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Modelling an Hourly Load Profile for an Archetypal Load Rural Community in Zimbabwe

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Abstract

The load profile is an important input to the designing of solar off-grid systems for electrification. This is the power requirements for the demand-side converters (appliance loads) over time. For an optimally designed solar off-grid system, the electrical load profile has to be estimated as accurately as possible to avoid oversizing or under sizing. Sizing of the storage and power generating system has to be critically done to ensure a cost effective and reliable system. Generally, solar off-grid systems have been designed assuming a uniform load profile throughout the day, that is, assuming that an appliance is switched on the whole day and consuming the same amount of energy every hour which is practically impossible. Due to this most systems have been oversized resulting in high cost of energy due to overinvestment. Practically, the load profile varies by the hour, day, week, month, season, or year. The peak demand spikes can be met from the batteries. The most convenient method of determining the load profile of a system is by measuring electricity demand using an energy (kilowatt / kilowatt-hour) meter, and logging the output hourly, or more often, for at least a week, preferably a month or year (seasonal variations). This can be done either manually if someone can read the meter at regular intervals, or a data logger can be used, in which case much more detailed information is available. This will reveal the daily and weekly profiles. If seasonal variations in load are suspected, longer-term (yearly) load monitoring will be required to reveal the seasonal profile. However, in developing countries, this cannot be done for every system if more of these are needed especially for larger systems like mini-grids. To have a better estimation, a typical load profile has to be determined that can be applied on all similar systems to save on time and money. This therefore triggered this study to develop a typical rural electrical load profile for Zimbabwe which can be used as a basis for development of a designing model tool for off-grid solar systems. This was done using a case study of a farming based rural community in Banket, Mashonaland West Province of Zimbabwe. The data was collected over a period of a month and was then standardized to ensure that it follows the typical rural electrical load profile for developing countries while having data for a typical Zimbabwean community. A solar off-grid system designed using this as an input proved more cost effective as compared to the one designed assuming a uniform demand profile.

Keywords: Zimbabwe, load profile, off-grid system, sizing, hourly demand

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1.1 Introduction

Limited grid infrastructure to certain sparsely populated parts of Africa still deprives many rural Africans of access to the basic energy requirements. Figures from the International Energy Agency (IEA) show that around 59% of the total African population do not have access to electricity (IEA, 2014). To improve living standards in remote parts of Africa, research towards rural electrification and the provision of clean green energy to isolated domestic rural settlements are essential (Dagbjartsson et al., 2007). A framework for rural renewable energy provision has shown that energisation options, based on hybrid renewable energy systems and resources, may be the only viable option for rural village energy supply and electrification (Kruger, 2007). This is true for many off-grid rural communities in Africa, where the nature of the population spread has resulted in small isolated villages. Such rural settlements call for smart energy management in stand- alone decentralised off-grid renewable energy systems (Mulaudzi and Qase, 2008), and zero-net-energy based 100% renewable energy systems in community-shared solar power solution configurations (Lund, 2015).

Renewable energy off-grid systems are designed mainly to satisfy a particular load centre. Each load centre has a unique load profile depending on the type of appliances used and time of use (Bopp and Lippkau 2008). Time of use is usually determined by the lifestyle of the people, which can either be agro-based, mining community or animal farming community or business centres (Blechinger et al. 2016). Renewable energy resources commonly used for renewable energy off-grid systems include, solar, wind, hydro and geothermal. These can be deployed either as stand-alone systems for example solar home systems or hybrid systems which are a combination of either two or more resources and sometimes combined with the diesel or petrol generators (Kempener et al. 2015).

Statement of the problem

Commonly, solar off-grid electrical systems were designed based on a uniform demand profile without taking into consideration the variation of demand with time of the day (Hove 2012; Sani Hassan, Cipcigan, and Jenkins 2017). This has resulted in oversized or undersized electric systems which do not take care of peaks and deeps at certain times of the day. This study was therefore done to establish a more realistic load profile which can be used to optimize for a cost effective electricity supply system with an acceptable reliability.

Literature Review

The section highlights literature on off-grid power systems and introduces the solar off-grid systems as the most common in Sub-Saharan Africa. The literature review will also introduce demand analysis and development of load profiles for general off-grid systems.

Renewable Energy Off-grid Systems

Off-grid systems are more autonomous and are meant only to serve the local loads (IRENA, 2012). These are usually used for clean energy access in rural and remote areas of developing countries (Deshmukh, Carvalho, & Gambhir, 2013a) Off-grid power generation systems based on renewable

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energy sources have a great potential to speed up the process of bringing electricity to the rural areas with sparse household population, centres of business and social enterprises in Zimbabwe(Kempener et al., 2015). This is because distributed power supply systems which are detached from the main grid are cost effective as compared to the centralised grid systems given their ability to be close to load centres and cut on transmission costs(Kempener et al., 2015),(Tawanda Hove & Tazvinga, 2012).

