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Simulating Hybrid Power Plants in Strategic Industrial Areas in Nigeria: Solar PV-Diesel Hybrid for Kano Free Trade Zone

Ahmad Garba Khaleel, Mridul Dharwal

Abstract*: *The review the power situation of one of Kano Free Trade Zone, one of the Federal Government of Nigeria's own Export Processing Zones and simulated a hybrid power plant for the Zone and nearby community. It is found that, the power requirements of the Zone are current provided for through an unreliable Grid and 1MW diesel generator, which is quite expensive and unsatisfactory for a manufacturing site. The paper gathered solar resources information of the site using Global Solar Atlas and use the HOMER Grid optimization feature to simulate the most appropriate capacity to provide the recorded load of the Zone. The simulation proposed four viable systems out of which two are considered and recommended for implementation at the Zone as they provide the opportunity for the Zone to provide itself with renewable power using Grid Tied Solar-PV/Diesel hybrid and even sell more power to the grid, nearby community and installations.

Keywords* : *Hybrid, power plant, export processing zone, Kano - Nigeria

I. INTRODUCTION

The impact of distributed power generation on overall access to (clean) energy, pressure on the national grid, total power generation and host of other economic and environmental factors have been documented by a good number of studies for some time now (Suberu *et al.*, 2013; Adaramola, Paul and Oyewola, 2014; Trotter, McManus and Maconachie, 2017; Oyedepo *et al.*, 2018). The situation of Nigeria's power sector can be greatly enhanced through distributed generation especially if strategically done to cluster around key industrial and commercial centres in various cities around the country. The Kano Free Trade Zone (KFTZ) in Kano city of Nigeria provides such good candidate location that stand to benefit the highest from such arrangement. Fortunately enough policy regulations have been evolving in the country over the years to enable the deployment of micro power plants at strategic locations (FMPS, 2006; FME, 2010; ECN, 2012; EREP, 2012; MoP, 2015). The Presidential Task Force on Power (PTFP) has come up with a number of initiatives in this regards (FGN, 2011; Dagogo-Jack, 2012; Oleka, Ndubisi and Ijemaru, 2016; US-ITA, 2018), however, the response of the public and private capital seem to be lagging behind (Agbetuyi, 2018), mainly due to a number of challenges including inadequate technical, management and financial capability locally (Emodi and Yusuf, 2015; Mas'ud *et al.*, 2015; Akinwale and Adepoju, 2019). The technical and financial absorptive capacities are also inadequate to the meet the current challenges not only in power, but other sectors. The use of simulation have been adopted for some years to build the needed confidence in technical, management and financial estimates that enable informed and effective decision making towards developing power and other project around the world (Abam and Effiom, 2015; Olatomiwa *et al.*, 2015; Olatomiwa, 2016; Acakpovi *et al.*, 2017; Ouedraogo, 2017; Movahediyan and Askarzadeh, 2019). The same can be used to train and develop the needed capacities and confidence in working towards meeting the ever growing energy demand in Nigeria strategically. The energy (and particularly power) demand growth in Nigeria and Africa has been and based on population projections will continue to grow towards 2050, and from the available studies there are available resources that can be harnessed to meet this growing demand (Adeyanju and Manohar, 2011; Adaramola, 2012; Felix *et al.*, 2012; Mas'ud *et al.*, 2015). Therefore, the use of modelling and simulation can help tremendously in this regards to provide the low cost avenue for design, development, deployment and testing of planned power plants in Nigeria (Khaleel and Chakrabartib, 2019). This study attempts simulating a hybrid power plant in Kano to generate and supply power first to KFTZ, and in the event of excess generation will then be supplied to the nearby communities. Current load information is obtained via telephonic interview with and email questionnaire sent to and responded to by the contact office representative of KFTZ. The use of HOMER Grid software and the World Bank Global Solar Atlas is employed to design, estimate and test the plant's capacity to supply all or a share of the power need of the KFTZ.

II. THE KANO FREE TRADE ZONE (KFTZ)

KFTZ is the Second Federal Government owned free trade zones established and run under section 1 of Nigeria Export Processing Zones (NEPZA) Act 63 of 1992, located in Kano, northern Nigeria with a growing number of local and foreign companies setting up manufacturing plants there.

