Investigation of net metering as a tool for increasing electricity access in Malawi

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Abstract: Globally increasing energy demand has had a significant impact on development. In Malawi, the net metering policy, which is part of the framework for independent power producers, has the potential to improve energy access. The purpose of this paper was to investigate the use of net metering policy as a means of improving reliability and access to electricity. The HOMER software was used to size solar PV systems while accounting for net metering at the household level. Reliability indicators such as forced outage rate (FOR), loss of load probability (LOLP), loss of load expectation (LOLE), and expected load loss (ELL) were calculated to be

6.746×10^{-12}, 2.462×10^{-9} days/year and 0.000504756 Watts, respectively. The findings indicate that the designed system is more reliable and economically viable than a system without net metre electricity. Thus, the Malawi Government should consider net metering to encourage more homes to sell excess energy to the grid.

Keywords: net metering; solar PV; grid; excess energy; policy; reliability; Malawi.

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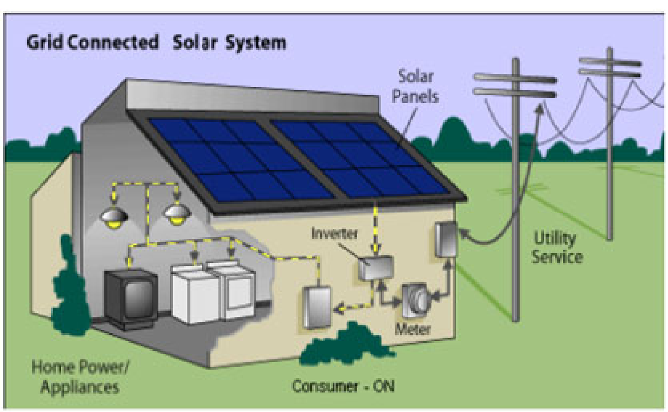
1 Introduction

The main world challenge in terms of electricity is to meet the growing demand. In Africa, the demand is growing due to urbanisation and industrialisation (Akpolat et al., 2019). Unfortunately, Africa has the least rate of electrification which in turn affects the development of most countries. Malawi compared to other Southern African Development Community (SADC) countries has the lowest electricity access rate.

Malawi's electrification rate as of the year 2018 was 18.02% mostly in urban households in the cities of Blantyre, Lilongwe, Mzuzu, and Zomba and the population is about 18.5 million (World Bank, 2021; Macrotrends, 2021). Renewable energy systems such as solar PV offers a clean and alternative energy source that can reduce emissions from fossil fuels. The power generation from solar energy is gaining more attention because of advancements in solar photovoltaic technology including enhanced efficiency of solar cells by incorporating good materials (Chaudhary and Rizwan, 2019). Solar PV rooftop mounted systems have been applied in most residential, commercial, and public buildings which have proven to be an economical and technically feasible approach to supply sustainable energy (Hunehen et al., 2020). Unreliable electricity in Malawi is pushing people in solar PV for several applications. A solar PV system can be an on-grid or off-grid system which may contain a battery or not. Most countries use the on-grid system without a battery because the system is cheap, however, with unreliable electricity in Malawi battery system is the way to go (Miah et al., 2020). Distributed generation of electricity reduces energy crises such as grid failure and also reduces carbon emissions, transmission, and distribution loss. Surplus energy can then be supplied to the grid through net metering (Tony et al., 2016).

Net metering is a mechanism in which a self-generating customer can inject the surplus into the grid and receives, for each kWh injected, compensation on his/her electricity bill (Roux and Shanker, 2018; IRENA, 2019). It involves the recording of net energy export to the grid and import from the grid through the use of a bidirectional metre (Talhar and Bodkhe, 2018). The net metering scenario is presented in Figure 1. Solar PV is one the best alternative for energy generation, however, it requires a lot of land for a big power plant. This problem is a big concern in urban setting hence installing rooftop PV systems in the consumer's place may help to solve energy challenge. On the other hand, government must allow consumers to export excess power to the grid (Nagananthini et al., 2019). Therefore, the purpose of this paper is to investigate the use of net metering policy instrument as a means of improving electricity access in Malawi.

