Optimal Solution for a Photovoltaic-Wind-Battery-Grid Hybrid Power System for People Living in Remote Areas

Brighton Chikomo

***Abstract*– Ever-increasing energy demand is pushing the world to look into renewable energies as the source of energy. Solar energy is only available during the day, and there is less solar energy during winter. In this view, an attractive solution is to use a Photovoltaic-Wind-Battery-Grid (PVWBG) hybrid power system. A hybrid system has the advantage of increasing reliability in power generation. Battery banks are used to store power in case the PV and wind are not able to meet the demand. Furthermore, the grid kicks in when the PV, wind and battery can not meet the demand. This paper seeks to provide a solution to minimise the operation cost for the PVWBG hybrid system. The quadprog MATLAB function is going to be used to solve this problem. Power flow graphs are going to be used to validate the proposed solution.**

***Keywords*– Photovoltaic, quadprog, battery bank, optimise, HOMER, SCADA.**

I. Introduction and the State-of-Art Literature Review

A. Introduction

There is a significant need for the grid or the diesel generator to get a constant power supply from renewable energy sources. Renewable energy sources such as solar and wind do not give a constant power supply compared to the convection power generation methods. The number of hours the diesel generator or the grid is used significantly reduces the operation cost of hybrid systems.

B. State-of-art literature review

Various authors reviewed many optimisation methods in search of the best strategy to minimise construction and operation for hybrid systems. Tazvivenga in [1] proposed the Potovitaic Diseal generator Battery hybrid power system with the limited generator on time. The solution is good as it can provide a constant power flow and carters for the non-fixed load. The drawback of Tazvivenga's solution is that a diesel generator's maintenance and operation costs are high [2], [3]. Various authors used HOMER Energy Modeling Software to optimise the hybrid system [4]–[8]. In [9], Shujun highlighted that HOMMER software is suitable for optimising low-power generation hybrid systems. This is considered one of the drawbacks of using HOMER software for high-power generation hybrid systems. Abdulsalam et al. in [10] proposed using SCADA to control and manage a hybrid system. Also, Alalwani in [3] used the forever power method to optimise PV arrays for hybrid systems. On the other hand, Irene et al. in [11] used Mixed Integer Linear Programming (MILP) to optimise the energy stored in the battery. He also optimised the size of batteries to reduce the cost of the system [12]. Yadala et al. minimised the annual life cycle cost of the hybrid system using a multi-objective artificial cooperative search algorithm (MOACS) [13]. Likewise, Pranoy et al. in [14] and Phonphan in [15] used Particle Swarm Optimisation approaches (PSO) to minimise the cost of battery banks for hybrid systems.

Most of these reviews use a fixed load demand. This paper addresses cost solutions for hybrid systems with a non-fixed load. The work uses a modification of the proposed solution in [1] to minimise the PVWBG hybrid system cost while mitigating the drawbacks outlined in the literature.

C. *Research Question*

How to reduce the operation cost for a PVWBG hybrid power system for non-fixed load profiles for people living in remote areas?

Fig.1 shows the overall scheme of a hybrid system.

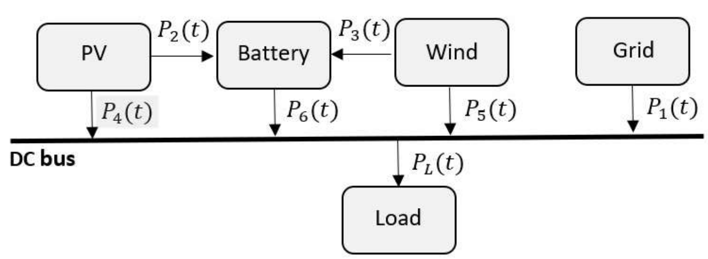

Fig. 1. Proposed PVWBG hybrid system

The design variables are power flow from the grid to the load ($P_1(t)$), power flow from PV panels to the battery ($P_2(t)$), power flow from the wind turbine to the battery ($P_3(t)$), power flow from PV panels to the load ($P_4(t)$), power flow from the wind turbine to the load ($P_5(t)$), power flow from the battery to the load ($P_6(t)$) and power flow to the load ($P_L(t)$).

II. EXAMINATION ASSIGNMENT SCOPE DISCUSSION AND ANALYSIS

A. Model and variables

This section gives the PV model and the preliminary results of the PV panel. A detailed description of the function to be optimised forms part of this section. The models for wind turbines, battery banks and the grid are not given as they will be discussed in the exam.

