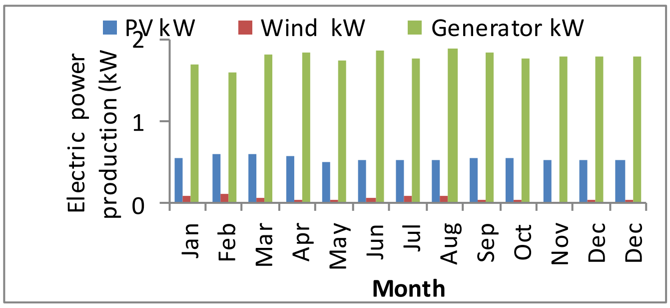
As table 1 reveals, the second best feasible hybrid energy system that is economically and environmentally viable among other combinations according to HOMER is the PV-DG-battery system. It consist of 3 kW PV module, 3kW diesel generator and 32 batteries, with total NPC, and COE of $252,228 and $1.081 kW/h respectively. The system brings about 23% of renewable fraction with 13,972kg of CO_2 emitted. The amount of CO_2 emitted in scenario 2 is higher than that in scenario 1.

4.2.3 Case 1 Scenario 3; DG-Battery

DG-Battery is the third best option of the combinations. It has a total NPC of $293,755 and a COE of $1.259 kWh. The amount of CO_2 emitted is 17,802kg and 0% renewable fraction. This system is not environmentally friendly as it releases a very high amount of CO_2 to the environment.

4.2.4 Case 1 Scenario 4; WT-DG-Battery

WT-PV-Battery system is scenario 4 in case 1, the results from table 1 show that the system is neither economically nor environmentally viable. It has a high total NPC and COE of $315,265 and $1.351kWh respectively. It emits the highest amount of CO_2 and a 0.02% of renewable fraction. From the results of the analysis in case 1, it is very o



bvious that the best scenario in case 1 is scenario 1.

Fig.5. Monthly average electric power production case 1 scenario 1

The figure shows that wind, PV array and Diesel generator contributed to the power production in scenario 1. The highest contribution of the electric power production is the DG generator with 75% of total power produced, followed by the PV system with 23% and then the wind turbine which contributed 2% of the total electric power produced, the figure demonstrate the feasibility of wind energy in Malaysia. The total power produced is as shown in table 2.

Table 2 Summary of electric power production, case 1 scenario 1

Production	kWh/yr	%
PV array	4,752	23
Wind turbine	498	2
Generator	15,563	75
Total	20,821	100

4.3 Case 2: PV-Wind-DG-Battery without the presence of ODGV

The categorized form of the optimization results for case 2 is shown in table 3. Four scenarios of hybrid system combinations are considered feasible by HOMER, and the most optimal hybrid system is selected as the best option. The four scenarios for case 2 is observed and analyzed.

4.3.1. Case 2.Scenario 1; PV-DG-Battery

From the results in table 3, the most optimal combination of all the four categorized hybrid renewable energy technology that is cost effective (less expensive) and environmentally friendly is **PV/DG/battery** system (scenario 1). The results from the analysis shows that the total NPC and COE costs for case 2 scenario 1 are $252,142 and $1.0810 respectively, 13,972kg of CO_2 were emitted and 23% renewable fraction was achieved. The electric power produced by case 2 scenario 1 is shown in fig. 6. The figure shows that only the PV and diesel generator contributed to the electric power produced by the system in case 2 scenario 1.

Table 3 Categorized optimization results of case 2 (without the presence of ODGV)

Scenarios	WT (kW)	PV (kW)	DG (kW)	Battery	Total capital cost ($)	Total NPC($)	Total O&M($)	Operating cost ($)	COE($)	Ren. Fraction	CO_2 Emission (kg)
PV-DG-Battery	0	3	3	32	23,460	252,142	12,977	17,889	1.08	23	13,972
PV-WT-DG-Battery	1	3	3	24	22,420	253,403	13,091	18,069	1.09	23	13,953
DG-Battery	0	0	3	32	23,560	293,803	16,498	21,923	1.26	0	17,818
WT-DG-Battery	1	0	4	16	11,080	317,169	17,762	23,944	1.36	0.02	18,556

4.3.2. Case 2.Scenario 2; WT-PV-DG-Battery

WT-PV-DG-Battery is the second best option for case 2. The total NPC and COE for scenario 2 are $253,403 and 1.086 $/kWh respectively. The system is not economically viable when compared to case 2 scenario 1 although about 23% of the renewable fraction is achieved with slightly less CO_2 emission of 13,953kg. This is as a result of the presence of the wind turbine. This scenario shows that although wind energy is feasible for the application, it is not economically viable.