Figure 1 Schematic representation of net-meter installation for rooftop



Source: Nagananthini et al. (2019)

1.1 Cross border experience of net metering

Net metering is being promoted to ensure high renewable energy penetration in most developed countries including the USA, Australia, Denmark, and Italy (Poullikkas, 2013). The promotion of rooftop photovoltaic systems in Cyprus was reinforced in 2013 through the adoption of a net metering scheme for domestic customers (Nikolaidis and Charalambous, 2016). Recently, many Asian countries have also taken the effort to promote renewable energy sources on a small scale for both commercial and residential applications. Some of the countries include Malaysia, Singapore, Thailand, the Philippines, and Indonesia have initiated frameworks to encourage solar PV rooftop installation for residential users (Zahid et al., 2020). India also availed net metering with its first metre installed in Verdean Industries Ltd. by Tata Power Company (Mudgil et al., 2019; Zahid et al., 2020). Recently, Indonesia also introduced a net-metering scheme (Hidayatno et al., 2020). Thailand and Malaysia are also initiating a net-metering mechanism (Khaliq et al., 2015). In Africa, most countries including Malawi have not yet started net metering. On the other hand, Ghana put in force law in 2015 to regulate net metering for plants under 200 kW. South Africa started net metering with piloting project in 2008 and installed the first system in 2013. Kenya also came up with a regulatory framework for net metering but has not yet started net metering (Roux and Shanker, 2018).

1.2 Renewable energy and net metering policies in Malawi

Malawi is endowed with several renewable energy resources which are not fully utilised. Electricity generation from hydro contribute about 95% which is mainly located on Shire River. Other renewables and alternatives such as solar, wind, solar-wind hybrid systems, natural gas, biogas, and briquettes made a small contribution towards total electricity demand (ESCOM, 2015). Malawi Government is committed to addressing the challenges that the energy sector is facing. As such, it has developed an integrated resource plan to guide and facilitate investments in the sector. In addition, the government has developed an independent power producers (IPP) framework of 2017, a Malawi Renewable Energy Strategy, and a SE4ALL Action Agenda (Malawi Government, 2018). The IPPs framework outlines the rules of engagement for all participants in the power sector (Malawi Government, 2017). Malawi Government through feed-in tariff specifically from renewable energy permits power producers to sell electricity to a distributor at a pre-determined fixed tariff for a given period. The Malawi Government guarantees third-party access to the grid for both transmission and distribution (MERA, 2012). These policies were designed to facilitate private sector participation in power generation and exploitation of renewable energy resources in the country. However, Malawi has no net metering policy for consumers to sell excess energy to the grid.

2 Related literature

Miah et al. (2020) assessed technical and economic aspects of a grid-connected rooftop solar PV generation system with net metering for a commercial building in Bangladesh. The estimated solar PV capacity for the system was 200 kWp. The study confirms excessive potential and benefits towards consumer, utility, government, and environmental with a payback period of five years. Zahid et al. (2020) analysed the effect of a net-metering scheme which was observed under different conditions, i.e., when solar is off and when solar is on. This study was carried out using ETAP software in Pakistan. The study depicts that net metering is beneficial for both a consumer and for a power system. Harmonics analysis depicts that solar energy integration with the grid through net metering is not harmful because THD was within the permissible limit of 2.5%. In Sahanaasree et al. (2014), a study was conducted to check the implementation of net metering in Tamil Nadu. The economic feasibility study was done on low, medium, and high consumers. This study showed that net metering is profitable for high-energy consumers. Shivalkar et al. (2015) carried out a feasibility study of net metering implementation for commercial buildings in Mumbai. A 15 kWp PV plant was studied and it showed great potential towards consumers, utility, and the environment. Annual savings for the system were Rs. 259,200 with a payback period of 4.63 years. In Sajjad et al. (2018), net metering was applied on a residential building with 70 apartments. The solar PV generation was estimated using PVGIS. If the aggregate demand for the entire building was considered then the savings for individual customers are about 760 €/year.

3 Location information and system description

This study was conducted in Blantyre, Malawi. The city of Blantyre (20.95°S, 37.44°W) is in the southern region of Malawi which relatively receives high rates and extensive hours of solar radiation. The solar GHI resource and temperature for Blantyre were obtained from NASA surface meteorology and solar energy database for a period of 22 years from 1983 to 2005. Table 1 shows solar resource and temperature data for Blantyre. The annual average daily radiation is 5.38 kWh/m^2/day while the annual average temperature is 23.33°C.

