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Optimization of Micro Grids Using Homer—A Comparative Analysis Between India and Botswana

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Fast dwindling fossil fuels and its impact on carbon footprint, encourage the use of renewable energy sources as an alternative power source supply. Renewable energy resources are now playing a pivotal role in gradually adding to the development of community and country. This paper provides a comparative analysis and insight into of two different countries with near similar climate profile. It focuses on optimal sizing and design, planning and operation of a microgrid solution for two communities and demonstrates the usage through the case study while taking into account cost factors, environmental emissions, economics. The modeling includes a combination of Solar PV's, Wind Generators, Grid. The simulations are carried out using well-known modeling software HOMER. The paper accommodates sensitivity analysis to perceive the impact of Solar insolation, investment costs of PV, Converters, and fuel price on the optimum result. The results also positively encourages use of renewable energy as a source to reduce greenhouse gases and reduce carbon footprint as per Kyoto Protocol.

Key Words: *Levelized Cost, O&M, Unmet Electricity Load, Annualized Cost*

INTRODUCTION

Energy plays a pivotal role in the socio and economic development of a country. With the depleting fossil fuels, it is crucial that the developing countries utilize other renewable sources and tap the potential for its evolution. The energy demand is expected to grow significantly (Anjan Kumar Sinha, 2017) in developing countries, and considering the limited resources used for generating electricity using fossils like Coal, Oil and other fuel sources it becomes a major bottleneck. It is therefore essential to tap the renewable and alternative energy resources to lower the impact on the planet and reduce carbon footprint (Jesús Rodríguez-Molina, Margarita Martínez-Núñez, José-Fernán Martínez, Waldo Pérez-Aguiar, 2014). Thus, it vital that renewable resources act as a catalyst to increase and improve energy access in remote rural areas (A.S. Maiga, G.M. Chen, Q. Wang, J.Y. Xu, 2008). India and Botswana are fast developing countries with a GDP per unit of average energy use5.6% and 9.45% as shown in figure 1(World Bank, 2017). Rapidly increasing energy demands result in emissions. The CO_2 emission levels in both India and Botswana have reached alarming rates as shown in figure 2 (World Bank, 2017). Both the countries are fighting hard, the need to mitigate global warming and mounting pressure to reduce carbon footprint and pollution have led to governments encouraging renewable energy generation by providing subsidies and incentives. As of 2016, over 5 million people across the globe have been living without electricity, and this poses a major challenge to the developing nations. Both Botswana and India are no exceptions to this rule. Access to energy in rural areas in developing countries is paramount as a means of increasing standard of living and sustainability and tops the agenda

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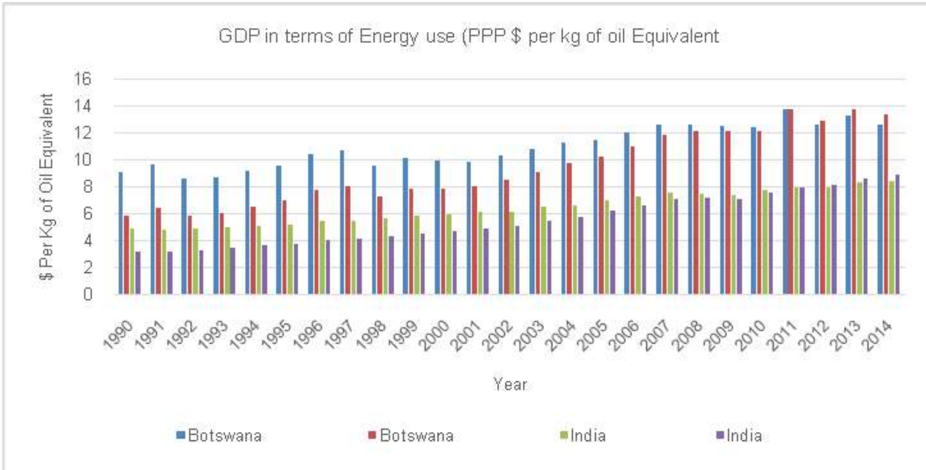

Figure 1: GDP in Terms of Energy use (PPP $ Per kg of Oil Equivalente)