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***Correspondence Author(s)**
Ahmad Garba Khaleel*, Department of Economics and Development Studies, Faculty of Arts and Social Sciences, Federal University - Dutse (Jigawa) Nigeria. Email: ahmad.khaleel@fud.edu.ng
Mridul Dharwal PhD, Department of Economics & Int'l Business, School of Business Studies, Sharda University, Greater Noida (UP) India. Email: mridul.dharwal@sharda.ac.in

KFTZ was pronounced an Export Processing Zone in 1998, however, the transformation to Free Trade Zone was approved by Mr. President-In-Council in 2001. Vested with the responsibilities of Licensing, Monitoring and Regulating the activities of enterprises located in an environment encoded in the dynamics of international trade and best practices, as the central attraction to the Zone. As contained in their documentations, the Zone is aimed at overcoming the difficulties and challenges companies encountered, especially in the areas of infrastructural development, functional amenities, taxation and high cost of production or overheads associated with capital intensive ventures. The Management of the Zone ensures that investors do not only have a soft landing and impressive economic advantage, but enjoys various incentives for setting up their businesses. Locating in Kano FTZ, automatically confers upon the investor certain advantages, benefits and incentives which have been strategically design by the Federal Government of Nigeria to create a completive business friendly environment for the investors. These incentives include:

- Complete Tax Holiday From All Federal, State and Local Government Taxes, Rates, Custom Duties and Levies.
- One-Stop approval for all the permits, operating license and incorporation papers.
- Duty- free, tax-free import of raw materials and components for goods destined for re-export
- Duty-free importation of capital goods, consumer goods, machinery, equipment and furniture.
- Permission to sell 100% of manufactured, assembled or imported goods into the domestic Nigerian market.
- When selling into the domestic market, the amount of import duty on goods manufactured int the Free Zone is calculated only on the basis of the value of the raw materials or components used in assembly, not on the finished products.
- 100% ownership of investment.
- 100% repatriation of capital, profits and dividends.
- Waiver on all import licences.
- Waiver on all expatriate quotas for companies operating in the Zone.
- Prohibition of strike and lockouts.
- Rent-free land during the first 6 months of construction

Among the collaborative national agencies are the Central Bank of Nigeria, the Standard Organization of Nigeria, NAFDAC, Nigeria Immigration Service, Nigeria Custom Service. On the Security side, the collaborating national agencies include Nigeria Police Force, Nigeria Airforce, Nigeria Army, Nigeria Security and Civil Defense Corps.

Steady power is crucial to the smooth operations of the manufacturing installations located in KFTZ, as the systems and machineries rely heavily on power to perform their respective tasks in the production line or provision of their specialized services. Lack of steady power supply was long documented as the most troubling challenge facing businesses in Nigeria (Dagogo-Jack, 2012; Suberu *et al.*, 2013; Emodi and Yusuf, 2015; Okorie *et al.*, 2018), with over 80% of firms reporting to own a power generator in their premises to ensure continuous running of their operations (Dagogo-Jack, 2012; Emodi and Yusuf, 2015; Campbell, 2018; Chakamera and Alagidede, 2018; A2EI, 2019). This makes cost of running businesses and factories very expensive, hence making their products and services a bit more expensive to their customers or users (Nkordeh *et al.*, 2017; WEC, 2017; Ebhota, 2019; WPP, 2019). This affects the ease of doing business in the country in general aside other spill-over loss effects ranging from labour efficiency etc. The use of micro power plants under the provisions of the PTFP initiatives and in line different energy policies in Nigeria can be utilized to enhanced the situation with the dedicated power plant. The daily peak demand load from KFTZ is assessed to determine the capacity and energy production of the simulated plant to optimize the use of the different technologies, namely solar and diesel as well as the grid.

III. CURRENT AND PLANNED POWER REQUIREMENTS/SUPPLY

The current power status and requirement of the Zone as obtained through a telephonic interview and email questionnaire are given in the following outline.

1. Peak Load (current and planned/future): 2MW
2. Average monthly or daily consumption: Nil
3. Minimum Load: 1.2 MW
4. Alternative power Source: Diesel Generator 500KVA X 2 = 1MVA
5. Grid supply: 33KVA step into 11KVA currently on 7.5 KVA transformer.

The current power situation in the KFTZ is that, there is an unreliable grid connection that is both expensive and unpredictable along with a back-up diesel generation of about 1MW. Several options are opened to KFTZ to utilize the available opportunities provided by the recent reforms in the Nigeria's power sector allowing on and off-grid sales of generated power. A very good example of these opportunities is off-grid captive power plants of 5 – 19 MW for resale to manufacturing industries like those within the KFTZ in strategic cities like Kano (US-ITA, 2018). Considering these circumstances and the other aspirations for sustainable development, a very good option is to utilize the most readily available power technology that fits both costs and environmental factors. The fisrt technology that usually comes to mind is solar for its availability and level of penetration in this part of the country, i.e. the best option is to develop a solar PV-Diesel hybrid for the KFTZ. The logic here is to put to use the currently installed diesel back-up generator at an environmentally acceptable manner through to its final depreciative age as this will improve the resilience of the hybrid power system. The configuration and simulation of the system is presented in the following section.