4.3.3. Case 2.Scenario 3; DG-Battery

DG-Battery system is the third best option for case 2. The system consists of only the diesel generator and Battery. The total NPC and COE for scenario 3 are $293,804 and 1.26 $/kWh. The amount of CO_2 emitted is 17,818kg with 0% of renewable fraction. The system is not economically and environmentally viable.

4.3.4. Case 2.Scenario 4; WT-DG-Battery

The fourth best option for case 2 is WT-DG-Battery system. The total NPC of scenario 4 is extremely high with no renewable fraction. The total NPC and COE for this scenario are $317,169 and 1.36 $/kWh respectively, with 0.02% renewable fraction and 18,556 kg of CO_2 emitted. This shows that WT-DG-Battery system is not environmentally friendly and it is not economically viable.

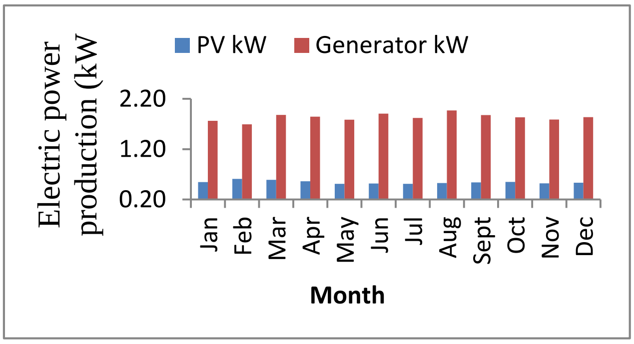


Fig. 6 Monthly average electric power production case 2 scenario 1

Fig. 6 shows the monthly average electric production for case 2 scenario 1. It can be observed from fig.7 that only the PV array and Diesel generator contribute to the power production with the higher contribution coming from the DG generator. The PV array contributed only 23% of the total electric power produced while the diesel generator contributed 77% of the total electric power produced.

Table 4 Summary of electric power production case 2 scenario 1

Production	kWh/yr	%
PV array	4,752	23
Generator	16,069	77
Total	20,821	100

4.4 Comparison between the best scenario in case 1 and the best scenario in case 2

The best scenario in case 1 is scenario 1 i.e WT-PV-DG-Battery system and the best scenario in case 2 is scenario 1 i.e PV-DG-Battery system. The results of these best two scenarios were compared and evaluation was made to ascertain the most optimal system between the two best scenarios as shown in table 5

Table 5 Comparison between the best scenario in case 1 and the best scenario in case 2

Parameter	Case 1, scenario 1 (with ODGV)	Case 2 scenario 1 (without ODGV)	Amount Saved by case 1 scenario 1
Total NPC	$247,347	$252,142	$4,795
Operating cost	$17,397/yr	$17,889/yr	$492
O&M	$12,591/yr	$12997/yr	$406
COE	$1.060/kWh	$1.081/kWh	$0.021/kWh
Renewable Fraction	25%	23%	2%
CO_2 emission	13,534kg/yr	13,972kg/yr	reduced by 438kg/yr

The results of the comparison indicate clearly that the ODGV has a significant impact on both the efficiency and techno-economic performance of the wind-solar-DG-battery system in Malaysia. It reduces the NPC, COE, operating cost, operation and maintenance cost and increases renewable energy penetration to 25% as compared to 23% in case 2, scenario 1

4.5 Sensitivity analysis

The sensitivity input variables were simulated by the HOMER software. HOMER eliminates all non-feasible configurations and selects the feasible configuration which will meet the required load demand. The sensitivity analysis shows how the output is sensitive to changes in the inputs. It deals with uncertainty and determines the optimum system under different conditions. For this study, the effect of changes in wind speed and diesel fuel price is considered for the sensitivity input variable. It shows how a particular system is optimal at a certain wind speed and diesel price. The systems were evaluated to explore the system characteristics using the optimal system type graph (OST) and line graph options. Fig.7 represents the optimal system type (OST) graph for case 1. The graph indicates that the WT-PV-DG-Battery system is feasible and an optimal system for application as hybrid energy system.