Source: World Bank

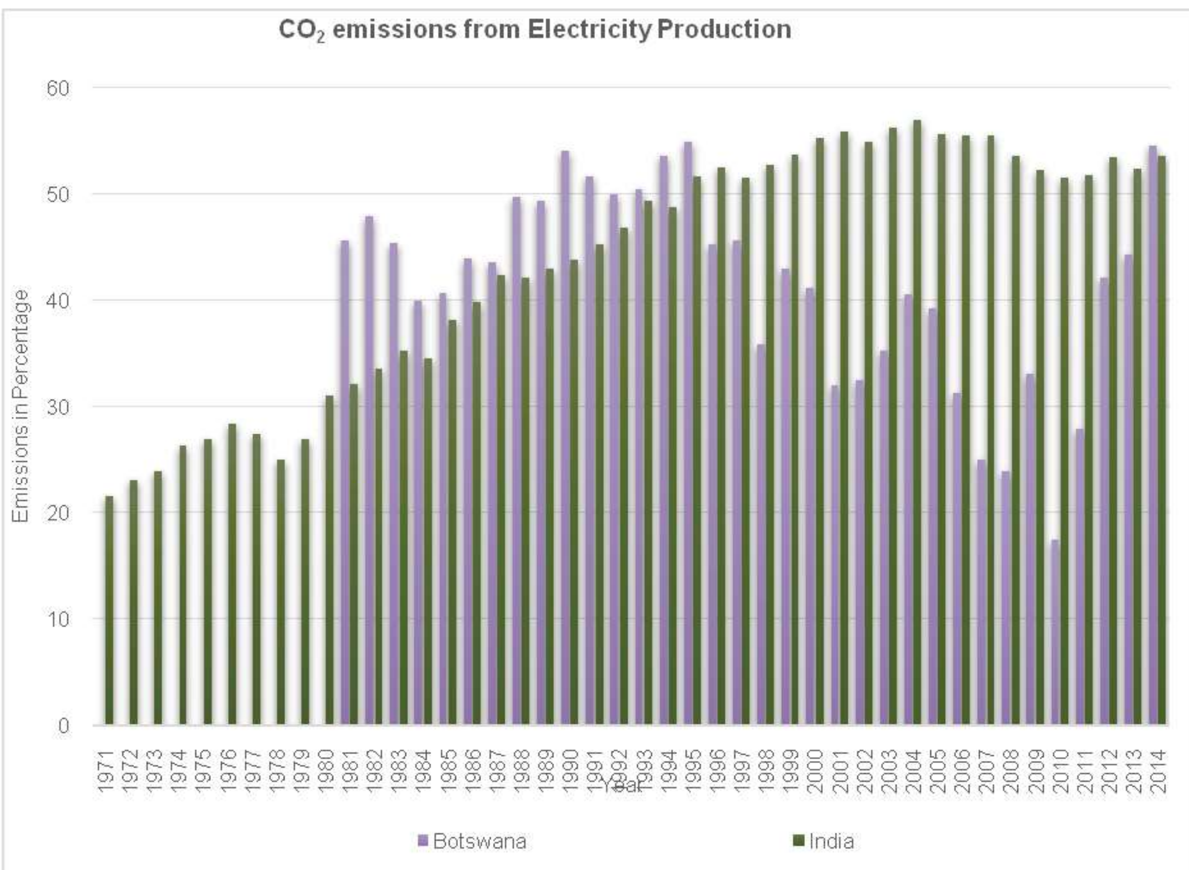

Figure 2: CO2–Emissions from Electricity Production(World Bank, 2017)

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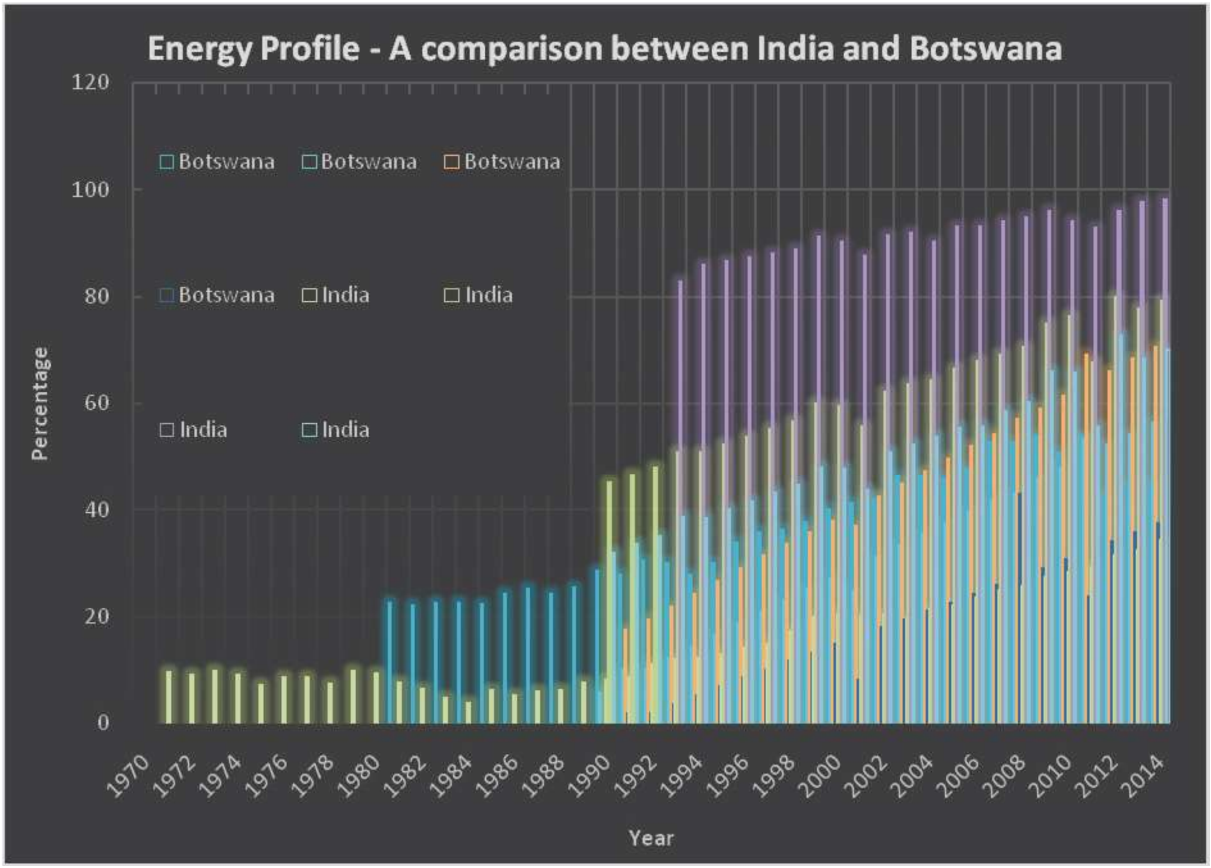

Figure 3: Energy Profile Comparison

in any developing country (Karekezi S, Ranja T, 1997) (Karekezi Stephan, Waeni Kithyoma, 2-4 June 2003) (Karekezi Stephen, Waeni Kithyoma, 2002) (Djiby-Racine Thiam, 2010).