Traditionally, diesel based off-grid systems were favoured due to their low initial capital costs. However, these also have their some disadvantages that include high life costs, low reliability and environmental costs consequently leading to high energy costs(Tawanda Hove, 2012). Deployment of optimally-reliable solar energy powered systems can address these shortcomings leading to achievement of sustainable tariffs for solar photovoltaic off-grid power supply systems.

There is a common understanding that off-grid systems differ from centralised grid systems in two main ways; Firstly, central grids are larger include several mega to gigawatts of power generation and high transmission voltages above 11kV stretching over long distances, across countries or even regions. On the other hand, off-grid systems are smaller in size; serve less number of people up to a few megawatts of generation capacity. Thus the term off-grid simply means not using power from the central grid and not generated by large centralised power systems (Feron et al., 2017). Secondly, off-grid systems are semi-autonomous in a way because they are capable of supplying local electricity demand from local power generation while central grids depend on central power generators. The term off-grid systems can include both min-grids (meaning serving multiple customers) and standalone systems (serving individual customers) for example solar home systems. Customers for off-grid systems can either be domestic and/or commercial (Kempener et al., 2015).

Despite this broad context definition, it should be clear, at what extend do an off-grid system be termed renewable energy off-grid system. This clarification is necessary especially for hybrid diesel-renewable energy off-grid systems. For off-grid systems based on 100% renewable energy source, there is no question, this is a pure renewable energy off-grid system, but for hybrid systems it has to be clarified what fraction is from a renewable energy resource, only that part is renewable(Kempener et al., 2015).

Renewable energy sources available for off-grid systems are biomass, hydro, wind and solar photovoltaic (PV). Geothermal energy can be used to provide base load for off-grid systems especially in (volcanic) islands. Mini grids and off-grid systems are commonly on diesel or petrol generators, renewable energy sources or hybrid systems(Deshmukh, Carvalho, & Gambhir, 2013b). Renewable energy power systems refer to those power systems whose source of energy is from renewable energy like solar photovoltaic with battery storage, mini or micro hydro run-off-river schemes, wind or biomass(S. C. Bhattacharyya & Palit, 2016).

Hybrid systems mean a mixture of two or more sources of energy such as, solar and battery, solar and wind plus buttery or solar, battery and diesel generator(S. C. Bhattacharyya & Palit, 2016; Kempener et al., 2015). The sustainance of the hybrid not grid connected systems is depended on the ability to economically and reliably satisfy the load in question(Baurzhan & Jenkins, 2016; Kempener et al., 2015). Prevailing climatic and environmental parameters also play a role in the optimisation of renewable energy off-grid systems(Bernal-Agustín & Dufo-López, 2009).

The role of Renewable Energy Off-grid Systems

For developing countries, the need to improve on energy access is an important driver for off-grid renewable energy systems(Kempener et al., 2015). Only about 20% of Zimbabweans in rural areas have access to electricity despite the Government’s efforts of Extended Rural Electrification Programme through grid extension(Frisk et al., 2016)(Zimstat, 2012). Traditionally diesel/petrol

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generator sets have been employed for off-grid electricity supply. Though with low capital costs, the operations and maintenance costs of these systems are very high(Tawanda Hove & Tazvinga, 2012). The Sustainable Development Goal number seven (7) encourages the achievement of universal access to sustainable forms of energy. Thus renewable energy and energy efficiency found a place in the electrification of the sparsely populated rural areas. Renewable energy off-grid system will avoid or reduce some of the greenhouse gas emissions.

Advantages of Off-grid Systems

Renewable energy off-grid mini-grid systems have a number of distinct advantages over centralised grid extension and other standalone systems in providing access to reliable and affordable electricity(Adaramola, Paul, & Oyewola, 2014; Benavente-araoz, Lundblad, Fournier, & Mayor, 2017; Deshmukh et al., 2013b; Franceschi, Ph, Rothkop, Miller, & Ph, 2014; Vinci et al., 2017);

1. Compared to central grid extension, off-grid mini-grid systems can be cost effective due to low capital cost of infrastructure necessitated with short distances and low operations cost as transmission losses are cut by being close to loads.
2. In countries with power shortages, supplying electricity to rural areas through grid extension can be very unreliable. Off-grid mini-grid systems can reliably supply power to rural load centres better than central grid extension.
3. Due to low capital requirements, off-grid systems projects can access funding easier as compared to capital intensive large systems.
4. Unlike other standalone systems like solar home systems and lighting and phone charging systems depending on size, off-grid mini-grid systems have the capability of providing electricity even to commercial centres like mills, oil presses and irrigation schemes.
5. Renewable energy mini-grid developers can employ demand side management as incentives to lower costs of the systems.
6. Development and operation of off-grid mini-grid systems can create employment and skills development for local people.