Table 1 Solar resource and temperature data for Blantyre

Month	*Clearness index*	*Daily radiation (kWh/m^2/day)*	*Daily temperature (°C)*
January	0.457	5.32	24.1
February	0.492	5.46	23.87
March	0.542	5.43	23.52
April	0.607	5.19	22.56
May	0.671	4.84	21.24
June	0.662	4.35	19.8
July	0.651	4.48	19.98
August	0.655	5.26	21.96
September	0.654	6.21	25.18
October	0.604	6.49	26.55
November	0.533	6.12	26.38
December	0.462	5.43	24.87

4 Methodology

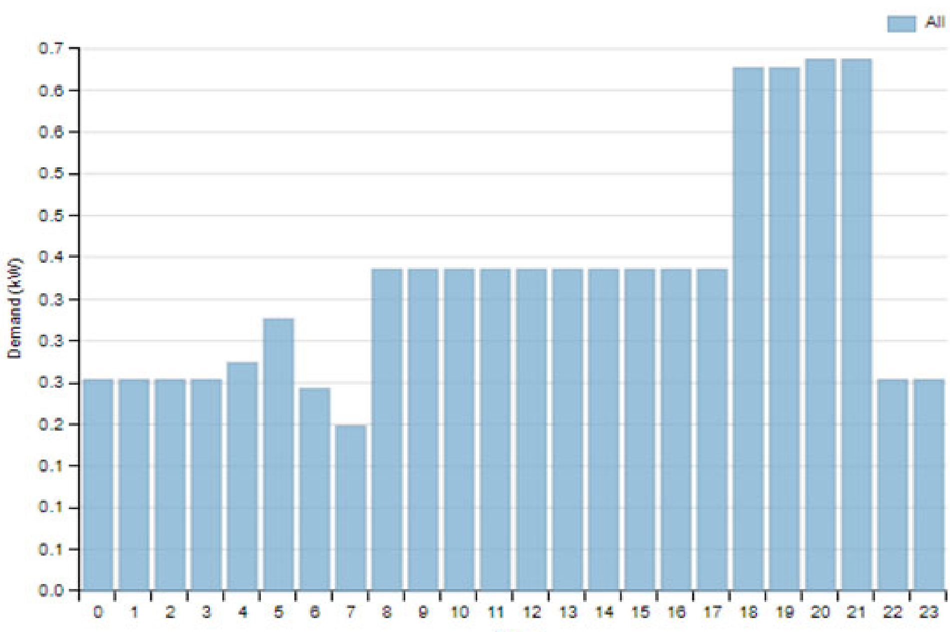
4.1 HOMER simulation software

The system design was simulated using hybrid optimisation of multiple energy resources (HOMER) software which an energy modelling and optimisation software developed by HOMER Energy LLC. It solves the complexities of a micro-grid system's cost and reliability issues. HOMER software has been used by energy utilities, technology developers, energy users to optimise their energy solutions and allow them to take critical decisions related to strategic planning and market analysis (Alhamad, 2018). HOMER software does optimisation of the key performance indicators of the hybrid power system as net present cost (NPC), fuel cost, operation cost, and cost of energy (COE) of the hybrid (Abdulhamed et al., 2020).

4.2 Power demand estimation

A household with basic appliances was assumed to represent a household in Blantyre, Malawi. The house was assumed to have three bedrooms, kitchen, family room, dining room, and two bathrooms. The house contains the following appliances: computer, electric Iron, fans, LCD TV, home theatre, decoder, refrigerator, 20 W Bulbs, and 30 W for inside and outside lighting respectively. The cooking load had not been considered because most people in Malawi use charcoal. 5% allowance added when people are awake from 05:00 to 22:00 while 1% allowance when people are assumed to be asleep. The household's annual average, peak load, and load factor are 8.943 kWh/day, 0.7482 kW, and 0.498, respectively. Figure 2 shows the household daily power load.

Figure 2 Daily load demand for the household (see online version for colours)



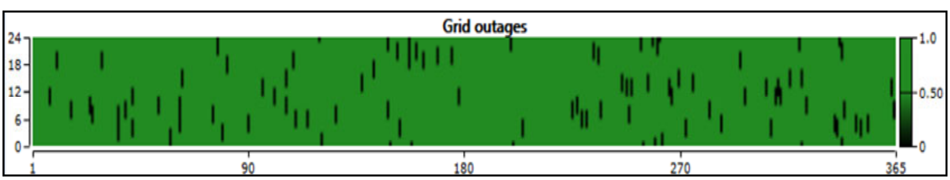
4.3 Solar PV system

A generic flat-plate PV of a rated capacity of 1 kW with an efficiency of 13% was considered for the system. The PV system was designed without a tracking system with a lifetime of 25 years. The capital cost of a 1 kW solar module was pegged at $950 with an operation and maintenance cost of $1 per battery per year. The replacement cost was pegged at $800 per kW. A derating factor of 90% was also considered for the solar module.