India and Botswana are nations that have been plagued by energy, and climate challenges for decades and has been a bottleneck in development. These challenges need to be addressed as they are critical for developing the socio-economic growth in the area. As indicated in figure 3, lack of access to critical commodity, 'electricity' is a major determinant of poverty in both the nations. According to world energy outlook report 2014, Sub-Saharan Africa has more than 620 million people that are nearly half of total global figure living without electricity and is rising day by day due to rapid population growth. The population without access to electricity in Botswana is about 1 million.(IEA, 2014) (IEA, 2014). According to world bank data 2014 (see figure 3), the percentage of the population with access to electricity in India and Botswana is 79.16% and 56.58% respectively. The population with access to electricity in urban and rural areas were 70.6% and 37.52% for Botswana while for India it was 98.2%and 70.02% respectively (World Bank, 2017).Although India has doubled its generation capacity, the country still faces energy and development challenges. About 240 million people that is one in five Indian citizens have no access to electricity and needs about 140 billion dollars in energy investment per year to 2040 that is more than 110 billion dollars for energy supply and another 30 billion dollars to improve energy efficiency. (IEA, 2015). The majority of thepopulation in both the countries live in rural areas. While India has concentrated on powering up rural areas (70.02%), Botswana has to enhance its access to the countryside which is about half of India's electricity access in rural areas (37.52%). This

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indicates that there is an urgent need for new technologies to be implemented to improve the energy profile for both the countries. The grid infrastructure across both countries still operate in the same manner, and not much has changed in its outlook. The same holds good for the generation part of the energy while there has been considerable expansion and growth in the non-renewable energy development in India, Botswana has a long way to go in comparison. The primary reason for the above scenario is the inability of the Governments to focus on advanced technologies. (Fangxing (Fran) Li,Wei Qiao,Hongbin Sun,Hui Wan,Jianhui Wang,Yan Xia,Zhao Xu,Pei Zhang, 2010) (Clement and Kevin, n.d.).

Virtual power plant or micro grids is a cluster of Distributed Generators with controllable loads and systems. Its unique nature can be a combination of the fossil generators, renewable energy source. The group of generators are connected to a centralized energy management system by mutual coupling and is bidirectional. CERTS first developed microgrids. (Consortium for Electric Reliability Technology Solutions. (Hina Fathima, K Palanisamy, 2015). The advent of artificial intelligence coupled with optimization algorithms has contributed hugely to the development of critical infrastructures, and research has paved the way for advancement in VPPs application (Wu Haitao,Huang Fuzhen, July 6-8, 2012), thus enabling to breakdown complex structures into simpler and efficient way. The virtual grid plays a relevant role in the process of optimization in a virtual power plant. The challenges in the virtual power plant are enormous because it is a combination of units like PV, Wind Turbines, Geothermal, Hydro, Wave. Due to this fluctuating nature of the energy resources, it is not easy to achieve the same. In a virtual power plant, each unit of DG is connected either directly or indirectly through the grid to the centralized management systems. It is therefore imperative to provide information about the actual participant in the cluster, and therefore communication becomes a critical aspect of the plant. Several components need to be taken into account when communication becomes the focus. Some of the components are grid security; grid data flow exchange, speed/ delays. Since the system is networked it is essential that the system is fast, reliable, provide minimum delay and expandable to adding new devices. (Pio Lombardi, Michael Powalko, Krzysztof Rudion, 2009; 2nd October 2009). It is essential to manage the combined production of electrical energy in a virtual power plant efficiently on network constraints (Roberto Caldon, Andrea Rossi Patria, Roberto Turri, August 22-27, 2004).

This paper provides insight on various techniques used in optimization and analyzes the possibility to develop simple micro ON grid model utilizing local renewable energy. The optimization is conducted using HOMER software. The paper is organized into five sections. The first section is introduction, the second provides insight into various methods used in optimization, the third section describes the system configuration of the proposed model and development using Homer Mode, the fourth section presents a comparative study of a small colony of houses in both the countries, results and discussion and the last (fifth) section concludes the research paper.

1. INSIGHT INTO ENERGY CONSUMPTION AND OPTIMIZATION TECHNIQUES

Studies have been carried out by various authors on electricity consumption pattern. Understanding energy consumption in the normal household is critical to understanding the energy usage in a country. It is an increasingly difficult task to identify the behavioural pattern despite numerous attempts by the utility companies. A micro-level, microeconomic approach was adopted by Pachauri, Pauchari et. al, Tiwari. The authors use household consumption and expenditure data to estimate price and income elasticities of electricity demand in the residential sector. (Anon., July 2008) (Shonali Pachuari, 2004) (Shonali Pachuari, Massimo Filippini, 2004) (Tiwari, P, 2000).Wood et.al, identified micro-level activities in the UK by studying 41 households by using different parameters and categorizing which included the age of the house, age groups in the house, behavioral patterns, time taken on activities especially daily

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chores, influential factors through a specially designed format (Wood G, Newborough M, 2003). Tso et.al made a similar study on energy by categorizing houses on income group, household characteristics, appliances used, the number of household members and concluded that the factors influenced on household energy consumption (Geoffrey K.F. Tso,Kelvin K.W. Yau, 2003). Firth et.al discuss the pattern and conclude that there was a significant 4% increase in consumption over a 2 year monitoring period recorded for 72 dwellings in the UK (S. Firth, K. Lomas, A. Wright, R. Wall, 2008). (Eng L Ofetotse, Emmanuel A Essah, Runming Yao, 2015). In their report, Aditya et.al indicate that the electricity consumption by households has increased by about 50% since 1971 in India, which now constitutes about a quarter of India's total electricity consumption. They also provide an insight into how much the electricity usage will increase in the next 5-6 years due to India's energy plans. (Aditya Chunekar, Sapekshya Varshney, Shantanu Dixit, December 2016).