Disadvantages of Off-grid Renewable Energy Mini-grid Systems

There are however a number of disadvantages and challenges faced by off-grid renewable energy mini-grid systems when compared to central grid. These include but not limited to the following, high upfront capital costs, low capacity factors and high energy tariffs when compared to central grid. Also limited financial support and investment, lack of effective institutional arrangements to ensure reliable operation and maintenance and also technological failures due to insufficient technical and economic designs(Deshmukh et al., 2013b). A holistic approach to design that encompasses reliability and system optimisation and battery performance considerations can go a long way in addressing some of these challenges and ensure sustainability.

Wind Stand-alone Systems

Wind energy conversion systems can be installed in remote areas to supply power where the central grid cannot reach. The performance of a wind power generating system is highly dependent on wind speed and prevailing wind direction of a given location. Wind speed increases with increase in height above the ground. When designing a wind generator, the geography/topography of the area is an input (Hove and Tazvinga 2012). The wind resource is highly stochastic as such a standalone wind generator may exhibit low power supply reliability.

Solar Photovoltaic (PV) Off-grid System

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The general classification of solar photovoltaic power supply systems is based on size of systems, system configuration and how the system is connected to other power sources and or loads. Mainly, there are the grid tied systems and the stand-alone systems. PV array (the generator), battery bank (storage), charge controller, inverter and the electricity transmission system. For small solar home systems, we can have direct current (DC) loads coupled direct to the battery and alternating current (AC) connected after the inverter (Hove and Tazvinga 2012). The simplest of these systems can be the direct coupled systems where a solar PV array is connected directly to a DC load without a battery like a water pump. This kind of load is only supplied with power during the day when there is enough power from the sun because they do not have storage for back up (Hove 2012).

Manufacturers of PV modules calibrate them under Standard Test Conditions (STC) to determine their performance levels. STCs are defined by a module (cell) operating temperature of 25o C (77o F), and incident solar irradiance level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance usually ranges from 85 to 90 percent of the STC rating (Tazvinga 2012). PV modules have a relatively long life with minimum failure ranging from 20 to 30 years. Manufacturers usually give a warranty period of 20 years. It is therefore important that one checks the power rating, performance and warranty specifications on the name plate of the module to ensure quality reliable products (Hove & Tazvinga012).

Diesel Stand-alone Power Systems

Stand–alone diesel powered generator systems have been deployed for off the grid power supply from long back given to their low capital costs, even though the costs of maintaining and operating them are high (Hove and Tazvinga 2012)(Deshmukh, Carvalho, and Gambhir 2013). The problem of selecting a diesel generator size for a newly established community, or one which has not had continuous power previously, is difficult while population fluctuations, seasonal demand, increase in number and use of electrical appliances are complex issues for designers to assess 30 minutes are the maximum time generator is allowed operated at its peak power output. Generators are more efficient when operated at their rated power output over a period of time, as compared to fluctuating loads (Hove & Tazvinga 2012;Tazvinga 2012).

Although the initial cost of diesel generators is relatively low and operation and maintenance support is readily available, many researchers have observed that there are significant limitations associated with this method of generation. Getting a maintenance crew on time in remote locations is not easy. Transportation of fuel and acquiring it poses its own accessibility and cost constraints (Hove & Tazvinga 2012). In addition to the diesel generators being very expensive to run and maintain they also have polluting effects to the environment with every litre of diesel releasing about 3 kg of CO2 and equivalent gases. Therefore, with the falling prices of generating power from solar and their limited to no environmental problems, diesel gensets are being replaced or combined with the widely available solar photovoltaic(Hove and Tazvinga 2012); (Hove 2012)(Kempener et al. 2015). These are termed hybrid power systems.

Hybrid Power Systems

Hybrid power systems are one way of supplying reliable power to remote areas where there is no connections to the main grid. A hybrid system has more than one source of energy of energy supplying a common load. These may be a combination of renewables that may include solar PV, hydro, biomass and or geothermal or either of the renewable with a diesel power generator (Kempener et al. 2015). Solar PV-diesel generators are common hybrid systems in developing countries. This type of combination helps eliminate problems associated with diesel and solar PV

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stand-alone systems. These systems are usually more reliable for off-grid power supply (Hove 2012; Kempener et al. 2015).