IV. THE HYBRID POWER PLANT SIMULATION (CAPACITY AND OUTPUT)

The electric load profile is essential for determining the appropriate plant capacity that will produce the require power in a reliably planned manner. The load profile, as a graph or table of the variation of electrical load over time gives the needed information on the pattern of energy use in a particular location over time.

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It is also known as load duration curve if plotted as a line graph over time, and is useful in the selection of capacity units for generating and supplying electricity. These essential details are not provided in the telephonic interview with and the questionnaire sent to KFTZ contact office. Therefore, capacity of the solar PV part of the hybrid system being considered here is determined based on the information obtained about the current peak and minimum loads in the zone, and also by looking at the site's solar associated resources and other key performance parameters like the air temperature. With data for only the current peak load of 2MW and minimum load of 1.2MW, an average load of 1.6MW is computed. The table below gives an overview of consumption possibilities for 12, 16 and 24 hours generated based on average load in MW along with assumed daily MWh energy requirement in KFTZ:

Table 1: KFTZ's Daily estimated consumption based on average load of 1.6MW

Daily load duration (Hours)	12	16	24
Consumption (MWh)	24	32	48

***Source:** Authors' calculations*

The logic behind these hours is considering the operational practices of most manufacturing lines ranging from 2 6hrs, 8hrs and 12hrs shifts daily, with the predominant being 2 8hrs shifts daily. Based on the above possibilities of load duration and energy requirement estimations, a probabilistic approach is used to arrive at the various possible capacities needed to meet the maximum daily load requirement using World Bank's Global Solar Atlas as shown in table 2.

Table 2: Possible solar PV capacities and their respective daily generations

Capacity (MW)	3	4	5	6	7	8	9	10
PV Output (MWh)	13.31	17.74	22.18	26.61	31.05	35.48	39.92	44.35

***Source**: GlobalSolarAtlas*

Within these possibilities, the capacity and PV output that fits the predominant two 8hrs shifts practice is 7MW producing 31.05MWh daily. Though this is slightly less than the 32MWh requirement, it is also assumed that, the grid and diesel-generator will be put to use when need, particularly for start-up power. These capacities are the inputs into our hybrid plant simulation using HOMER software. The system is expected to supply power to KFTZ and sell excess to nearby installation, community or back to the grid during the day at the Renewable Energy Feed-In-Tariff (REFIT) benchmark set by the Nigerian Electricity Regulatory Commission (NERC), which is currently about $191.63/MWh of energy generated using solar. The average solar resources of the location as obtained from Global Solar Atlas are given in Figure 1, where it can be seen that, the global horizontal irradiation (GHI) is about 5.827kWh/m^2 per day, direct normal irradiation (DNI) is 4.153kWh/m^2 per day and average air temperature is 26.9°C.

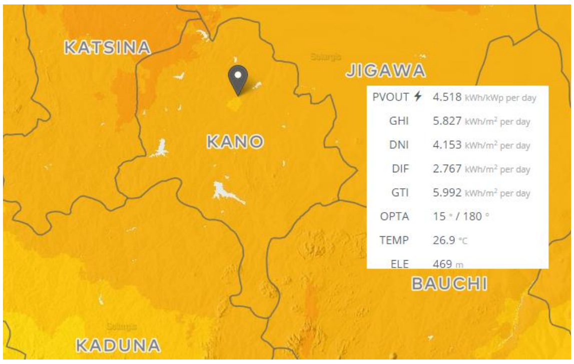

Figure 1: Project Location and solar resources

Source: *Global Solar Atlas*

The data used in this simulation are obtained from KFTZ, NERC and Global Solar Atlas to build the assumptions that form the foundation of the model. These assumptions regarding the load, generation requirement and tariff for buying and selling electricity as well as the guiding policies are summarized in Table 3, while capacity and capital coasting are allowed to be generated by HOMER Grid optimization feature.

Table 3: General Assumptions

Description	Units	Amount
KFTZ Peak Load	MW	2
KFTZ Minimum Load	MW	1.2
KFTZ Average Load	MW	1.6
Average daily energy requirement	MWh	32MWh
KEDCO Energy charge/kWh	USD	0.064
Monthly Fixed Charge	USD	779.89
REFITs for solar	USD	0.19163
Exchange rate (N to $)	Naira	362
Local Inflation	%	11.22
Project Life time	Years	20

Based these assumptions, the study modelled four alternative power system using HOMER Grid Optimization namely; Grid Tied Solar-PV/Diesel Hybrid system, Grid Tied Solar PV system, Grid Tied Diesel system, Grid Only system. From the onset, it is already stated that, the grid is unreliable, so that is removed by default, while the current energy system that KFTZ is on is the Grid Diesel system which is exorbitantly very expensive to run. The two contending systems left are Grid Tied Solar PV and Grid Tied Solar PV Diesel Hybrid, the summary of which are presented in Table 4:

Table 4: Optimized Energy System for KFTZ

Description	Grid-Tied Solar-PV	Grid Tied Solar PV/Diesel
Capacity	PV (96MW)	PV (96) Diesel(2.5)
NPC	USD636 Mil	USD635 Million
COE	USD 0.1523	USD0.1522
Initial Capital	USD133 Million	USD136 Million
Operating Cost	USD27.8 Million	USD27.9 Million
Production ()	169,111,936 kWh/yr	169,111,936 kWh/yr
Energy Cost	USD26.3 Million	USD26.3 Million
Energy Purchased	5,361,906kWh	5,361,906 kWh
Energy Sold (kWh)	139,447,840	139,447,840
Renewable Fraction	96.5%	96.5%
IRR (%)	20	20
Pay Back Period	4.8 yrs	5 yrs
Utility Bill Savings	USD27 Mil/yr	USD27 Mil/yr

The two systems are both economically viable despite the very slight differences in some of the technical and economic parameters including the capacity (2.5MW), NPC (USD1 Million), initial capital (USD3 Million), operating cost (USD0.1 Million) and simple payback period (0.2 year). Based on these differences the Grid Tied Solar PV/Diesel Hybrid appears to be more expenses even though it has a cheaper cost of electricity by the margin of 0.0001USD. Nevertheless, unless if a strong power purchase agreement PPA is put in place with strong penalties for non-compliance, the unreliability of the grid will still make the hybrid more preferable than the Grid Tied Solar PV. Several benefits are present in both systems apart from their financial viability especially the increased overall power generation, reduction in the kWh cost of energy and improved reliability, predictability and control of both costs and generation.

V. CONCLUSION

It is established that, adding a 96MW solar capacity to the existing 1MW diesel generation and grid connection will improve the level of generation, reduce the cost per kWh of energy within the zone, and autonomy in terms of control on costs and generation which improves reliability and predictability – resilience of the power supply in KFTZ. It also gives the site the status of energy provider as the total energy generated can be sold to the grid at the REFITs rate which is higher than the grid's rate, thereby making a huge gains in terms of both reducing the volume of energy purchase and the volume of energy sold. Adjacent to the KFTZ is Mallam Aminu Kano International Airport, which is the largest and busiest airport in the whole of Northwestern Nigeria that is run by the Federal Airport Authority of Nigeria (FAAN). Surplus energy can as well be sold the Airport on an agreed upon rate apart from the grid.

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AUTHORS PROFILE

Ahmad Garba Khaleel is currently a Doctoral Candidate at the Department of Economics and International Business, School of Business Studies, Sharda University, Greater Noida (UP), India. Back in Nigeria, he works with Economics and Development Studies Department of Federal University Dutse, Jigawa State - Nigeria. He holds M.Sc. Economics from Bayero University, Kano - Nigeria. During the course of his Ph.D. research, he consulted at Resource and Information System for Developing Countries, one of the most prestigious Indian Government's Think Tank under the External Affairs Ministry, New-Delhi. Prior to that, he completed the Entrepreneurship Training Workshop – ETW of the Empretec, an UNCTAD Entrepreneurship Programme with presence in over 40 transition economies and served as an Associate Facilitator of the programmes of Empretec Foundation of India.

His broad research interest covered a number of areas in Development Economics, as Energy Economics, Digital Economy, Natural Resources Economics and the role of Entrepreneurship in these fields. He is currently working as part of his PhD research on ways of enhancing Transition to Renewable Energy in African Countries with focus on West Africa and Nigeria through power sector collaboration under the principles of South-South and Triangular Cooperation.

Dr. Mridul Dharwal is working as an Associate Professor in School of Business studies, Sharda University, Greater Noida Since 10th July, 2007 to till date. He has visited UNO head quarter at Geneva in 2011 to understand the functions and role of UNO for the development of country like India. He has travelled many of countries for academic assignments and for developing the understanding about the various economies for instance Italy, U.K., France, Switzerland, Singapore Thailand Dubai and Canada. He has successfully coordinated several International study Programmes .His research papers have been published in various national and international refereed journals and Proceedings. He has participated in various national and international conferences on various contemporary economic issues. He has a rich experience and expertise to conduct training session on Teaching Strategy, Teaching Learning Process and Classroom Management. He is a Member of IQAC (Internal Quality Assurance Cell) and Member of Core Team of NIRF (National Institutional Ranking Framework) He has been assigned the responsibility of Joint Coordinator of NAAC Steering Committee. He has Participated in the WOSA (World Summit on Accreditation) organized by NBA.

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