In mathematics, the optimization problem is to find a most optimal solution. Optimization techniques may be applied in energy grid to obtain best optima. In power systems optimization the main objective is to minimize unwanted input like energy loss, errors, and to maximize desirable elements like profit, quality, efficiency. Heuristics includes trial and error solution but feasible solutions within time limits. Various optimization techniques have been studied and applied to solve many complex power system problems since 1950&60's by different authors. (D.P. Kothari, A. Ahmad, 1998) (Kothari D.P, 1988), (S. Sen, D.P. Kothari, 1998), (J.A. Mamoh, El Hawary, R. Adapa, 1999) (J.A. Mamoh, El Hawary, R. Adapa., 1999), (M.S. Sachdev, R. Billinton, C.A. Peterson, 1977). Optimization can either aim at minimizing energy production costs and maximizing profits or maximizing reliability, power quality, in short, on generation, control, operational,and distribution side. In a virtual power plant, it is essential to minimize generation costs and maximize profits. There are several optimizing techniques applied successfully in Energy. Muis et.al demonstrate optimal planning of renewable energy systems using mixed integer linear programming (MILP) for Malaysia to reduce the carbon dioxide emission by 50% from current emission level. They use IGCC (Integrated Gasification Combined Cycle, NGCC (Natural Gas Combined Cycle) and biomass from landfill gas and palm oil resources (Muis Z,Hashim H,Manan Z,Taha F, Douglas P, 2010). (Omar Hafez, Kankar Bhattacharya, 2012) Nazir et.al proposed a microgrid model that integrates the power plants driven by employing micro hydro (MHP) and photovoltaic system (PV) connected to the grid system. They analyze the possibility to develop the simple microgrid model optimizing the utilization of local renewable energy for the on-grid area by using HOMER and MATLAB simulation (R. Nazir, H. D. Laksono, E. P. Waldi, E. Ekaputra, P. Coveria, 2014). Thiam studies feasibility analysis in remote areas of Senegal on off-grid stand-alone renewable energy technology systems to compare the electricity costs with normal grid operations and shows that cost of renewable energy technology is lower than the cost of energy generated from the grid. (Djiby-Racine Thiam, 2010) Aris et.al studies PSO algorithm for optimal sizing of Photovoltaic grid connected systems (Aris Kornelakis, Yannis Marinakis, 2010). Eberhart et.al study stochastic based Particle Swarm Optimization, which based on the population of birds flocking social behavior. A randomly selected population initializes the system and searches for optima by updating generations and has no crossover and mutation. (Eberhart R C, Kennedy J, 1995). Nayar et.al successfully implemented the hybrid system in three remote islands of Maldives (Nayar C, Tang M, Suponthana W, Nov 2008). Mizani et.al propose a mathematical model and optimization algorithm to identify the optimal microgrid configuration and obtained results for an optimal selection of renewable energy in conjunction with an optimal dispatch strategy in a grid-connected microgrid. (Shervin Mizani, Amirnaser Yazdani, 2009). (Omar Hafez, Kankar Bhattacharya, 2012) Amin Salmani et.al propose a non-linear profit maximization using General Algebraic Modeling system with constraints for the supply of electric energy for all loads in a VPP (M. Amin Salmani, S.M. Moghaddas Tafreshi, Hosein Salmani,

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28-30 September 2009). Zhao et.al analyses and suggests optimization model considering the battery life costs, operation, maintenance cost, fuel cost including lifetime characteristics of lead-acid batteries. They propose a multi-objective optimization model to minimize power generation cost and to maximize the life of lead acid batteries using anon-dominated sorting genetic algorithm (NSGA-II).(Zhao Bo, Zhang Xuesong,Chen Jian,Wang Chen, 2013).

1.1 Solar Resources in Distributed Grids / VPP

A distributed grid or VPP can have multiple sources of inputs to the grid. It can be a combination of PV Systems, Bio Gas Generators, Diesel Generators, Wind, Wave. This paper mainly focuses on three sources of input Solar, Wind and Bio Diesel generators. Since virtual power plant is a combination of resources where small individual DG's make up a combined power unit, the total electricity generated can be combined as follows

$$P_{grid\_total} = P_{Chp/PV} + P_{Gas} + P_{Wind} + P_{Wave} \quad (1)$$

Where Pgrid_total is a summation of all the power units generated in the VPP system, P_{Chp} is Combined Heat Power or PV systems, P_{Gas} is Bio Gas Generators, P_{Wind} is Wind turbine, P_{Wave} is Wave.

The PV System comprises of a photovoltaic array made of silicon semiconductor crystalline materials which capture the light photons and converts it to electrons. The generated output is non-sinusoidal or DC and is converted to AC using converters. Therefore specific MPPT system is employed to maximize the energy from the sun by tilting the angle of the PV's or tracking the sun. As solar insolation varies with the direction of the sun, the MPPT system adjusts itself to maximize its capture of solar radiation to generate maximum real power at a constant voltage. Efficiency in solar panels is measured by the ability to convert sunlight into energy and is a very significant factor in choosing the correct panel for PV system.

The output of PV depends on many factors like temperature, irradiance, type of material. Its efficiency can be represented and expressed as follows

$$R = \frac{Pmax}{F(rf)*A} R = \frac{Pmax}{F(rf)*A} \quad (2)$$

Where R represents Maximum Efficiency, rfrepresents Incident radiation flux in W/m2 or Solar irradiation, and A represents Area in Sq.mt

Or

$$Ppv = Pstc \frac{Gc}{Gstc} [1 + k(Tc - Tstc)$$

CITATION Zha13 \l 1033 | (Zhao Bo, Zhang Xuesong,Chen Jian,Wang Chen, 2013) } (3)

Ppv = the output power,

STC = Standard Test Condition (Solar Irradiance Gstc is 1000 W/m^{2,}

PV temperature Tstc = 25^{0}C,

Relative atmospheric optical quality is AM 1.5 condition

Gc = irradiance of operating point,

K = power temperature coefficient in deg kelvin.

Pstc = rated output power under STC,

PV = PV temperature of operating point

Energy can be represented by the formula

$$E = A * R * h * pr \quad (4)$$

Where E = Energy in Kwh

A = Total Area of Solar Panel

R = Efficiency of solar panel

H = Annual solar radiation on tilted panels

Pr = Performance ration, coefficient for losses (range between 0.5 and 0.9; default value = 0.75)

1.2 Wind Power

The Wind is a good source of alternative energy. Many countries have installed wind farms. India is one among the top 5 countries to tap this market extensively, and the Sate of Tamil Nadu leads in wind power generation. The wind energy is calculated by using the formula

$$P_{wind} = 0.5A_pV^3C_p \quad (5)$$

Where A is rotor sweep in m2, p is air density in kg/m3, V is velocity in m/s, and Cp is the coefficient of power, which is a function of tip speed ratio and rotor speed. Since the power generated is directly proportional to wind velocity, a small difference in speed results in either increasing or decreasing the power generated and the cost. (Hina Fathima, K Palanisamy, 2015)

1.3 Diesel Generators

Diesel generators are mostly used as back-up resources. In the event of the solar PV's failing to supply the required load, the generators kick in to meet the required load. Factors that influence Diesel generators include fuel costs, maintenance and running costs, transportation costs, load etc. (Alexis Kwasinski, Vaidyanathan Krishnamurthy, Junseok Song, Ratnesh Sharma, 2012), Generators efficiency is determined by the total power or load in the circuit and the total watts produced by the generator and is expressed in percentage and the losses include transformer, copper windings, magnetizing losses in the core and rotational friction of the generator. Normally generators on full load is more efficient and economical. In simple words generator efficiency is expressed as