Advantages of solar off-grid systems

Photovoltaic systems have a more advantages over conventional power- generating technologies. PV systems designs can vary according to applications and operational needs and can be either grid connected or stand-alone power generation. PV systems have no moving parts thus less wear and tear, are modular, easily expandable and even portable in some cases. The two main characteristics of PV systems are that they are friendly to the environment and they reduce energy dependence. The sun is free and PV systems do not generate any form of pollution when they are in operation. Generally, PV systems that are properly designed correctly installed need less maintenance and have longer service lives (Tazvinga 2012)(IRENA 2012).

Sizing a Solar Min-grid System

Sizing of a solar off-grid system has to critical types of data required for its effectiveness. The data can be divided into the technical data which include the resource data and the demand data (Blechinger et al. 2016). These help in the technical sizing of the equipment which is then augmented with the costing and economics data to define the cost of energy and finally the tariff (Blechinger et al. 2016). The resource data for solar mini-grids is made up of the radiation data, ambient temperature, wind speed and other factors that define the climatic conditions of the place (Blechinger et al., 2016; Lee, Soto, & Modi, 2014; Munawwar, 2006). Demand data is collected under two considerations; that is, whether it is a green field or brown field project (Blechinger et al. 2016). Green field project meaning that there was no form of electricity supplying energy to the clients or community in question while the later means a mini-grid powered from diesel or petrol or grid electricity was in use before the thought of a solar mini-grid (Blechinger et al. 2016).

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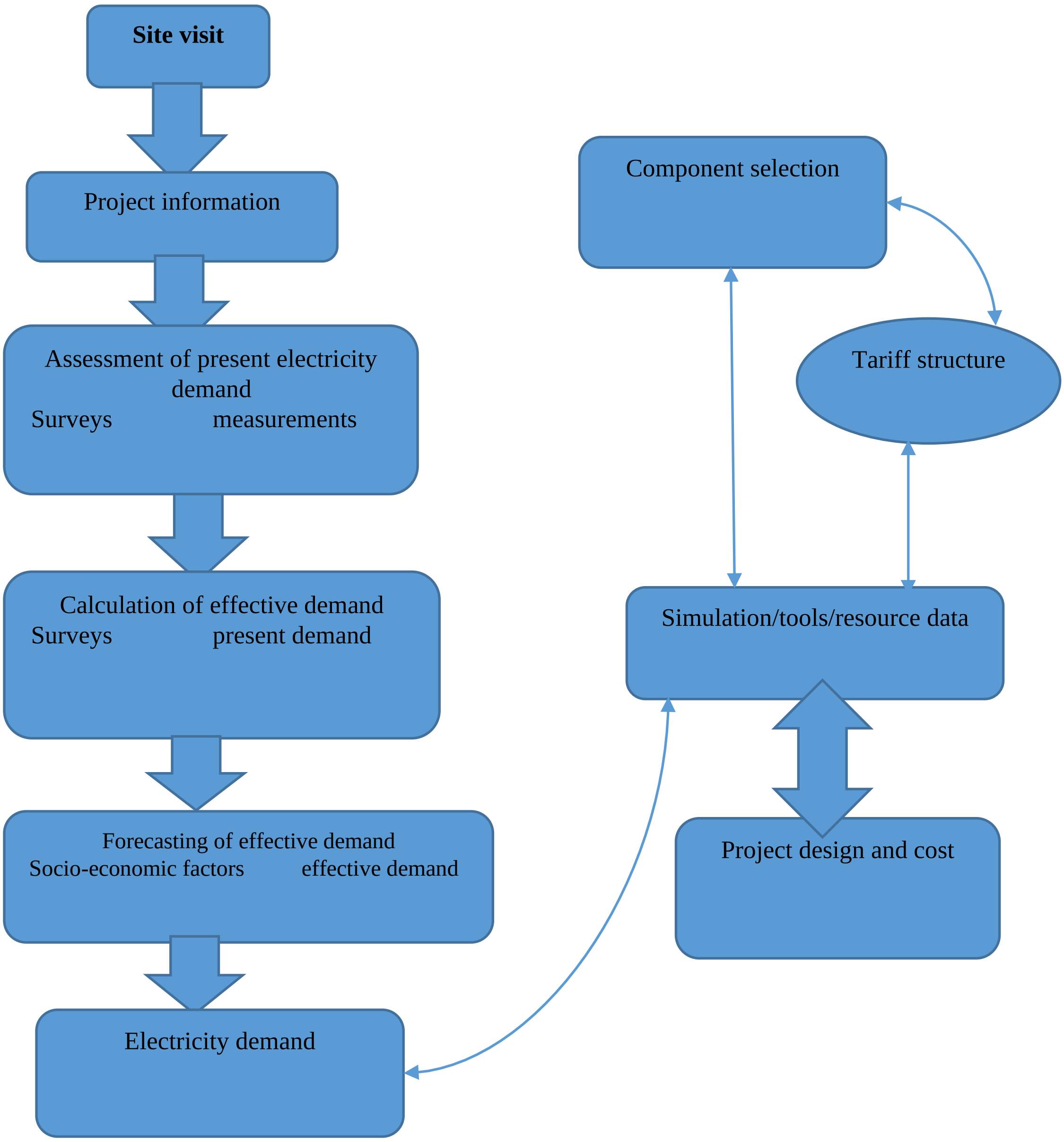