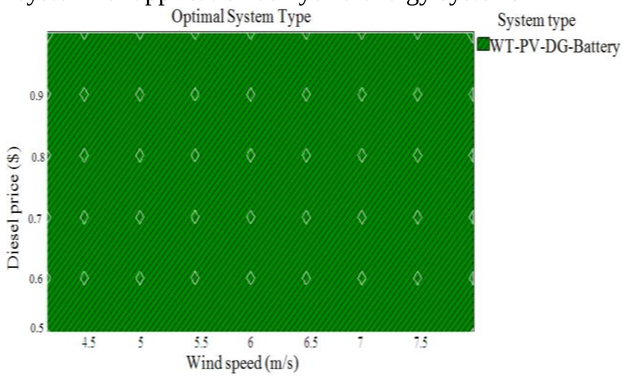


Fig. 7: Optimal system type over increase wind speed and fuel price for Case 1 scenario 1

In figure 8 case 2, the optimal system type (OST) graph considered PV-DG-Battery system as the most feasible and optimal system. But it can be observed from the optimal system type graph that at a certain wind speed of 3.5 m/s, wind become feasible and the optimal system considered cost effective by HOMER is the WT-PV-DG-Battery system. Although it is not economically viable as the WT-PV-DG-Battery system in case 1 scenario 1

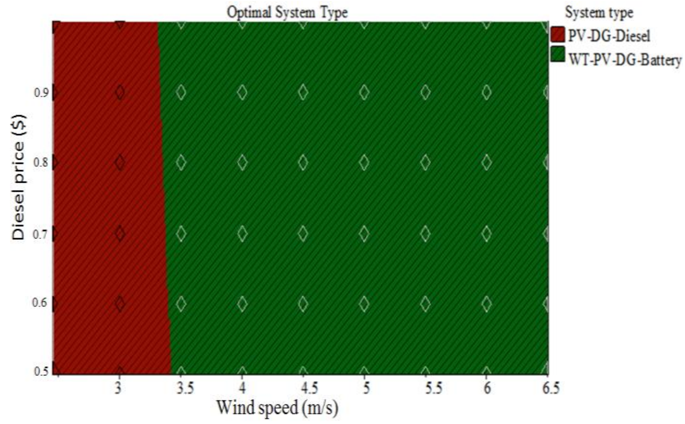


Fig. 8 Optimal system type over increase wind speed and fuel price for case 2 scenario 1

Fig. 9 shows how the variation in wind speed affects the changes in the Levelized cost of energy and NPC for the system. From fig. 9, it can be observed that the increase in wind speed positively affects the total NPC of the system. Thus as the wind speed increases at a fixed diesel price, the total NPC also decreases as shown in fig. 9.