$Ntot = Nbt \times Ng$ CITATION Placeholder5 \l 1033 | (Hina Fathima, K Palanisamy, 2015) }

Where

Ntot = Overall

Nbt = brake thermal

Ng = generator

1.4 Economics in Power Generation

Different components in electricity generation influence the costs and these costs can be calculated at grid or the point of connection to a load. The costs are typically given in kWh or MWh, and it typically includes capital, discount rates, subsidies, operational costs like fuel, maintenance. Since electrical generation connected to the grid is from many sources hydro, PV, nuclear, the costs of these need to be standardized or levelized. Levelized cost is the measure which attempts to compare different methods of electricity generation on a constant basis, in short, it is averaging the total cost to build and operate a power generating equipment. LCOE can be regarded as the minimum cost at which electricity must be sold to end users to achieve break even over the lifetime of a project. (Wikipedia, 2017) (Matthew Wittenstein, 2015)

The elements influencing the total cost of the system is net cost and cost of energy. The following equation is normally used for calculating total net cost

$$CTot = \frac{CAnnual}{F(interest, years)} + \frac{CAnnual}{Ei+Eg} \quad (6)$$

Where

CTot = total net cost,

CAnnual = annualized cost,

F = capital recovery factor

Interest = annual interest rate,

Years = no of years.

Ei = electrical energy that microgrid serves

Eg = Amount of electricity sold to the grid by micro grid

Levelized cost can be calculated by using the following formula

$$LCOE = \frac{\text{Sum of Costs}}{\text{Sum of Electrical energy produced}} \quad (7)$$

CITATION Mat15 \l 1033 | (Matthew Wittenstein, 2015) }

$$LCOE = \frac{\sum_{t=1}^{n} \frac{It+Mt+Ft}{(1+r2)}}{\sum_{t=1}^{n} \frac{Et}{(1+r2)}} \quad (8)$$

It = Yearly Investment Expenditure

Mt = Yearly Maintenance and Operations Expenditure

Ft = Yearly Fuel Expenditure

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Et = Yearly Electricity generated

r = discount rate

n = lifetime expectancy of the system or power station

2. SYSTEM CONFIGURATION, DESCRIPTION AND CASE STUDY

Case Study

HOMER is a product developed by the U.S. National Renewable Energy Laboratory (NREL) to assist simulation, planning of renewable energy systems and used for designing smart grids, microgrids, VPP. The system allows to simulate both off-grid and on-grid scenarios and can be employed in remote and rural areas for simulating loads, estimating costs and optimizing the system. The system also helps in considering various factors influencing the system like sensitivity analysis, future fuel prices. In HOMER the cost of the system is total cost comprising of capital cost, replacement and maintenance cost, operation cost, fuel consumption costs, miscellaneous costs. The system also includes costs for pollution tax, emission costs, grid costs and many more features. The difference between the interest rates and the inflation rate is equal to real interest rate is also accommodated and needs to be entered by the programmer. (Felix A. Farret, 2006) (HOMER) (Lambert T)

Model Inputs and Assumptions

Figure 4 illustrates the available energy supply options for proposed schematic microgrid system for the communities, under consideration, are PV's (array), Wind farm, Battery bank, convertors. The method proposed is ON grid. Two different locations were taken up for study one in Gaborone, Botswana and other in Coimbatore, Tamil Nadu, India for comparison. The solar-climate profile and wind profile for the two test sites are given in figure 5. As seen from the climate profile, both the countries have more or less similar solar penetration, but however, the wind profile differs. India has a superior wind profile when compared to Botswana.

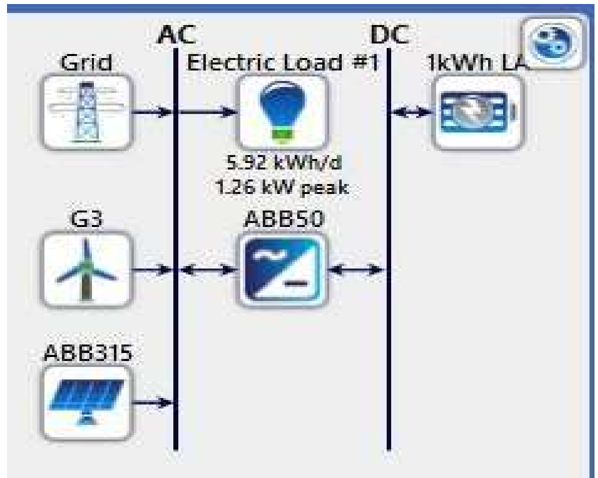

Figure 4: Model selection with Available Energy supply

Electrical Load Profile

Data for the study was collated to develop an energy usage pattern in the households, through an energy measurement calculation sheet designed for assessing consumption. The sheet was circulated to individuals living in different localities of two test sites through electronic means. The responses received were used for accessing energy usage on a day, month. Based on that the total energy usage a load profile for each month from January to December was designed for data inputs in HOMER. Power consumption data inputs tabulated in Appendix I, Table 6, was used for calculating the load profile. The period during the afternoon hours in the evening and the night was assumed at constant values. 15% daily noise and 20% hourly noise was considered for the study. The HOMER profile for daily profile and seasonal profile is shown in figure 5. Energy was calculated based on simple formula

Eapp = Napp * Arat * Hrs (Essah E. A, Ofetotse E. L, 2014) (9)

Where Eapp is energy use per appliance, Napp is the number of the appliance, Arat is rating of the appliance in watts, and hrs is the duration of an appliance usage in hrs.

Economics

The annual real interest rate considered is 0.7%. The real interest rate is equal to the nominal interest rate minus the inflation rate. The project lifetime is 25 years. The model constraints include maximum annual capacity shortage, varying from 0% to 10%.