Figure 1: Flow chart of the general sizing process of off-grid systems
Source: (Blechinger et al. 2016)

Demand data will therefore be collected either by use of existing and future projected appliances or just purely new future appliances power consumption pattern (Hove 2012) Figure 1 above shows the flow chart of the sizing process of a solar off-grid system. The demand assessment is the most critical step in the system sizing process of a mini-grid for a village or community. The results of the assessment have the highest impact on specifying the system size of the mini-grid(Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018). The final product of the demand assessment is a load curve or demand profile in kW over time. This is then provided as input to various simulation and sizing tools, which sometimes also require additional specific data and information. By making use of these simulation tools, a tailored technical design and financial modelling of the mini-grid can be provided (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018).

Understanding Demand Terms

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Demand

The demand is the amount of power, measured in kW or MW, that the project area's loads require, and that the distribution company must provide [NRECA 2011], (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018).

The Present Electricity Demands

The present electricity demand is the current electrical demand of all the inhabitants. Where the community is not yet electrified, the present electricity demand amounts to zero. If residents have solar home systems (SHS) installed or if a diesel generator is in place, their present electricity demand amounts to the size of their SHS and/or their diesel generator (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018).

The Assessed Electricity Demands

This is the amount of electricity that customers state they would use if there was electricity at this moment. It is assessed using surveys on site (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018).

The Effective Electricity Demand

This is electricity demand backed by the financial resources to pay for it. It is the demand that can actually be converted into money. Consumer 'effective demand' is determined through data acquisition and analysis of prospective consumers. The willingness to pay (WTP) and ability to pay (ATP) influence the effective electricity demand (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018)

Future Effective Electricity Demand

Effective electricity demand in future years (e.g. 20 years from now). The forecast of effective electricity demand is estimated by using certain socio-economic development factors (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018).

Estimation of Electrical Load

For one to carry out the demand assessment and forecast or the system sizing, some information is necessary beforehand. Community- and customer- based data, which are specific to every project location, have to be assessed (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018). Firstly, general project information such as GPS coordinates, total number of inhabitants, current local diesel price, existing centralised power generation systems (i.e. installed diesel generator, size and operation mode), its location and distance to the consumers, as well as available land area for possible PV installation and its distance to the village, has to be compiled in order to proceed in the design and sizing process (Blechinger et al. 2016; Prinsloo, Dobson, and Brent 2016; Roche and Blanchard 2018). The electrical loads can be estimated if the power used by each appliance is known. The total energy required will depend on this power draw and the operating time of the appliance(Lee, Soto, and Modi 2014). Overall electrical loads can be determined by drawing up a list of all items, their power use and their specific operation time and fraction of demand per time per day. The total obtained from the demand matrix will be used in determining the size and type of system required (Lee, Soto, and Modi 2014).

Load Profiles

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The load profile has been defined by (Prinsloo, Dobson, and Brent 2016) as the power requirements for the demand-side converters (appliance loads) over time. Once energy conservation (demand side management) techniques are used to reduce the electrical load as far as economically possible whilst still providing the required service, the load profile should be determined to decide the type of hybrid system needed to provide power. The load profile may vary by the hour, day, week, month, season, or year. The peak demand spikes can be met from the batteries. The most convenient method of determining the load profile of a system is by measuring electricity demand using an energy (kilowatt / kilowatt-hour) meter, and logging the output hourly, or more often, for at least a week, preferably a month or year (seasonal variations). This can be done either manually if someone can read the meter at regular intervals, or a data logger can be used, in which case much more detailed information is available. This will reveal the daily and weekly profiles. If seasonal variations in load are suspected, longer-term (yearly) load monitoring will be required to reveal the seasonal profile (Hove 2012; Nazir et al. 2014).

