International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 482

ENERGY SUPPLY WITH PHOTOVOLTAICS/WIND HYBRID SYSTEM: A RELIABILITY ASSESSMENT IN NORTHERN NIGERIA

Ismail Abubakar Jumare [1, 3 *], Ramchandra Bhandari [2], Abdellatif Zerga [3]

[1] *Mechanical Engineering Department, Faculty of Technology, University of Tlemcen,* B.P. 119 | Pôle Chetouane, Tlemcen 13000, *Algeria*

[2] *Institute for Technology and Resources Management in the Tropics and Subtropics, TH Köln - University of Applied Sciences, Cologne, Germany*

[3] *Pan African University Institute of Water and Energy Sciences – PAUWES c/o University of Tlemcen,* B.P. 119 | Pôle Chetouane, Tlemcen 13000, *Algeria*

ABSTRACT
Electricity is a precondition to economic growth and development hence paramount. However, the source for the electricity generation is a strong indicator for sustainability. This paper offers a techno-economic assessment regarding the use of renewable-based electricity in a hybrid, looking at standalone and grid-connected scenario in the Northern Nigerian context for addressing energy deficits. In doing so, physical component modelling and optimization was done for both scenarios in seeing the overall techno-economic and environmental/emissions benefits. The results showed 15% increment in system energy generation, 77% decrement in Net Present Cost (NPC) and Levelized Cost of Energy (LCOE), with avoided emissions all in favor of the grid-connected scenario. Hence, an opportunity for a massive and effective transition if well implemented and especially on a larger scale basis. This is indeed appropriate, provided utility grid security and stability are made certain as well as appropriate policy measures set in place in favor of such energy sector bloom for the case study country in the nearby future.

Keywords: Electricity; modelling; optimization; grid-integration; off-grid; sustainability

1. INTRODUCTION

Energy access and use is of paramount importance in line with sustainability at all sectors of economies. The storyline of Africa is a critical one due to the fact that a lot of energy resources both conventional and renewables exist, but adequate final energy services, particularly electricity has been a challenge. It is evident that more than half of the African population have no access to electricity [1], most especially the sub-Saharan Africa which included the case study country i.e. Nigeria.

Based on the preceded point, it is of great interest to diversify energy sources for electricity generation. This calls for strong incorporation of the renewable energy sources in complementing the existing conventional sources majorly participating in country's electricity mix. This will not only increase electricity access but also address economic and environmental concerns in completing the basic requirements and pillars for sustainable energy transition. Furthermore, hybridizing different renewable energy sources is equally important due to outstanding benefits of such, viz.: fuel flexibility, efficiency and balance of system, energy security and lots more [2].

Therefore, the main purpose of this research paper is to offer a techno-economic analyses of standalone and grid-connected PV/Wind hybrid system for ascertaining the suitability and reliability of application to the Nigerian context.

2. SITE SPECIFICATION AND RESOURCE ASSESSMENT

A specific site in the country of study is in the Northern part (coordinate: 11.09˚N and 7.7˚E), at 670m above sea level [3]. This is solely due to the resource availability of the site, as solar and wind potentials of the country are stronger in the northern part.

This led to the renewable resource information as crucial for the system analyses. The solar irradiance with the accompanied temperature and wind speed are the fundamental climate data of consideration. These have been presented in figure 1 and figure 2:

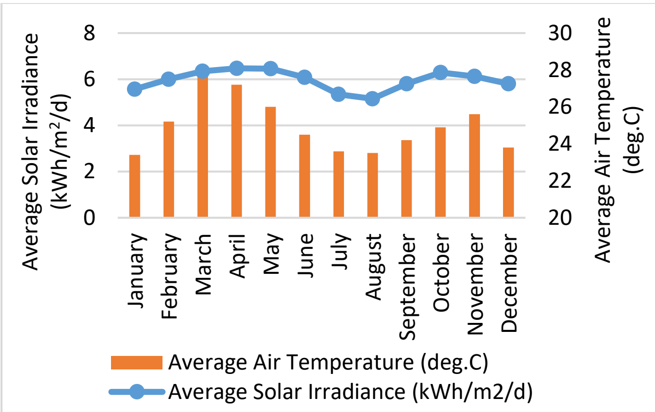

Fig. 1. Average monthly solar irradiation and air temperature for the site [4]