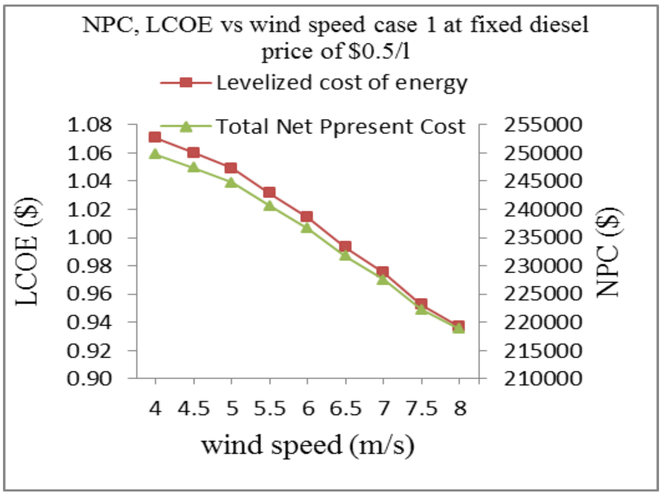


Fig. 9: Levelized cost of energy, NPC and wind speed

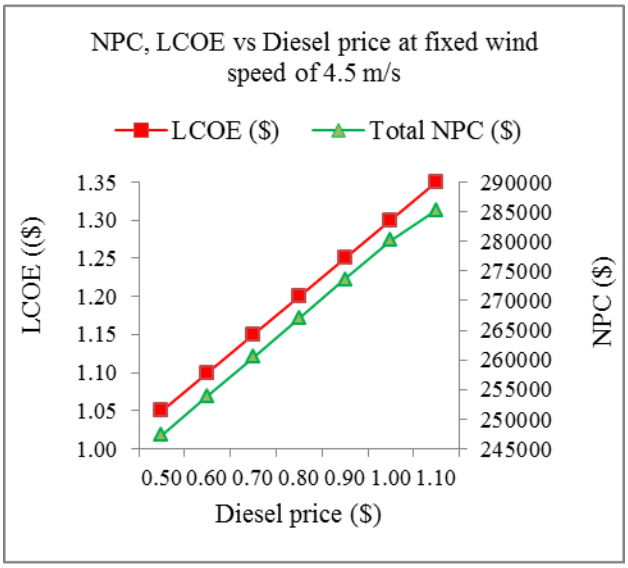


Fig.10 Levelized cost of energy, NPC and diesel price

Figure 9 reveals that there is a direct relationship between the wind speed and the Levelized cost of energy and NPC. As the wind speed increases, the Levelized cost of energy (LCOE) and the NPC decreases. likewise figure 10 shows that as the diesel price increases, the Levelized cost of energy and the NPC also increases. This shows that an increase in wind speed and Diesel prices has great effect on the general cost of the system.

4.6 Economic analysis

The ultimate aim of HOMER is to reduce the cost and optimized the system. Therefore, the economics of the system plays a vital role in the simulation. HOMER uses the total NPC and the cost of energy as an indicator for comparing different combinations /configurations of the system in terms of increasing NPC. The total NPC is calculated using,

$$NPC = \frac{TAC}{CRF} \quad (2)$$

Where TAC is the total annualized cost and CFR is the capital recovery factor which is given by

$$CFR = \frac{i(1+i)^N}{(1+i)^N-1} \quad (3)$$

Where the number of years is denoted by N and i is the annual real interest rate in (%) [18].

The present worth, annual worth and simple payback of the system in Scenario 1 case 1 is $4,881, $382/yr and 3.05yrs respectively. Despite the high initial capital cost of the system for case 1 scenario 1, results of the analysis indicate that the system is cost-effective, feasible and economically viable and environmentally friendly as compared to case 2 scenario 1.

4.7 Environmental Analysis

Atmospheric CO_2 has been a global challenge as the global economy grows, hence the need to take appropriate measures. From the environmental analysis, by integrating the WT-PV-DG-Battery system with the ODGV (case 1 scenario 1), 438 kg/yr (2.3%) of CO_2 could be reduced, and 25% renewable energy penetration could be achieved thus making the system case 1 scenario 1 to be more environmentally friendly than scenario 2 case 1.

II. CONCLUSION

As the main finding of this article, Wind-PV hybrid energy system integrated with the ODGV has been introduced as a reliable solution in Malaysia. The study shows the influence of the ODGV on the optimization of a wind-PV hybrid energy system in low wind speed areas in Malaysia. The results indicate that with the presence of the ODGV in case 1, the hybrid energy system WT-PV-DG-Battery system is a feasible, optimized, cost effective and environmental friendly option. Furthermore, the economics analysis reveals that with the presence of the ODGV $4,834 of the total net present cost can be saved. The result of the environmental analysis indicates that with the presence of the ODGV, 438 kg /yr (2.3%) of CO_2 emission could be reduced and 25% of renewable penetration can be achieved. Despite the high initial capital cost of the system with the ODGV in case 1 it has proved to be more cost effective and environmentally friendly than the system without the ODGV in case 2. The study further demonstrates that it is feasible to harness wind energy in low wind speed areas in Malaysia if the wind turbine is integrated with the ODGV.

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