Methodology

This section describes the procedure for energy demand analysis, demand matrix, demand profile and the methods used to determine the sizes of the solar PV generator and minimum battery capacity for an off-grid system to operate under the worst case when the weather conditions are not favorable. With solar, the actual battery size for instance is determined by simulation from a model. The methodology involved data collection of appliances used by a sample of 30 households plus the farm activities. Through interviews a review of the pattern of electricity time of use was established. This allowed for the development of the appliance demand matrix. The resulting electricity demand profile was then standardized to smoothen some spikes and maintain to main peaks on typical rural energy demand profile graphs.

Energy Demand Analysis

The first step was to carry out an energy demand analysis which was done through identification of appliances that are commonly used in rural communities and their power ratings. Also the actual power consumption per each category was established through establishment of the population of a typical village community in Zimbabwe. The load data gives detailed information about the appliances or equipment to be powered: their number, nominal power, and the hours of the day they are in operation and at approximately what percentage of demand on a typical day. The first column shows the code number of the appliance followed by the appliance and the number of appliances. The power rating in watts is shown in the next column the last column shows the total power obtained by multiplying the appliance number by the power rating of each appliance and can be treated as an NA *1 matrix where NA is the number of appliances. The appliance data is shown in appendix A.

Appliance Usage Matrix

Appendix B shows an appliance usage matrix, which is a method convenient for the computation of the above data. It shows the time of the day and the appliance in use for each hour. This represents a 24* NA matrix which when multiplied by the NA *1 matrix give a 1*24 matrix that represents the load as shown in Appendix B.

Design Load Profile

The electrical load profile is the electrical load on a certain time axis, which varies according to customer type, temperature and seasonal effects(Blechinger et al. 2016). The load profile is normalized to follow a typical double hump rural profile for standardisation of results(Prinsloo,

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Dobson, and Brent 2016). Rural energy consumption usually has a peak in the morning and another peak in the evening, mostly due to cooking and entertainment (Hove 2012; Howells et al. 2005; Prinsloo, Dobson, and Brent 2016).This standardized profile will render results of this study re-usable for optimisation of other similar load profile shape no matter the size of daily load.

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Table 1: Standardized Demand Profile

Time (hours)	Power (W)	Prob %
1	795.202965	0.02125
2	795.202965	0.02125
3	795.202965	0.02125
4	935.5329	0.025
5	1091.45505	0.029167
6	1403.29935	0.0375
7	1715.14365	0.045833
8	2182.9101	0.058333
9	2182.9101	0.058333
10	1559.2215	0.041667
11	935.5329	0.025
12	935.5329	0.025
13	935.5329	0.025
14	1247.3772	0.033333
15	1247.3772	0.033333
16	1715.14365	0.045833
17	2494.7544	0.066667
18	2806.5987	0.075
19	3118.443	0.083333
20	3430.2873	0.091667
21	2806.5987	0.075
22	764.018535	0.020417
23	764.018535	0.020417
24	764.018535	0.020417
Total Daily Consumption (Wh)	**37421.316**	**1**

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3.0 Load Profile

The resulting load demand profile as depicted in figure 3.1 was obtained by plotting power demand fraction against time of day.

