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Decentralized Grid-Connected Hybrid Renewable Energy System Design in Nigeria, Case Study of Zaria Municipal

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Abstract:
Electricity shortage in Nigeria is very critical hence, need arises for joint, adequate and timely intervention especially by incorporating the available alternative energy sources. This paper is aimed at designing a Grid-Connected Hybrid Renewable Energy System for the case of Zaria, Nigeria. This was done by considering different scenarios starting from the conventional standalone diesel and gasoline generator systems to renewable off-grid hybrid system and finally to the proposed grid-connected renewable hybrid system design coupled with energy efficiency measures. The considered scenarios were addressed for a defined number of households and the clear benefits have been seen on implementing the proposed target as a transition from the conventional energy systems arising from grid unreliability and power shortages in the study region. In all the scenarios, physical components modelling, simulations and optimization were done using HOMER Pro Software, and finally the energy management aspect to the proposed grid-connected energy system scenario was addressed using ADVANCED EXCEL via a VISUAL BASIC Conditional Programming. The results obtained showed that the proposed scenario i.e. the grid-connected system design was the best of all the scenarios considered in terms of total NPC, LCOE, ghg emissions and pollutants. It ensures for example a total NPC and LCOE reduction from the off-grid hybrid renewable system scenario by 69%. Incorporating the energy efficiency measures to the proposed grid-connected scenario results in improved benefits hence an opportunity for a more rapid transition. Therefore, the proposed approach is the best to implement coupled with expansions for effective solution to energy deficit and climate change challenges in the country of study and the African continent at large.

Key Words: [Grid, Hybrid System, Renewable Energy, Energy Efficiency, Energy Management]

1.0 Introduction

The various researches conducted with outcomes showing the depletion nature of conventional sources specifically fossil fuels as well as their direct consequences of global warming have necessitated going for alternatives in providing energy solution. It must be mentioned that these alternatives were the renewable energy sources such as solar, wind, hydro, biomass, and geothermal. However, the combination of 2 or more of these sources is sometimes necessary and that gives rise to the hybrid system. Therefore, by definition, Hybrid

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Energy System according to the U.S Department of Energy (2001) is the combination of 2 or more energy conversion devices of which is aimed at overcoming limitations inherent in either. Some of the Advantages are fuel flexibility due to different adjustment that could be made in the different combinations for ensuring optimum system, efficiency of systems, reliability, and viability in terms of economics, energy security, improved power quality, reduced carbon emission, fossil fuels saving and employment opportunities (U.S DOE, 2001; Negi & Mathew, 2014).

This paper therefore is aimed at designing a 100% renewable energy system with grid connection for a specific site of Zaria, a region in Northern part of Nigeria. However, it will focus on different scenarios starting from standalone conventional systems i.e. diesel and gasoline generator sets to 100% hybrid renewable system in off-grid configuration and then to the proposed grid-connected configuration.

2.0 Methodology

The research methodology is divided in to 2 segments, first is the load demand assessment and then followed by the detailed energy system design approach in addressing the load demand for the selected study site.