PV Selection

ABB PVS800-315 was selected for the PV component. The selection is made as a 3 phase grid tied inverter. The capital cost is calculated at 4500$/kW for Botswana and $3500/kW for India including the cost of purchasing solar panels, mounting panels, control systems, wiring, and installation. Based on the specifications the age of the module is fixed at 25 years, and the calculation is based on 25 years The default derating factor of 96 is maintained for the proposed system.

The PV Power generation out is determined by the following equation

Power in PV (P) = derating factor of PV * rated capacity (Solar Irradiance / Standard radiance) and can be expressed as

$$P = f * r \left(\frac{Ir}{Is}\right) \quad (10)$$

Where P is power in kW, f is derating factor of PV, r is rated capacity of PV in kW, Ir is solar radiation in kW/m2, Is is the standard amount of radiation in kW/m2.

Wind Resource

The wind profile for Gaborone, Botswana, and Coimbatore, Tamil Nadu, India is considered for this research work. Botswana has a low profile wind data, and the annual average is 4.44 m/s. The figure 5 & 6, shows the wind profile for one year for Gaborone, Botswana and Coimbatore India downloaded from NREL. Wind turbine costs include capital cost, replacement cost. The height is set at 15m.

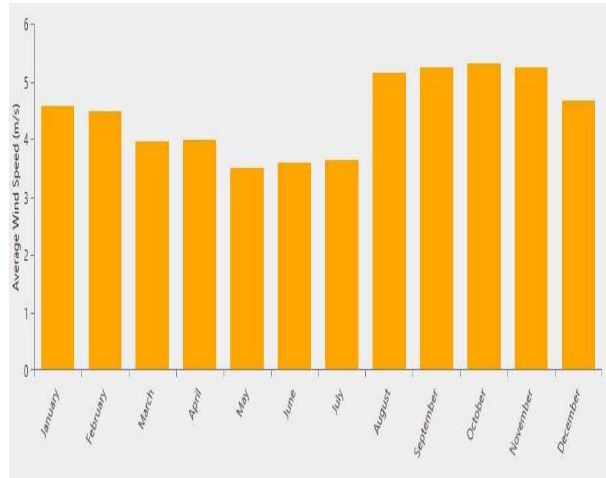

Figure 5: Wind Profile for Gaborne, Botswana

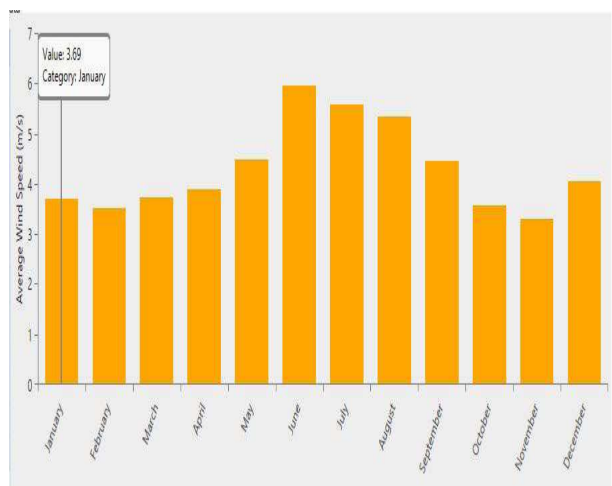

Figure 6: Wind Profile for Coimbatore, India

Battery and Converter Model

1 KVA Li-ion battery per kVA is provided to improve the system performance of the micro-grid. The device is used in the event of short time disturbances and climate variations and also to act backup power. The number is adjusted to suit the capacity of the PV generation. The capital cost and replacement cost is assumed at 300$. A DC to AC converter system is also provided to manage the flow of the electrical power in both the directions. The cost for the converter is a part of the ABB PV system.

Utility Grid Operations

The current laws in Botswana and India do not allow selling of electricity back to the grid. However new laws are being enacted to accommodate the above.

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Simulation and Optimization

Homer analyses the technical feasibility and lifecycle costs of microgrid for each year and tests the input components over the given period. The simulation capability is long term for HOMER. The optimization and sensitivity analysis is performed to determine the simulation capability with the configurations defined by the user. The minimum cost of microgrid depends on the total net cost. The optimization is carried out based on these inputs and results tabulated. While doing the optimization, HOMER takes into consideration the profile of each generator based on the user specifications.

Sensitivity Analysis

Homer can analyze the effects of parameter variations to find out optimal values for the different sizes and quantities. The model is scaled to accommodate the increase in Solar scaled average (kWh/m^2/day), wind average and nominal discount rates.

3. RESULTS AND DISCUSSION

The current model depicts connection of PV solar system, practically, free from many of the aforesaid factors. The model was optimized using HOMER. The optimal grid design considers various optimization reports obtained from HOMER using the input parameters as detailed in Table 1. Botswana is a landlocked country hence micro-hydro, hydro, were not a part of the profile as depicted in summary of cases studied (Table 2). The grid rates included the peak demand rates and unit rates and were converted from Pula to USD at 1:12 and INR to USD at Rs.66:1$. The discount rates at 8%, annual shortage capacity at 5% and project life at 25 years were used as base components.

Electrical Components and Renewable Penetration

The simulation is aimed at finding least cost and best utilization of resources available locally. From Table 3, figure 7,8, the renewable energy penetration is maximum and in both the cases, the grid component is minimal.