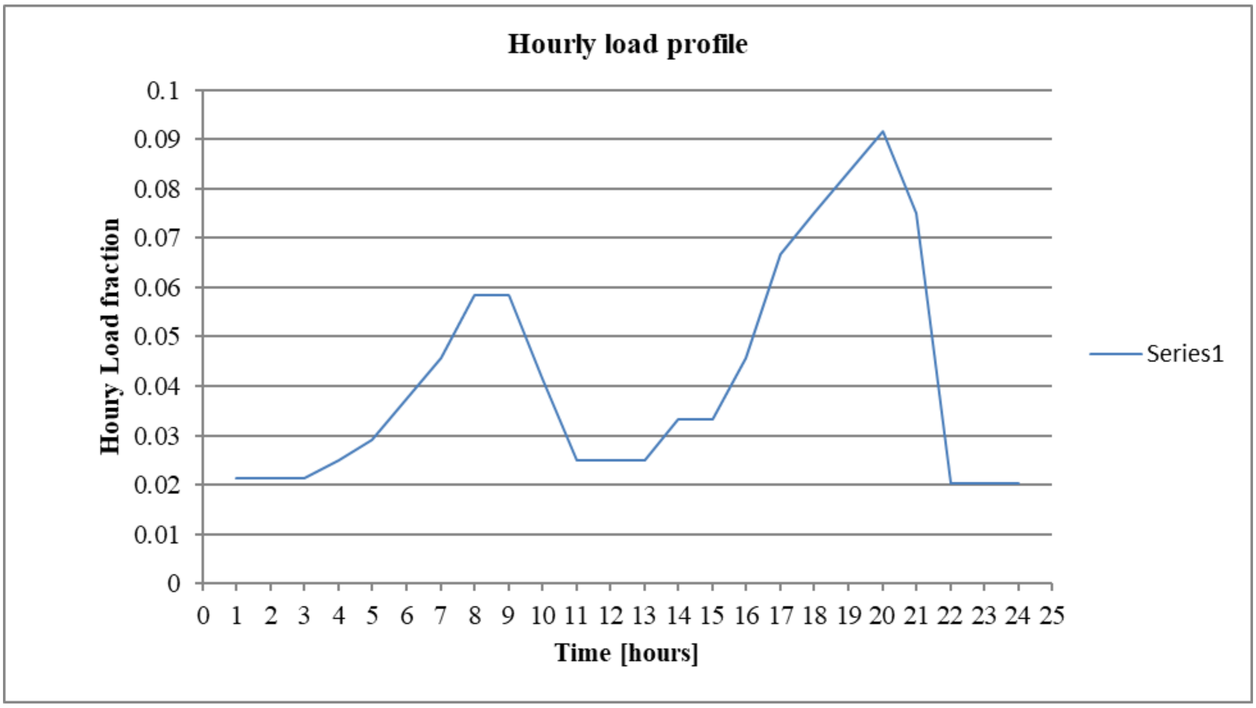

Figure 2: Load Demand Profile for a Typical Rural, Zimbabwe community

This load profile was used as an input to excel based design model of a solar PV-battery off-grid system. Levelised cost of energy of the optimum system combination was determined and compared to that of similar system designed assuming a uniform demand profile. The levelised cost of energy of the system designed assuming a uniform demand was found to be USD 1.39/Kwh while that for the optimized system was USD0.31.

4.0 Conclusion and Recommendations

From the results, it was thus deduced that it is more cost effective to design solar off-grid systems basing on demand profile that takes into consideration time of use consumption of appliances than assuming a uniform and maximum consumption throughout the day. The motivation for all designers of solar off-grid systems is to lower the cost of energy and make them as affordable as possible to improve acceptability by target customers while at the same time attracting private sector investment. The load profile with a standardized shape and developed taking account of the energy use variations with the hour (time) help to optimise system designs and there are lower chances of overdesigning since a system will be sized to suit hourly demand.

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Reference

Blechinger, Dr. Philipp et al. 2016. "What Size Shall It Be? A Guide to Mini-Grid Sizing and Demand Forecasting." *The German Climate Technology Inititaive*: 65.

Bopp, Georg, and Anja Lippkau. 2008. "World-Wide Overview about Design and Simulation Tools for Hybrid PV Systems." *IEA PVPS Task 11. Report IEA-PVPS T11-01:2011* (1)

Deshmukh, Ranjit, Juan Pablo Carvalho, and Ashwin Gambhir. 2013. "Sustainable Development of Renewable Energy Minigrids for Energy Access : A Framework for Policy Design National Laboratory." (March): 28.

Hove, Tawanda. 2012. "A Techno-Economic Model for Optimising Component Sizing and Energy Dispatch Strategy for PV-Diesel-Battery Hybrid Power Systems." 23(4): 18–28.

Hove, Tawanda, and Henerica Tazvinga. 2012. "A Techno-Economic Model for Optimising Component Sizing and Energy Dispatch Strategy for PV-Diesel-Battery Hybrid Power Systems." *Journal of Energy in Southern Africa* 23(4): 18–28.

Howells, Mark I. et al. 2005. "A Model of Household Energy Services in a Low-Income Rural African Village." *Energy Policy* 33(14): 1833–51.

IRENA. 2012. "IOREC 2012 International Off-Grid Renewable Energy Conference." *International off-grid Renewable energy Conference*. http://www.irena.org/DocumentDownloads/Publications/IOREC_Key Findings and Recommendations.pdf.

Kempener, Ruud et al. 2015. Irena *Off-Grid Renewable Energy Systems: Status and Methodological Issues*. http://www.irena.org/DocumentDownloads/Publications/IRENA_Off-grid_Renewable_Systems_WP_2015.pdf.

Lee, Mitchell, Daniel Soto, and Vijay Modi. 2014. "Cost versus Reliability Sizing Strategy for Isolated Photovoltaic Micro-Grids in the Developing World." *Renewable Energy* 69: 16–24. http://dx.doi.org/10.1016/j.renene.2014.03.019.

Munawwar, Saima. 2006. "Modelling Hourly and Daily Diffuse Solar Radiation Using World-Wide Database." (April). http://researchrepository.napier.ac.uk/4163/.