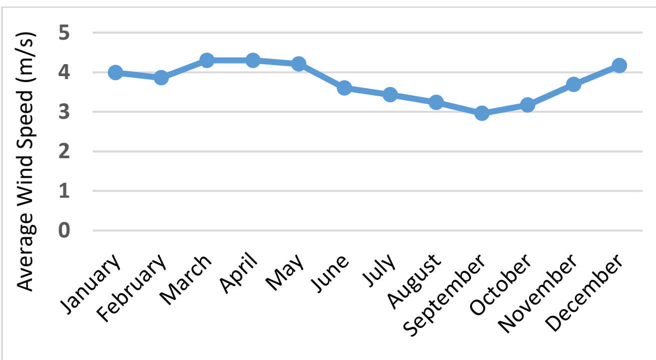

Fig. 2. Average monthly wind speed for the site [4]

3. METHODOLOGY

The methodology employed in this research paper begins with the load demand assessment and then the stepwise approach in addressing the demand for the specified site as follows:

3.1. Energy demand profile

The load demand for the specified location was evaluated based on different appliances used in the residential domain on daily basis, with their utilization times specifications. However, 2 different seasonal experiences i.e. summer and winter have been analyzed, and in overall, scaling was done to 50 households with the final load profile presented in figure 3 and the supplementary specifications i.e. the applied random variability in table 1.

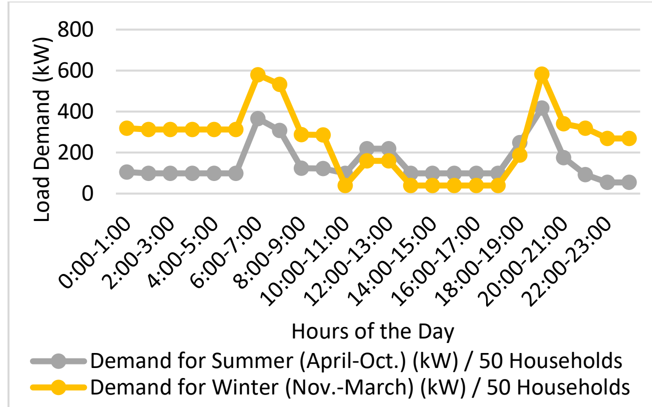

Fig. 3. Load profile for the site

Table 1. Load profile random variability assumptions

Day to day = 15%, Time step to time step = 20%		
Parameter	Baseline	Scaled
Average energy need (kWh/day)	4,633	4,592
Average power demand (kW)	193	191
Peak power demand (kW)	582	1,006
Load factor	0.332	0.19

3.2. Adopted approach in addressing the demand

In addressing the specified load demand for the considered site, the assessment was network-based hybrid system i.e. grid-connected and standalone using a combination of solar PV and wind turbine. The choice of these components of the systems was due to the resource availability in the site as specified previously. The major approach was techno-economic assessment coupled with emissions parameters estimations via physical component modelling, simulations and optimization. This was solely addressed using HOMER (Hybrid Optimization Model for Electric Renewables) tool, being the most appropriate for the study. The modelling was done for firstly the standalone system case of the hybrid, where a secondary storage system was incorporated i.e. battery system as back-up to the whole system for better balance and efficient operation. Secondly, on the grid-integration system, the storage was neglected due to the fact that the grid-system serves as back-up for intervention when necessary. All the necessary technical, economic/costs, and emission input parameters were offered for the physical components, the storage system, as well as the utility grid where necessary, and the project life span was specified as 25 years. Explicit discussion was offered inclusive of the reliability arguments for both scenarios. The overall systems architecture has been presented in figure 4.