4.4 Grid system

Malawi's grid system is less reliable with frequent power outages. Hence, outage parameters were considered for the system design. The monthly average number of outages and average duration of outage in Malawi were 7.4 and 3.6 hours, respectively (Ramachandran et al., 2018). Thus, in HOMER, the mean outage frequency was set at 88.8 per year while the mean repair time was 3.6 hours for the software to determine random outages. Figure 3 shows calculated random grid outages for the year. The COE on the grid for household use in Malawi as of December 2020 was 0.1 $/kWh (MERA, 2021). Considering the use of a net-metering system, the sell-back COE was set at 0.08 $/kWh. The sell-back COE is relatively lower as compared to grid cost because Malawi has not yet implemented net metering.

Figure 3 Random grid outages for Malawi (see online version for colours)



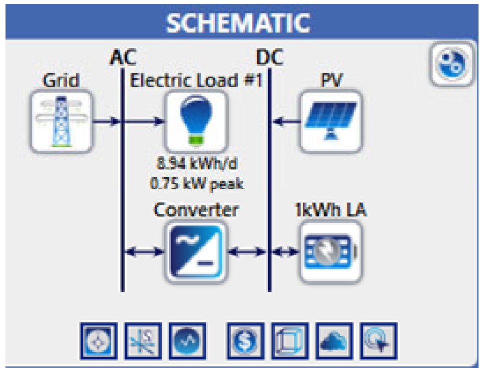
4.5 Battery

Renewable energy such as solar PV may not be capable of meeting the load requirements due to a mismatch between generation and demand. A power backup system is very important for unreliable grid since solar is an intermittent source of energy. Thus, the battery becomes useful during cloudy days and at night when the grid is down (Shabani and Chaaban, 2020; Fernandez and Prajapati, 2020). A generic lead-acid battery of nominal capacity, nominal voltage, and the maximum capacity of 12 V, 1 kWh, and 83.4 Ah, respectively. The cost of a single battery was estimated at $200 while the operation and maintenance coat for each battery was pegged at $1 per year. Battery life also depends on its depth of discharge (DoD); hence, DoD was set at 60% and lifetime at five years.

4.6 System converter

A converter is made up of an inverter and rectifier. A 1 kW generic system converter was considered with efficiencies of inverter and rectifier of 95% and 90%, respectively. The converter lifetime was set at 15 years. The capital cost of a 1 kW system converter was pegged at \$200 while the replacement cost was \$140. The operation and maintenance cost for a 1 kW converter was set at \$4 per year which is 2% of capital cost. The schematic diagram shown in figure 4 gives a summary of the system design.

Figure 4 Schematic diagram of system design (see online version for colours)



4.7 System's economic evaluation

A system's total NPC is used to represent its life-cycle cost. NPC combines all costs and revenues incurred throughout the project's life cycle into a single sum, with future cash flows discounted back to the present using the discount rate. NPC includes the costs of initial construction, component replacement, maintenance, fuel, as well as the cost of obtaining power from the grid, and other miscellaneous costs such as pollutant emissions penalties. HOMER uses equation (1) to calculate the total NPC (Lambert et al., 2006).

$$C_{NPC} = \frac{C_{ann,tot}}{CRF\left(i, R_{proj}\right)} \tag{1}$$

where $C_{ann,tot}$ is the total annualised cost, i the annual real interest rate (discounted rate), R_{proj} the project lifetime and $CRF(\cdot)$ is the capital recovery factor given by equation (2) (Lambert et al., 2006).

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{2}$$

where i is the annual real interest rate and N is the number of years. In HOMER, the levelised COE is calculated using equation (3) (Vendoti et al., 2020).

$$COE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \tag{3}$$

where $C_{ann,tot}$ is the total annualised cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load respectively. $E_{grid,sales}$ is the amount of energy sold to the grid per year. Other economic indicators calculated in HOMER include IRR and payback period.