1) PV model:

Eq(1) [1], [16] show the PV panel model used to get the power supplied by the panels.

$$P_{PV} = \eta_{PV} \times A_C \times [(I_B + I_D)R_B + I_D] \tag{1}$$

P_{PV} is the power supplied by the PV panel, η_{PV} is the PV panel efficiency, A_C is the PV panel surface area exposed to the sun, I_B is the hourly global irradiation, I_D is diffuse irradiation, R_B relates beam irradiance on the tilted plane and the horizontal plane.
The solar efficiency is calculated as follows:

$$\eta_{PV} = \eta_R \Big[1 - 0.9\beta \Big(\frac{(I_B + I_D)R_B + I_D}{I_{PV,NT}} \Big)(T_{C,NT} - T_{A,NT}) - \beta(T_A - T_R) \Big] \tag{2}$$

η_R is the PV generator efficiency referenced from the cell temperature, T_R, β is the cell efficiency temperature coefficient; $I_{PV,NT}$ is the solar irradiation incident on the panel at NT $(0.8kWh/m2)$; $T_{C,NT}$ and $T_{A,NT}$ are the cell and ambient temperatures respectively [1].

B. Proposed method to solve the problem

Non-linear optimisation programming is used to get the optimum operation cost for the PVBWG hybrid system. The proposed method offers a more practical approach to the problem as it caters for non-fixed loads. The approach seeks to optimise the power flow from the grid to the load $(P_1(t))$. The quadprog MATLAB function tool was used to show the problem. Eq(3) [1] shows the quadprog function used.

$$min \frac{1}{2} x^T H x + f^T x \tag{3}$$

subject to constraints: $Ax \leq b$, $A_{eq} = b_{eq}$ and $lb \leq x \leq ub$
Where: H is the Hessian matrix, x is the control variables, f is the vector matrix, A is the inequality constraints matrix, A_{eq} and b_{eq} are the equality constraints matrix.

1) Analysis of the proposed solution

The task is to solve the optimum operation cost of the proposed hybrid system in equation 4. The function below is used to solve for the optimum electricity cost supplied by the grid to meet the supply-demand balance when the PV, wind, battery or the combination of the three cannot meet the demand.

$$min\ C_{grid} \sum_{t=1}^{N} \left(aP_1^2(t) + bP_1(t)\right) \tag{4}$$

The constraints for the optimisation problems will be formulated and provided in the exam assignment.

2) Preliminary results

Fig. 2 shows a plot of the power flow from a solar panel to the load. The graph was obtained using the daily irradiation data of the site where the system is to operate and eqn(1) and eq(2)

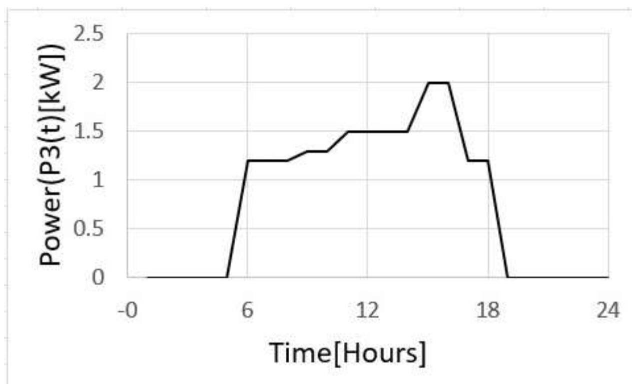

Fig. 2. Power flow profile from the PV panel to the load

3) Discussion of preliminary results

The preliminary results show that a stand-alone PV system as part of the PVWBG can not give a constant power supply. PV system can only supply power from 6 AM to 6 PM. This confirms that there is a need to have a hybrid system. From the PV's power flow profile, it can be deduced that renewable energies can not be used alone as the power of the source. The exam will focus on formulating the Hessian matrix, the control variables, the vector matrix and the inequality constraints matrix. The optimised hybrid system will reduce the operation cost compared to a combination of the stand-alone PV, Wind, Battery and grid systems.

III. Conclusion and future work

It can be concluded that the proposed solution will offer a minimum cost solution as compared to the combination of the stand-alone PV, wind, battery and grid. The advantage of the proposed system is that it offers a more practical approach to the problem. The proposed solution caters for non-fixed demand. One of the drawbacks of the proposed solution is that it is not 100% green. Furthermore, the solution does not feed back to the grid if the generated power is more than the demand and the battery banks are fully charged. Incorporating the function to provide back to the grid will generate extra funds to accomplish other projects. To improve the performance of the proposed solution, flow from the battery banks to the grid ($P_7(t)$) is to be added. The optimisation problem is to be determined, considering the power flow to the grid. Furthermore, the proposed system can be converted to 100% green by removing the grid and increasing the battery bank capacity, number of PV panels and wind turbines.