2.1 Load Demand Specification (200 Households)

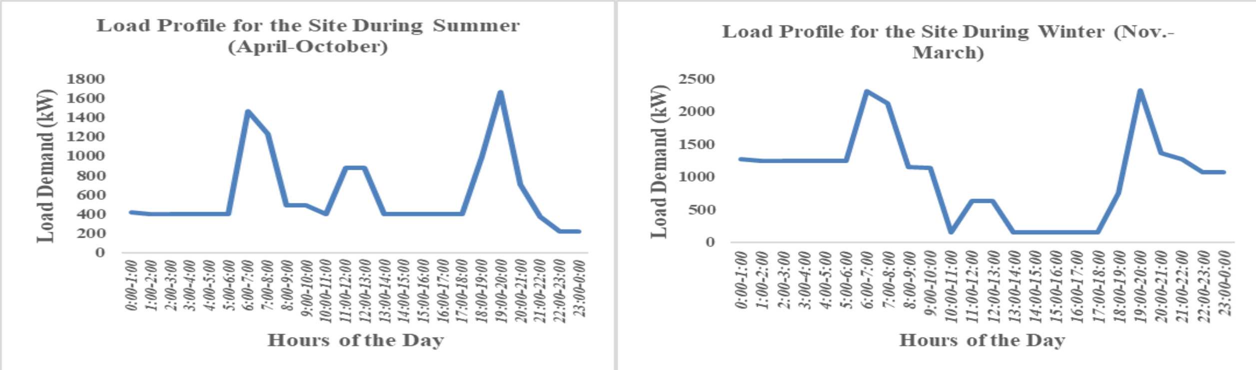

Fig.1: Load Demand Specification for the Site

Table1: Additional Load Demand Specifications for Safety

Random Variability Assumption for Scaling: Day to Day = 15%, Time Step to Time Step = 20%		
Parameter	Baseline Data (without Random Variability)	Scaled Data
Average Energy Demand (kWh/day)	18,531	18,367
Average Power Demand (kW)	772	765
Peak Power Demand (kW)	2,329	4,023
Load Factor	0.332	0.19

2.2 Approach Adopted in Addressing the Specified Load Demand

For addressing the specified load demand, different scenarios were considered in parallel to the proposed grid connected 100% renewables scenario such as the hybrid renewable system in its off-grid configuration as well as the conventional diesel and gasoline split generator systems in seeing the overall benefits of the successful transition. In specific terms, the 4th scenario considered was the standalone conventional split gasoline generator system with battery storage, the 3rd scenario was the standalone conventional split diesel generator with battery storage, the 2nd scenario was the hybrid PV/Wind-Turbine/Biomass-Gasified-Generator System with battery storage, and finally the 1st scenario i.e. being the proposed grid-connected hybrid PV/Wind-Turbine/Biomass-Gasified-Generator System.

In all the scenarios, physical component modelling was done, coupled with simulation and optimization using HOMER Pro in getting the optimized design parameters with specifications. Energy Efficiency assessment was also done for the proposed grid-connected hybrid system with further simulations and re-optimization in seeing clearly the opportunities for a more rapid transition. This was finalized with energy management / control measures in system execution for the proposed grid-connected hybrid system using ADVANCED EXCEL via a VISUAL BASIC Conditional Programming. The system energy management is to be addressed by the SUPERVISORY CONTROLLERS. Below figure defines the inputs and the expected outputs for a HOMER Pro design execution as proposed by Sunanda and Chandel (2014), and applicable in all the considered scenarios.

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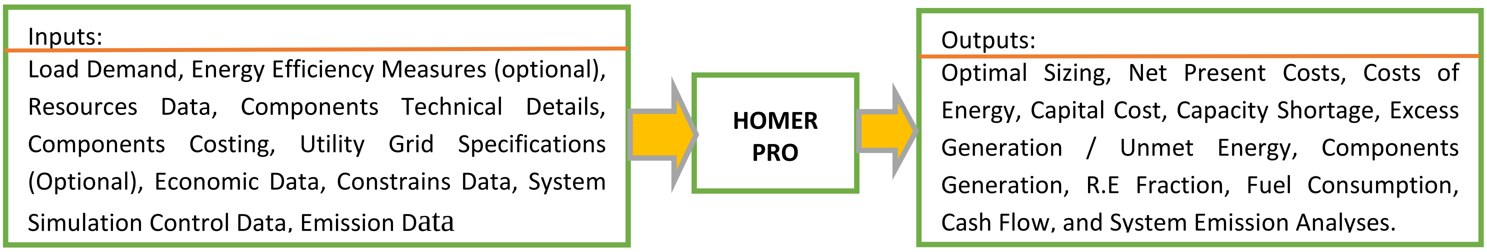

Fig.2: HOMER Scheme Description

3.0 Results and Discussion

Based on the clear methodology specified as well as all the necessary input specifications for the systems, the following results were successfully obtained.

Table2: Overall Assessment for all the Scenarios Considered (Conventional and Proposed Renewables)