4.8 Reliability assessment

The designed system needs to be assessed in terms of reliability. There are several reliability indices used in different assessments and this paper will assess reliability using loss of load probability (LOLP), loss of load expectation (LOLE), and expected load loss (ELL). This study is limited to the forced outage rate (F.O.R.) for each generating system in the hybrid system. F.O.R. is mathematically given by equation (4) (Zafir et al., 2016).

$$F.O.R. = \frac{\lambda}{\lambda + \mu} \tag{4}$$

where λ represents the expected failure rate and μ represents the expected repair time.

The monthly average number of outages and average duration of the outages on Malawi's grid were 7.4 and 3.6 hours respectively, then the calculated F.O.R. for Malawi is 67.3%. As indicated in Mahmood et al. (2012), the average F.O.R. values for the static and rotary converters are 0.016 and 0.013, respectively. F.O.R. for solar PV and battery are 0.03 and 0.04, respectively (Esan et al., 2019). Based on literature searches for different characteristics of generating sources, F.O.R. for each unit are presented in Table 2.

Table 2 F.O.R. for each generating unit

Generators	*Forced outage rates (F.O.R.)*
Solar PV	0.03
Battery	0.04
Malawi's grid	0.673

A LOLP is a probabilistic approach for the determination of required reserves. The LOLP is defined as the probability of the system load exceeding available generating capacity under the assumption that the peak load is considered as constant through the day (Esan et al., 2019). LOLP expresses a statistically calculated value representing the percentage of hours or days in a certain time frame when energy consumption cannot be covered considering the probability of losses of generating units (Pillai, 2015). LOLP for the whole system is mathematically defined using equation (5) (Cepin, 2011).

$$LOLP = \sum_{i=1}^{n} P_i t_i \tag{5}$$

where P_i is the probability of loss of capacity, and t_i is the percentage duration of loss of capacity.

LOLE is defined as the expected number of days or number of hours in the period investigated when the maximum load exceeds the system's effective capacity. Mathematically, LOLP is a LOLE index and the relationship is given in equation (6) (Qamber and Al-hamad, 2019).

$$LOLE = LOLP \times T \tag{6}$$

where T is 365 days if the load model is an annual continuous load curve and the unit of LOLE is days per year. T is 8,760 hours if the load model is a day curve and the unit of LOLE is hours per year. Expected load lost (ELL) for the system is defined as the cumulative product of the load loss and the probability of load lost produces the total ELL of the hybrid system. ELL is defined using equation (7) and this can be calculated from COPT (Esan et al., 2019).

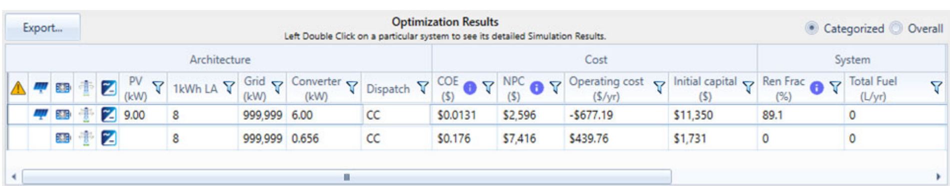
$$ELL = \sum_{i=1}^{n} Load\ lost \times Probability\ of\ load\ lost \tag{7}$$

5 Results and discussion

5.1 Optimisation results

HOMER software's simulation has shown that the best system design is comprised of solar PV, battery, grid, and converter. The simulated capacity of solar PV was found to be 9 kW while converter capacity was 6 kW. The required quantity of batteries of 1 kWh capacity was 8. The initial capital cost for the system was $11,350 with a CoE of 0.0131 $/kWh. Optimisation results for the system are shown in Figure 5.

Figure 5 Optimisation results for the system (see online version for colours)



Export... | Optimization Results | Left Double Click on a particular system to see its detailed Simulation Results. | Categorized | Overall

Architecture						Cost				System	
PV (kW)	1kWh LA	Grid (kW)	Converter (kW)	Dispatch		COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
9.00	8	999,999	6.00	CC		$0.0131	$2,596	-$677.19	$11,350	89.1	0
	8	999,999	0.656	CC		$0.176	$7,416	$439.76	$1,731	0	0

5.2 Solar PV performance

Rooftop type solar PV system is ideal for residential capacity. The optimised results suggested a 9 kW capacity for the house. The proposed PV system has mean output power and energy of 1.75 kW and 42.1 kWh per day, respectively. However, the maximum power for the system is 8.06 kW as shown in the hourly time series in Figure 6. The annual energy production for the system is 15,366 kWh. Solar PV operates 4,350 hours in a year with a capacity factor of 19.5%. The required area for solar panel installation was estimated to be 10 m^2 for a 1 kW PV system (Alhamad, 2018). Thus, more than 90 m^2 is required for the system capacity of 9 kW. The building rooftop is more than 200 m^2 which is sufficient space for the system.