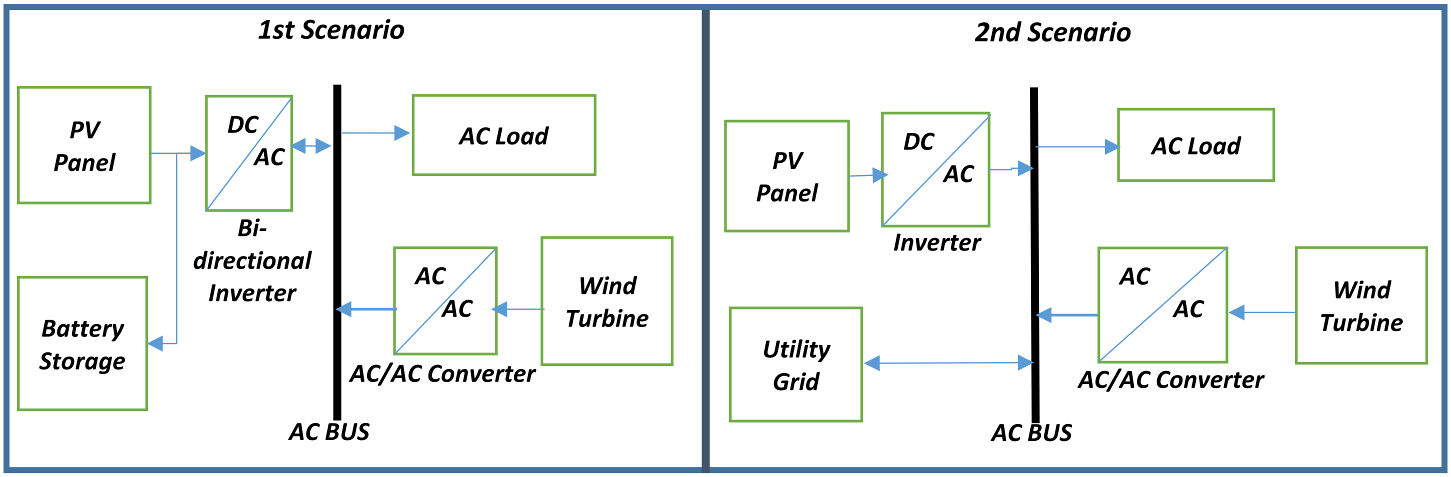

Fig. 4. Standalone and the grid-connected PV/Wind systems architecture

4. RESULTS

Based on the clearly specified methodology with the necessary and analyzed input parameters, the overall simulation and optimization results have been presented in table 2, for the 2 scenarios, i.e. the grid-connected and standalone PV/Wind system scenarios. Supplementary results on the two distinguishing parts of the 2 scenarios viz. battery storage and the utility grid performances have been presented in table 3.

The major results as obvious from the table 2 highlighted different analyzed parameters ranging from the technical to economic and lastly to the environmentally linked parameter specifically the CO_2 emission.

Table 2. Summary of the simulation and optimization results for the 2 scenarios

Optimum parameters	1st Scenario (Standalone PV/Wind System)	2nd Scenario (Grid-connected PV/Wind System)
Optimized configuration	PV: 1500kW; WT: 5; Batteries: 3000; Conv.: 1000kW	PV: 400kW; WT: 20; Conv.: 500kW; Grid out: 800kW; Grid in: 1500kW
Energy production (kWh/yr.)	3,245,124	System: 3,739,694; Grid: 684,689
Energy utilization (kWh/yr.)	1,675,253	Load: 1,675,790; Grid: 2,305,774
Excess energy (kWh/yr.)	1,174,680	381,951
Unmet energy (kWh/yr.)	826	289
Renewable fraction (RF)	1.0	0.845
Capacity shortage (kWh/yr.)	1,552	1,523
Initial capital Cost ($)	10,494,075	4,423,300
Operating cost ($/yr.)	256,126	-97,762
NPC ($)	13,768,228	3,173,577
LCOE ($/kWh)	0.643	0.148
GHG emission /CO_2 (kg/yr.)	0	-612,770

Table 3. Supplementary results for the storage and grid back-up systems

Battery storage system of 1st Scenario		Grid-back-up system of 2nd scenario	
Parameter	Specification	Parameter	Specification
Energy-in	1,255,854 kWh/yr.	Energy purchased from grid	684,689kWh/yr.
Energy-out	1,010,826 kWh/yr.	Energy sold to grid	2,305,774kWh/yr.
Storage depletion	6,853 kWh/yr.	Net purchase	-1,621,084kWh/yr.
Losses	238,175 kWh/yr.	Peak demand	800kW
Annual Throughput	1,130,138kWh/yr.	Energy charge	-$145,898/yr.
Expected life	12 years	Demand charge	$0/yr.