Scenarios Analyzed / Optimum Parameters	4th Scenario / Gasoline Sys	3rd Scenario / Diesel System	2nd Scenario / H.R.E Off-grid	1st Scenario / H.R.E On-grid Proposed	1st Scenario + EE / H.R.E On-grid
Optimized Configuration	Gen1: 1200kW Gen2: 1500kW Gen3: 600kW Gen4: 400kW Batteries: 100 Conv.: 400kW	Gen1: 400kW Gen2: 800kW Gen3: 1000kW Gen4: 1200kW Batteries: 100 Conv.: 400kW	PV Sys: 1500kW Wind T: 30 B. Gen: 3500kW Batteries: 150 Conv.: 1000kW	PV Sys: 400kW Wind T: 30 B. Gen: 2500kW Conv.: 200kW Grid-out:1000kW Grid-in: 3000kW	PV Sys: 400kW Wind T: 30 B. Gen: 1500kW Conv.: 200kW Grid-out:500kW Grid-in: 3000kW
Energy Production (kWh/yr.)	6,765,573	6,763,782	12,734,692	12,101,616	8,947,024
Energy Utilization (kWh/yr.)	6,703,592	6,702,344	6,702,966	Load: 6,703,029 Grid: 5,060,868	Load: 3,753,899 Grid: 4,813,517
Excess Energy (kWh/yr.)	431	280	5,958,749	283,141	325,294
Unmet Energy (kWh/yr.)	363	1,611	988	926	323
Renewable Fraction (RF)	0.00	0.00	1.00	0.89	0.95
Capacity Shortage (kWh/yr.)	2,095	5,455	2,567	4,320	1,332
Initial Capital Cost ($)	962,400	3,515,600	15,234,080	9,486,880	7,814,120
Operating Cost ($/yr.)	5,004,847	1,815,008	3,372,377	687,094	224,800
NPC ($)	64,941,144	26,717,498	58,344,372	18,270,252	10,687,822
LCOE ($/kWh)	0.758	0.312	0.681	0.213	0.223
Fuel Utilized per annum	4,307,388Litres	2,526,709Litres	19,271tonnes	13,961tonnes	8118tonnes
GHG Emission /CO_2 (kg/yr.)	9,944,943	6,629,749	18,208	-1,404,259	-1,627,605

Based on the Overall results shown for all the scenarios concern and having seen clearly the benefits of having the successful transition, the model below defines the operational principle for the SUPERVISORY CONTROL.

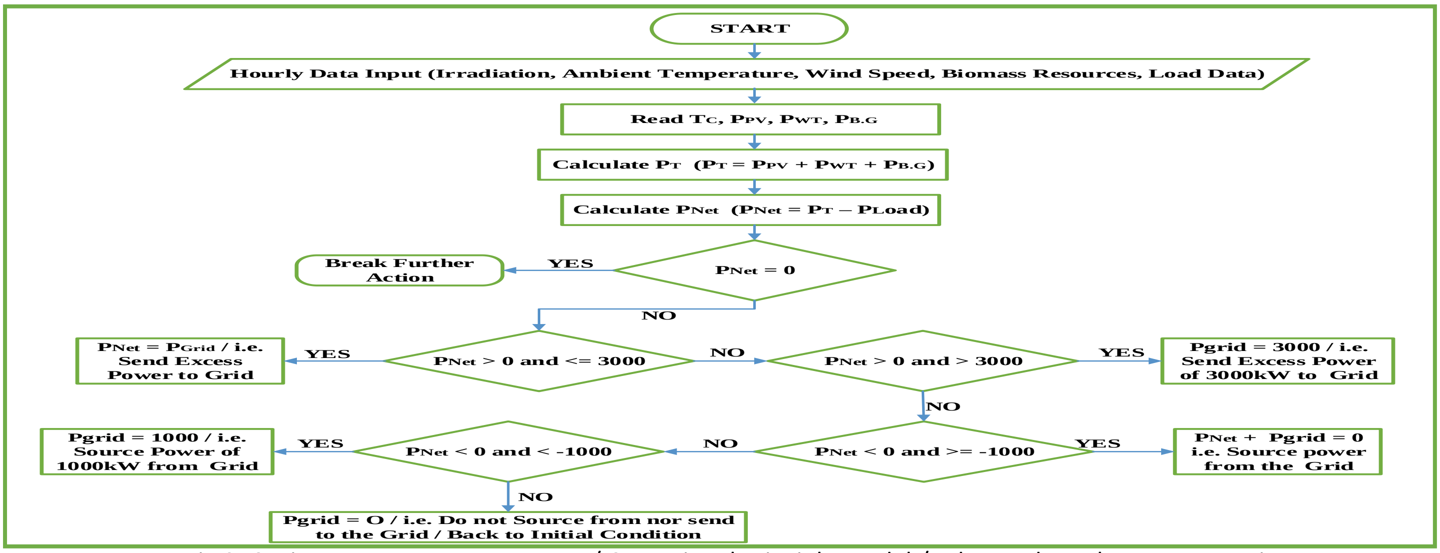

Fig.3: Optimum Energy Management / Operational Principle Model / Advanced Excel VB Programming

The results have been obtained on hourly basis from the operational principle model with the effective management / control, and the below figure shows the power generation with load and grid interaction for a typical day in summer and winter.