5.3 Grid performance

The overall grid performance shows that most energy is being exported to the grid and energy purchased from the grid is very little. Thus, monthly net energy purchased from the grid is always negative resulting in surplus energy available for the grid. This system is more favourable for a country with unreliable electricity like Malawi. Grid in this case is helping to distribute energy where it is needed at that particular time. Table 3 shows energy purchased and energy sold every month with their peak demand.

Figure 6 Annual hourly power output for solar PV (see online version for colours)

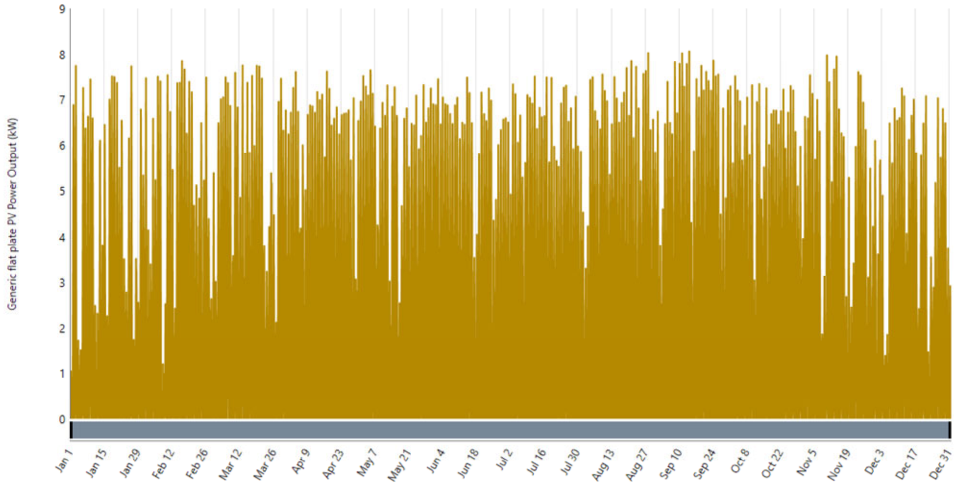


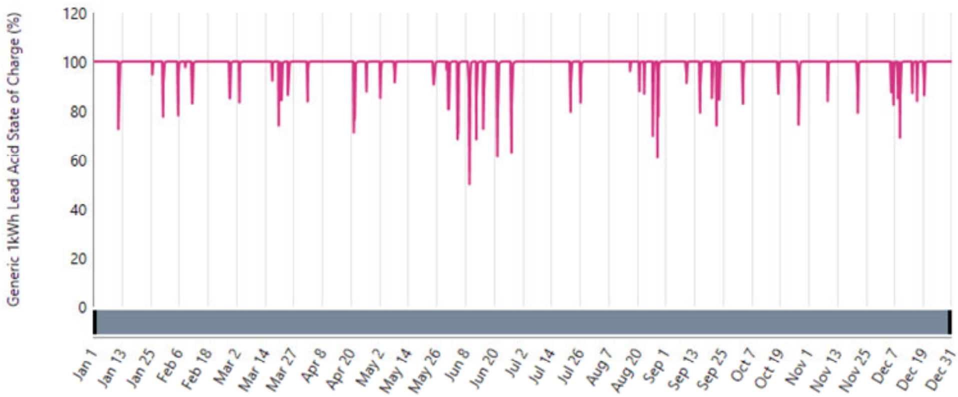
Table 3 Energy purchase and energy sold every month with their peak demand