Nazir, R. et al. 2014. "Renewable Energy Sources Optimization: A Micro-Grid Model Design." *Energy Procedia* 52: 316–27. http://dx.doi.org/10.1016/j.egypro.2014.07.083.

Prinsloo, Gerro, Robert Dobson, and Alan Brent. 2016. "Scoping Exercise to Determine Load Profile Archetype Reference Shapes for Solar Co-Generation Models in Isolated off-Grid Rural African Villages." *Journal of Energy in Southern Africa* 28(3): 1–33.

Roche, O M, and R E Blanchard. 2018. "Design of a Solar Energy Centre for Providing Lighting and Income- Generating Activities for off-Grid Rural Communities in Kenya." *Renewable Energy* 118: 685–94. https://doi.org/10.1016/j.renene.2017.11.053.

Sani Hassan, Abubakar, Liana Cipcigan, and Nick Jenkins. 2017. "Optimal Battery Storage Operation for PV Systems with Tariff Incentives." *Applied Energy* 203: 422–41. http://dx.doi.org/10.1016/j.apenergy.2017.06.043.

Tazvinga, Henerica. 2012. "Hybrid Pv Diesel Battery Power Supply System."

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Appendices

Appendix A: Appliance power ratings

Call #	Equipment	Quantity	Power Rating (W)	Total Power (W)
A	Energy saver lights	350	5	1750
B	Refrigerators	32	300	9600
C	Security flood Lights	20	20	400
D	Fluorescent lights	44	15	660
E	DVD/decoder	50	20	1000
F	LED TV	30	80	2400
G	Cathode Ray tube TV	20	150	3000
H	Low power radio	40	5	200
I	High power radio	10	80	800
J	Lantern Charging	200	5	1000
K	Computer	70	120	8400
L	Communication Equipment	4	100	400
M	Cooking	50	2500	125000
N	Water pump	1	1200	1200
O	Grinding mill	1	1200	1200
P	Dovi/Cooking oil press	1	1200	1200

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Appendix B: Appliance usage matrix

Time of Day (Hrs)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	0.15	0.4	1	0.15	0	0	0	0.2	0.2	0	0	0.2	0	0	0	0
2	0.15	0.4	1	0.15	0	0	0	0.2	0.2	0	0	0.2	0	0	0	0
3	0.15	0.4	1	0.15	0	0	0	0.2	0.2	0	0	0.2	0	0	0	0
4	0.15	0.4	1	0.15	0	0	0	0.2	0.2	0	0	0.2	1	0	0	0
5	0.15	0.4	1	0.15	0	0	0	0.2	0.2	0	0	0.2	1	0.5	0	0
6	0.1	0.4	0.5	0.1	0.5	0.5	0.5	0.5	0.5	0	0	0.2	1	0.5	0	0
7	0	0.4	0	0	1	1	1	1	1	1	1	1	1	0.5	0	0
8	0	0.4	0	0	0.5	0.5	0.5	0.5	1	1	1	1	0	0.5	0	0
9	0	0.4	0	0	0.5	0.5	0.5	0.5	0	1	1	1	0	1	1	0.5
10	0	0.4	0	0	0	0	0	0	0	1	1	1	0	1	1	0.5
11	0	0.4	0	0	0	0	0	0	0	1	1	0.5	0	1	1	1
12	0	0.4	0	0	0	0	0	0	0	1	1	0.5	0.5	1	1	1
13	0	0.4	0	0	0.1	0.1	0.1	1	1	1	1	0.5	0.5	1	1	1
14	0	0.4	0	0	0.1	0.1	0.1	1	1	1	1	0.5	0	1	1	1
15	0	0.4	0	0	0.1	0.1	0.1	0	0	1	0.2	0.5	0	0.3	1	1
16	0	0.4	0	0	1	1	1	0	0	1	0.2	0.5	0	0.3	1	0.5
17	0	0.4	0	0	1	1	1	0	0	0	0.2	0.5	1	0.3	1	0.5
18	1	0.4	0	0	1	1	1	0	0	0	0.1	0.5	1	0.5	0	0
19	1	0.4	0.5	1	1	1	1	1	1	0	0.1	0.5	1	0.5	0	0
20	1	0.4	0.5	1	1	1	1	1	1	0	0.1	0.2	1	0.2	0	0
21	1	0.4	1	1	1	1	1	1	1	0	0.1	0.2	1	0	0	0
22	1	0.4	1	1	1	1	1	1	1	0	0.1	0.2	0	0	0	0
23	0.15	0.4	1	0.15	0.5	0.5	0.5	0.2	0.2	0	0.1	0.2	0	0	0	0
24	0.15	0.4	1	0.15	0	0	0	0.2	0.2	0	0	0.2	0	0	0	0