5. DISCUSSION

To proceed with the results discussions, it is obvious on the technical parameters the change in the solar PV optimized capacity from 1500kW to 400kW from the first to the second scenario however with an increment in number of wind turbines from 5 to 20. Notwithstanding, the system annual energy generation had increased tremendously from 3.25GWh to 3.74GWh due to more rapid production from the wind component. But the overall energy supply increment was to 4.42GWh due to the incorporation of the grid purchases on occasions of deficits as opposed to the standalone case where the battery may not really contain the needed energy when on intervention. The energy utilization parameter had showed an additional grid-power utilization arising on surplus cases, hence, strongly driving the economic parameters in a positive way as credit has to be secured on such occasions. Moving to the economic parameters, majorly the Net Present Cost (NPC) and the Levelized Cost of Energy (LCOE). These parameters have been drastically affected with an indication of 77% decrement in each, all in favor of the grid-connected system. Lastly, from the zero emissions of the standalone system, which is the direct emissions at the system operational level, moving to the grid-connected system showed negative emissions, which could be interpreted as avoided emissions resulting from the interactions with the utility grid that contains more of fossil-based generations.

On extension, the Nigerian grid-infrastructure is in dire challenge at the moment. This is due to persistent power cuts arising from inefficiency of power evacuations, voltage control challenges, and inadequate mesh networks [5]. Hence, this might serve as a limitation to the integration of the hybrid system at the moment despite its outstanding benefits over the standalone hybrid system case. So, adopting the standalone system is still a perfect idea and considered more reliable for the power supply to the demand site until the utility grid challenges are fixed sooner. Therefore, ensuring the reliability of the utility grid and ensuring appropriate policy measures in support of such integration in the nearby future makes the transition a tremendous idea. This is owing to the improved benefits ascertained on the technical, economic and net emissions aspects addressed in the results section. This is essentially more appropriate on power decentralization grounds.

6. CONCLUSION

Explicit comparative analyses of grid-connected and standalone PV/Wind hybrid system in arriving at the most feasible configuration for application in Northern Nigeria has been successfully conducted with added reliability arguments. The analyses were based on techno-economic modelling and optimization in obtaining technical and economic outcomes, coupled with emission parameters. The results clearly showed decrement in optimized configurations specifically of solar PV subsystem but with slight increment in the number of wind turbines on moving from the standalone system to the grid-connected system. Never the less, system energy generation had increased by 15%, but overall energy supply by 36%, with less ''excess energy generations'' over the yearly simulation all in favor of the grid-connected system. Added also was the advantage of avoided emissions due to the grid-interventions. On the economic aspect, obviously the NPC value had also drastically reduced by 77%. These in overall showed better energy efficiency and effectiveness practice with the grid-connected configuration, and makes it strongly advocated for, provided the utility grid reliability is ensured, and with appropriate policies for such interventions and decentralization.

ACKNOWLEDGEMENT

This study was financially supported by the German Federal Ministry of Education and Research (BMBF) via its project management agency DLR, under the project "Water and Energy Security in Africa (WESA-ITT)''.

REFERENCES

[1] P. Thornley, B. Tim, V. Emil, G. Johan, L. Jim and S. Nico, "Bioenergy Research; Prospect of South Africa," SUPERGEN Bioenergy Hub, Manchester, U.K, 2015.

[2] S. Negi and L. Mathew, "Hybrid Renewable Energy System: A Review," International Journal of Electronic and Electrical Engineering, p. 8, 2014.

[3] I. O. Stephen, G. Egwuonwu and I. Osazuwa, "Delineation of All-season-recharged Ground Water Reservoir from Two Valleys, Zaria, Nigeria," Journal of Environmental Hydrology, vol. Vol. 20, p. 9, 2012.

[4] National Aeronautics Space Administration (NASA), "Surface Meteorology and Solar Energy," n.d. [Online]. Available: https://eosweb.larc.nasa.gov/sse/RETScreen/. [Accessed October 2017].

[5] F. O. Akpojedge, M. E. Onogbotsere, E. C. Mormah and P. C. Onogbotsere, "A Comprehensive Review of Nigeria Electric Power Transmission Issues and Rural Electrification Challenges," International Journal of Engineering Trends and Technology (IJETT), vol. 31, p. 9, 2016.