Annualized Cost Summary

While comparing the costs between the Nations,it can be noticed from the table 4, cost

TABLE 1
Input Parameters

Input Components and Costs				
Model	**Components**	**Capital Cost**	**Replacement Cost**	**O&M Cost**
Gaborone, Botswana				
Lat: 24 deg 39.01m S; Lon:25 deg 53.03 min E				
HOMER	Solar (1 KW) - ABB 800-315/kW	$4,500.00	$4,500.00	$15.00
	Generic Wind 3 kW	$18,000.00	$18,000.00	$15.00
	ABB Converter (per Kw)	$300.00	$300.00	$15.00
	Battery (Per Kw)	$300.00	$300.00	$15.00
Coimbatore,India				
Lat: 10 deg 56.98m N; Lon:76 deg 53.18 min E				
HOMER	Solar (1 KW) - ABB 800-315/kW	$3,500.00	$3,500.00	$15.00
	Generic Wind 3 kW	$18,000.00	$18,000.00	$15.00
	ABB Converter (per Kw)	$300.00	$300.00	$15.00
	Battery (Per Kw)	$300.00	$300.00	$15.00

TABLE 2
Components used for the study

Components used for Study			
Model	**Components**	**Description**	**Test Case**
HOMER	Grid	Grid connected	
	Wind	Generic 3 kVA	Renewable Wind energy
	PV	ABB PV 800-315 inverter with Tata BP 315kp used	Renewable Based using PV, Battery, Converter
	Battery	Li-ion 1K	

TABLE 3
Electrical Components

	Production			
	India		Botswana	
ABB PVS800-315 with Generic PV	676,091	99.7	857,967	99.7
Generic 3 kW	1,272	0.188	1,438	0.167
Grid Purchases	705	0.104	1,103	0.128
Total	678,069	100	860,508	100
	Consumption			
	India		**Botswana**	
AC Primary Load	2,161	0.319	3,245	0.377
DC Primary Load	0	0	0	0
Grid Sales	675,908	99.7	857,263	99.6
Total	678,069	100	860,508	100

Figure 7: Simulated Components

TABLE 4
Cost Summary

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
India						
ABB PVS800-315 with Generic PV	$945,000.00	$0.00	$33,625.54	$0.00	$0.00	$978,625.54
ABB Trio50.0	$150,000.00	$101,661.25	$8,006.08	$0.00	($10,951.34)	$248,715.99
ABB315 Dedicated Converter	$1,102,500.00	$347,553.98	$84,063.86	$0.00	($53,661.58)	$1,480,456.26
Generic 1kWh Lead Acid	$300.00	$162.66	$106.75	$0.00	($17.52)	$551.88
Wind Generic 3 kW	$18,000.00	$3,861.87	$1,921.46	$0.00	($1,971.24)	$21,812.09
Grid	$0.00	$0.00	($360,005.65)	$0.00	$0.00	($360,005.65)
System	$2,215,800.00	$453,239.76	($232,281.95)	$0.00	($66,601.69)	$2,370,156.12
Gaborone, Botswana						
ABB PVS800-315 with Generic PV	$1,417,500.00	$0.00	$61,082.52	$0.00	$0.00	$1,478,582.52
ABB Trio50.0	$175,000.00	$154,601.58	$6,463.76	$0.00	($20,961.31)	$315,104.03
Generic 1kWh Lead Acid	$400.00	$282.70	$129.28	$0.00	($38.33)	$773.65
Wind Generic 3 kW	$18,000.00	$5,738.53	$4,653.91	$0.00	($3,234.03)	$25,158.41
Grid	$0.00	$0.00	($552,688.02)	$0.00	$0.00	($552,688.02)
System	$1,610,900.00	$160,622.82	($480,358.57)	$0.00	($24,233.67)	$1,266,930.58

Figure 8: Simulated Components

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summary, the capital investment, will require substantial investment for the PV and wind turbine. However, the cost of replacement remains low in the cases for PV and wind turbine. The levelized cost of energy for Botswana model one is $0.1139 as compared to that of India model which is at $0.3274 which is much lower due to significantly high PV penetrating capacity (figure 7,8). The full tables computed for 25 years, the nominal cash flow and discounted cash flow is not given here. However, it is readily available with the authors for reference.

EMISSIONS

The usage of nonrenewable resources reduces the emissions and carbon footprint as shown in Table 5. The carbon dioxide, Sulfur Dioxide, and Nitrogen Oxide Emissions reduction in case of India and Botswana comparatively less than that of Botswana.

TABLE 5
Emission Components

Component	Value Kg/ year	Value Kg/ Year
	India	Botswana
Carbon DiOxide	-426,728	-541,093
Carbon Monoxide	0	0
Unburned Hydrocarbons	0	0
Particulate Matter	0	0
Sulfur Dioxide	-1,850	-2,346
Nitrogen Oxides	-905	-1,147

Grid Components

Since the model is ON grid model, it is possible to feed back the excess electricity generated by the models back into the grid. The ratio for each of the models will vary due to factors influencing them.

CONCLUSION

This research paper presents a comprehensive summary and comparison of two same climate profile countries India and Botswana and how renewable energy potential can be tapped. The research also signifies on the transfer of technology between both the countries to significantly utilize renewable energy penetration. The study compares the renewable models and how it can be beneficial in powering up of electricity-starved communities and also how it can accommodate frequent power cuts and disruptions and also encourage the use of renewable energy resources in the countries. Analysis revealed that renewable (Robert A Freling, 2017) on grid model has the lowest net present cost and is suitable for both the localities. It is observed that microgrid, when connected to the grid, is economically favorable. However, it is noted that the peak load demand needs to be met from the grid. Though 99% of the power generated is from the renewable energy sources, grid architecture can be used efficiently by encouraging the local community to sell the excess electricity back to the grid thereby enhancing the livelihood of the communities. It is to be noticed that there is much research work to be carried out in the renewable energy systems due to its initial capital and replacement costs. However, on a positive note it needs to be appreciated that due to subsidies by government agencies and with advancement in technologies and efficiency in operations of the PV, the cost of PV/watt has come down significantly.

When comparing with Wind Vs Solar systems, the decision on solar comes to high upfront costs and low long-term operating costs. While looking at the demographic profile, it should be noted that the Botswana as a country is sparsely populated and dispersed across, while in India it is dense. This poses significant challenges in providing electricity supply through the grid across various communities and opens up new avenues like microgrids, virtual plants that could be community driven. Adaptation of new microgrid models or virtual power plant systems will also enhance the livelihood of the communities, while significantly reducing the carbon footprint. With its climate profile, there is significant potential to develop on the solar segment. Both Botswana and India makes a major contribution to biomass as well due to its abundant cattle and animal population. This area largely remains untapped, and this profile encourages the use of biomass generators. It is critical to understand that a combination of PV or biomass or diesel can be a successful model for Botswana. The reason that could be is due to poor battery or system performance of PV, in particular on a long overcast day, so installing a hybrid system could aid the development of village electricity profile. HOMER can be used to analyze different combinations of hybrid models and is a useful tool to calculate costs and in the planning of microgrids or distributed grids. With proper planning and sizing, it is possible to provide electricity to the deprived community in Botswana.