Month	*Energy purchased (kWh)*	*Energy sold (kWh)*	*Net energy purchased (kWh)*	*Peak demand (kW)*
January	135.1	845.3	–710.1	2.3
February	116.4	838.0	–721.6	0.7
March	140.3	998.0	–857.6	1.7
April	144.7	1,020.5	–875.8	2.4
May	148.1	1,128.8	–980.7	0.7
June	145.8	1,044.6	–898.7	2.3
July	150.8	1,110.2	–959.4	1.4
August	149.4	1,149.3	–1,000.0	2.3
September	140.4	1,071.2	–930.8	1.7
October	140.0	1,130.6	–990.6	2.2
November	135.0	885.0	–749.9	1.4
December	132.6	895.8	–763.3	2.0
Annual	1,678.7	12,117.2	–10,438.5	2.4

5.4 Battery performance

The system requires eight batteries with a string size of 4 and 2 connected in parallel resulting in a bus voltage of 48 V. The overall nominal capacity is 8.01 kWh while autonomy time is 12.9 hours. The annual energy output for the battery system is estimated as 70.1 kWh. The most common battery lifetime is 2–5 years (Manimekalai et al., 2015), this system's battery life is expected to be 10 years. This is due to reduced usage of the battery because of the presence of grid electricity and DoD which was set at 60%. Figure 7 shows the battery state of discharge throughout the year. The majority of the time, the battery system is fully charged and on average the state of discharge is greater than 60%.

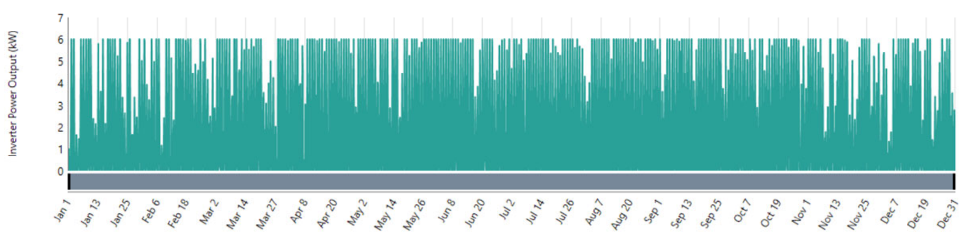
Figure 7 State of discharge for the battery system (see online version for colours)



5.5 System converter performance

The required system converter capacity is estimated to be 6 kW with a capacity factor of 26.1%. It has a mean and maximum output power of 1.57 kW and 6 kW respectively as shown in Figure 8. Annual energy input and output for the converter are 14,458 kWh and 13,735 kWh, respectively, representing 723 kWh of losses. It is expected to operate 4,522 hours throughout the year. Figure 8 shows the annual inverter power output and its performance.

Figure 8 Annual inverter power output and performance (see online version for colours)



5.6 Energy analysis

Solar PV and grid as the two main electricity sources and the electricity produced by solar PV are much greater than electricity obtained from the grid. The annual estimated energy production by solar PV is 15,366 kWh while the total energy estimated to purchase from the grid is 1,679 kWh/year. The primary load for the proposed system was 3,264 kWh/year. Thus, the proposed system is designed to use net metering, then 12,117 kWh of energy can be available for sale to the grid. Figure 9 shows annual excess electricity production from solar PV. The average operating hours of a solar PV in a year is about 4,350. Figure 10 shows the percentage share of energy consumption from solar PV and grid.

Figure 9 Annual excess electricity production by solar PV (see online version for colours)