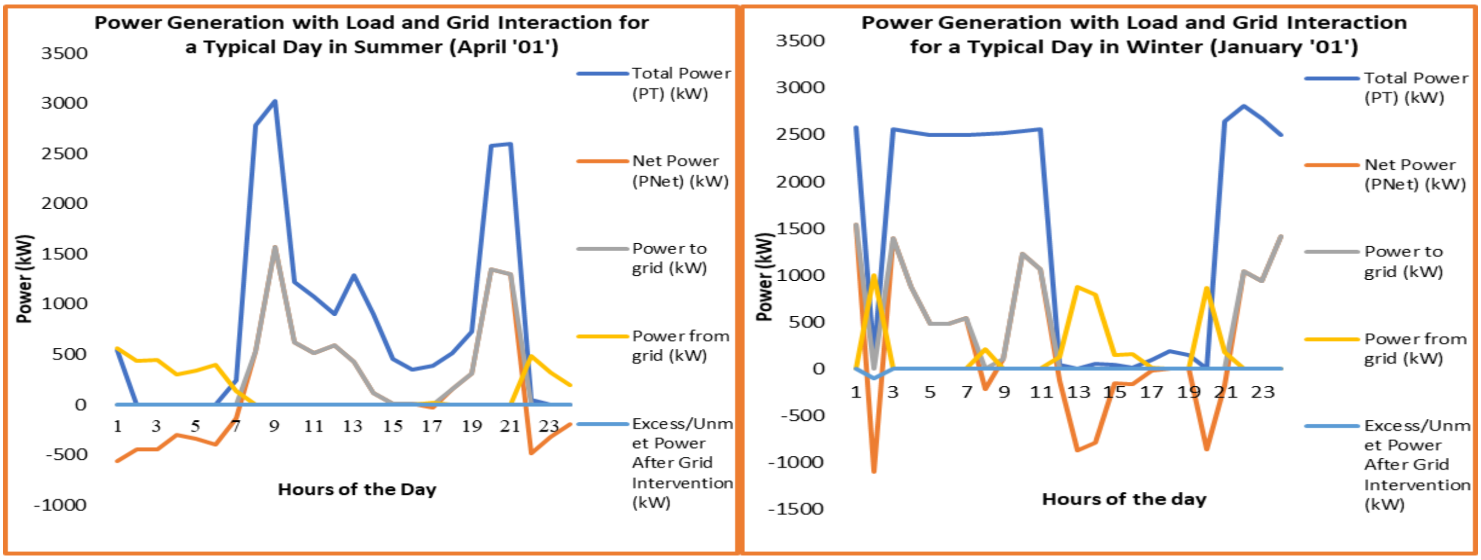

Fig.4: Power Generation with Load and Grid Interaction for a Typical Day in Summer and Winter

4.0 Conclusion

Detailed design of a grid-connected hybrid renewable power system has been proposed and conducted with comparison to other scenarios both off-grid hybrid renewable power system design as well as the conventional standalone diesel and gasoline genset systems for having the clear benefits of the successful transition. It became obvious that for the conventional scenarios, the 4th Scenario i.e. Gasoline Generator System is the worst as obvious from its NPC, LCOE and GHG emission. 3rd scenario as compared to the 2nd scenario is relatively less expensive in terms of NPC and LCOE basing to same generation, however, from emissions, perspective, the 3rd scenario is not sustainable and hence not a viable option. It could be seen clearly that the proposed 100% renewables in its grid connected configuration (i.e. 1st Scenario) is the best option in terms of both overall NPC and LCOE reduction as well as avoided GHG emission and Pollutants. It ensures an overall NPC and LCOE reduction from the 2nd scenario both by 69%. Applying the Energy Efficiency to the proposed 1st scenario even ensures more rapid transition in terms of energy demand reduction, overall costs reduction as well as more avoided emissions. On a final note, the hourly results showed a perfect energy management in the system execution based on the VISUAL BASIC Conditional programming applied.

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