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APPENDIX I

TABLE 6
Load Profile

Hourly Load Profile (Created using HOMER)												
Hour	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Kovaipudur, Coimbatore, Tamil Nadu, India												
1	0.087	0.09	0.098	0.109	0.12	0.128	0.131	0.128	0.12	0.109	0.098	0.09
2	0.076	0.079	0.085	0.095	0.105	0.111	0.114	0.111	0.105	0.095	0.085	0.079
3	0.076	0.079	0.085	0.095	0.105	0.111	0.114	0.111	0.105	0.095	0.085	0.079
4	0.076	0.079	0.085	0.095	0.105	0.111	0.114	0.111	0.105	0.095	0.085	0.079
5	0.262	0.271	0.294	0.327	0.36	0.383	0.392	0.383	0.36	0.327	0.294	0.271
6	0.4	0.415	0.45	0.5	0.55	0.585	0.6	0.585	0.55	0.5	0.45	0.415
7	0.44	0.457	0.495	0.55	0.605	0.644	0.66	0.644	0.605	0.55	0.495	0.457
8	0.4	0.415	0.45	0.5	0.55	0.585	0.6	0.585	0.55	0.5	0.45	0.415
9	0.336	0.349	0.378	0.42	0.462	0.491	0.504	0.491	0.462	0.42	0.378	0.349
10	0.344	0.357	0.387	0.43	0.473	0.503	0.516	0.503	0.473	0.43	0.387	0.357
11	0.396	0.411	0.446	0.495	0.545	0.579	0.594	0.579	0.545	0.495	0.446	0.411
12	0.426	0.442	0.48	0.533	0.586	0.624	0.64	0.624	0.586	0.533	0.48	0.442
13	0.553	0.574	0.622	0.691	0.76	0.808	0.829	0.808	0.76	0.691	0.622	0.574
14	0.415	0.431	0.467	0.519	0.571	0.607	0.623	0.607	0.571	0.519	0.467	0.431
15	0.334	0.347	0.376	0.418	0.46	0.489	0.502	0.489	0.46	0.418	0.376	0.347
16	0.318	0.33	0.357	0.397	0.437	0.464	0.476	0.464	0.437	0.397	0.357	0.33
17	0.327	0.339	0.368	0.409	0.45	0.479	0.491	0.479	0.45	0.409	0.368	0.339
18	0.526	0.546	0.592	0.658	0.724	0.77	0.79	0.77	0.724	0.658	0.592	0.546
19	0.985	1.022	1.108	1.231	1.354	1.44	1.477	1.44	1.354	1.231	1.108	1.022
20	0.802	0.832	0.903	1.003	1.103	1.174	1.204	1.174	1.103	1.003	0.903	0.832
21	0.541	0.561	0.608	0.676	0.744	0.791	0.811	0.791	0.744	0.676	0.608	0.561
22	0.384	0.398	0.432	0.48	0.528	0.562	0.576	0.562	0.528	0.48	0.432	0.398
23	0.24	0.249	0.27	0.3	0.33	0.351	0.36	0.351	0.33	0.3	0.27	0.249
24	0.163	0.169	0.184	0.204	0.224	0.239	0.245	0.239	0.224	0.204	0.184	0.169
The Village, Gaborone, Botswana												
1	0.131	0.128	0.12	0.109	0.098	0.09	0.087	0.09	0.098	0.109	0.12	0.128
2	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
3	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
4	0.114	0.111	0.105	0.095	0.085	0.079	0.076	0.079	0.085	0.095	0.105	0.111
5	0.392	0.383	0.36	0.327	0.294	0.271	0.262	0.271	0.294	0.327	0.36	0.383
6	0.6	0.585	0.55	0.5	0.45	0.415	0.4	0.415	0.45	0.5	0.55	0.585
7	0.66	0.644	0.605	0.55	0.495	0.457	0.44	0.457	0.495	0.55	0.605	0.644
8	0.6	0.585	0.55	0.5	0.45	0.415	0.4	0.415	0.45	0.5	0.55	0.585
9	0.504	0.491	0.462	0.42	0.378	0.349	0.336	0.349	0.378	0.42	0.462	0.491
10	0.516	0.503	0.473	0.43	0.387	0.357	0.344	0.357	0.387	0.43	0.473	0.503
11	0.594	0.579	0.545	0.495	0.446	0.411	0.396	0.411	0.446	0.495	0.545	0.579
12	0.64	0.624	0.586	0.533	0.48	0.442	0.426	0.442	0.48	0.533	0.586	0.624
13	0.829	0.808	0.76	0.691	0.622	0.574	0.553	0.574	0.622	0.691	0.76	0.808
14	0.623	0.607	0.571	0.519	0.467	0.431	0.415	0.431	0.467	0.519	0.571	0.607
15	0.502	0.489	0.46	0.418	0.376	0.347	0.334	0.347	0.376	0.418	0.46	0.489
16	0.476	0.464	0.437	0.397	0.357	0.33	0.318	0.33	0.357	0.397	0.437	0.464
17	0.491	0.479	0.45	0.409	0.368	0.339	0.327	0.339	0.368	0.409	0.45	0.479
18	0.79	0.77	0.724	0.658	0.592	0.546	0.526	0.546	0.592	0.658	0.724	0.77
19	1.477	1.44	1.354	1.231	1.108	1.022	0.985	1.022	1.108	1.231	1.354	1.44
20	1.204	1.174	1.103	1.003	0.903	0.832	0.802	0.832	0.903	1.003	1.103	1.174
21	0.811	0.791	0.744	0.676	0.608	0.561	0.541	0.561	0.608	0.676	0.744	0.791
22	0.576	0.562	0.528	0.48	0.432	0.398	0.384	0.398	0.432	0.48	0.528	0.562
23	0.36	0.351	0.33	0.3	0.27	0.249	0.24	0.249	0.27	0.3	0.33	0.351
24	0.245	0.239	0.224	0.204	0.184	0.169	0.163	0.169	0.184	0.204	0.224	0.239