REFERENCES

[1] H. Tazvinga, X. Xia, and J. Zhang, "Minimum cost solution of photovoltaic–diesel–battery hybrid power systems for remote consumers," *Solar Energy*, vol. 96, pp. 292–299, 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0038092X13003046

[2] Y. Singh, B. Singh, and S. Mishra, "A High-Performance Solar PV Array-Wind and Battery Integrated Microgrid for Rural Electrification," *9th IEEE International Conference on Power Electronics, Drives and Energy Systems, PEDES 2020*, pp. 1–6, 2020.

[3] S. H. Alalwan and J. W. Kimball, "Optimal sizing of a wind/solar/battery hybrid microgrid system using the forever power method," *IEEE Green Technologies Conference*, vol. 2015-July, pp. 29–35, 2015.

[4] R. Al-Rashed, T. Faza', and O. Ayadi, "Potential of using Off-grid PV/Wind/Diesel Battery Hybrid Energy System in Jordan," *2021 12th International Renewable Engineering Conference, IREC 2021*, 2021.

[5] S. Ghose, A. El Shahat, and R. J. Haddad, "Wind-solar hybrid power system cost analysis using HOMER for Statesboro, Georgia," *Conference Proceedings - IEEE SOUTHEASTCON*, pp. 27–29, 2017.

[6] N. A. Khan, A. K. Sikder, and S. S. Saha, "Optimal planning of off-grid solar-wind-tidal hybrid energy system for sandwip island of Bangladesh," *2014 2nd International Conference on Green Energy and Technology, ICGET 2014*, no. September, pp. 41–44, 2014.

[7] F. Mthethwa, C. Gomes, and D. Dorrell, “Optimization of a Micro-grid with Solar PV, Wind Energy and Battery Storage Hybrid System for an agro-based off-grid rural landscape,” *2021 IEEE PES/IAS PowerAfrica, PowerAfrica 2021*, pp. 5–9, 2021.

[8] M. Nurunnabi, N. K. Roy, E. Hossain, and H. R. Pota, “Size optimization and sensitivity analysis of hybrid wind/PV micro-grids- A case study for Bangladesh,” *IEEE Access*, vol. 7, pp. 150 120–150 140, 2019.

[9] S. Liu, Z. Wu, X. Dou, B. Zhao, S. Zhao, and C. Sun, “Optimal configuration of hybrid solar-wind distributed generation capacity in a grid-connected microgrid,” *2013 IEEE PES Innovative Smart Grid Technologies Conference, ISGT 2013*, pp. 1–6, 2013.

[10] A. B. Abdulsalam, H. Adil, J. Alsaadi, and Z. Hamodat, “Control And Management of Solar PV Grid Using Scada System.”

[11] I. Masenge and F. Mwasilu, “Hybrid Solar PV-Wind Generation System Coordination Control and Optimization of Battery Energy Storage System for Rural Electrification,” *2020 IEEE PES/IAS PowerAfrica, PowerAfrica 2020*, pp. 1–5, 2020.

[12] S. Bahramirad and H. Daneshi, “Optimal sizing of smart grid storage management system in a microgrid,” in *2012 IEEE PES Innovative Smart Grid Technologies (ISGT)*, 2012, pp. 1–7.

[13] Y. Pavankumar and S. Paul, “A multi objective approach for optimal design of solar / wind / biomass / battery-based grid connected microgrid system,” 2022.

[14] P. Roy, J. He, and Y. Liao, “Cost Minimization of Battery-Supercapacitor Hybrid Energy Storage for Hourly Dispatching Wind-Solar Hybrid Power System,” *IEEE Access*, vol. 8, pp. 210 099–210 115, 2020.

[15] N. Phonphan and P. Khamphakdi, “Home energy management system based on the photovoltaic – battery hybrid power system,” in *2020 International Conference on Power, Energy and Innovations (ICPEI)*, 2020, pp. 213–216.

[16] P. Toma, P. Dorin, E. Radu, and M. Daniel, “Sizing photovoltaic-wind smart microgrid with battery storage and grid connection,” *Proceedings of 2014 IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2014*, no. 1, pp. 1–5, 2014.

.