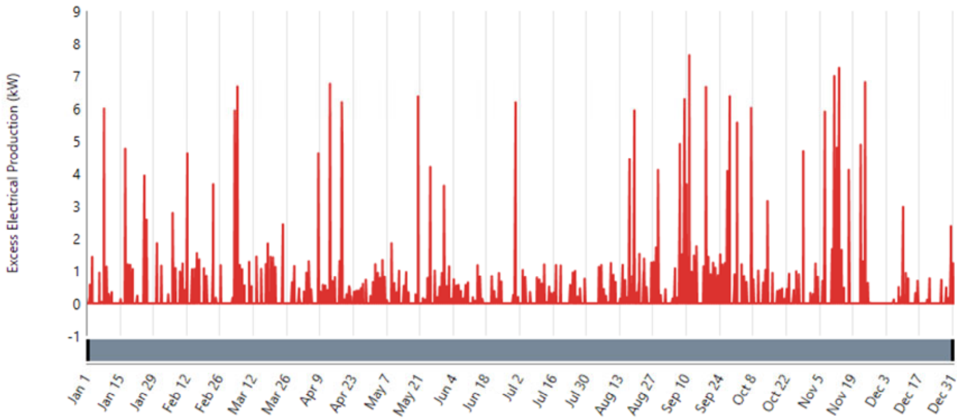
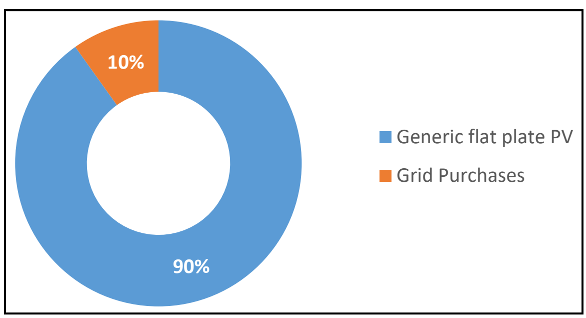
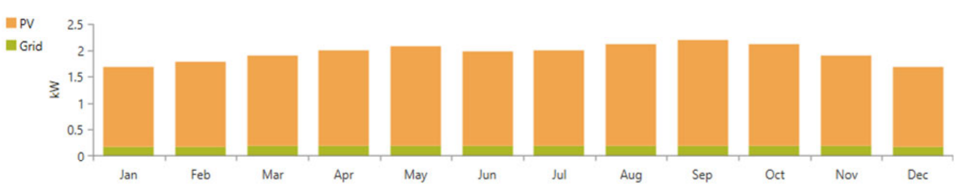


Figure 10 Percentage share of energy consumption from solar PV and grid (see online version for colours)



Throughout the year, solar PV showed dominance with relatively high energy production during August, September, and October which is the summer season in Malawi. Regardless of using net metering technology, the grid may sometimes not be available hence excess electricity generation for the system was calculated to be 920 kWh per year which is representing 5.4% of the total energy produced from solar PV. Figure 11 shows monthly power production in a year.

Figure 11 Monthly power production in a year (see online version for colours)



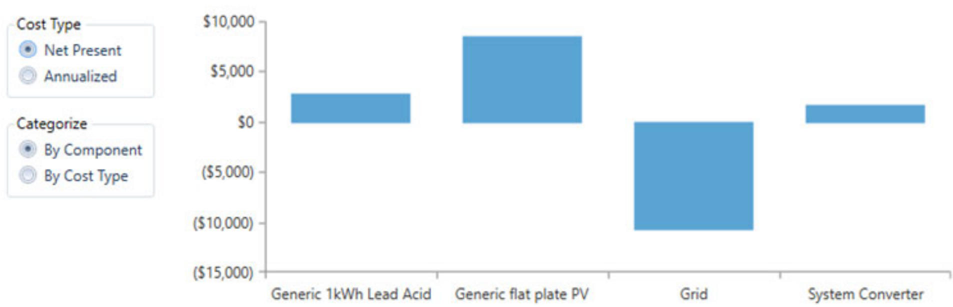
5.7 *Financial analysis*

The net present value (NPV) of individual components indicated that more money is needed for solar PV modules followed by battery storage. However, the grid has a negative NPV due to net metering as shown in Figure 12. This makes net metering attractive. Additionally, replacement, operation, and maintenance costs for the proposed system can be covered by grid sells making it cheaper to implement. Table 4 shows capital, replacement, and O&M costs for all system components.

Table 4 Capital, replacement and O&M cost for the system's components

Component	*Capital ($)*	*Replacement ($)*	*O&M ($)*
Battery	1,600.00	1,413.50	103.42
Flat plate PV	8,550.00	0.00	116.35
Grid	0.00	0.00	–10,795.52
Converter	1,200.00	356.39	310.26
System	11,350.00	1,769.89	–10,265.49

Figure 12 The NPV for system components (see online version for colours)



The proposed solar PV-grid-tie net-metered system had the present worth of $4,821 and an annual worth of $452. The NPV of the system is $2,595.68. The system has also a relatively shorter simple payback period of 8.46 years and discounted payback period of 12.05 years. The proposed system has a return on investment and internal rate of return (IRR) of 11.6% and 10.7%, respectively. These results have proven that the system is more profitable and an attractive business idea if the government introduces net metering in Malawi. With solar PV and net metering, household bills will reduce from $326.4 per annum to $39.33 per annum.

5.8 *Reliability assessment results*

Simulated and optimised results from HOMER software were further analysed to determine the reliability of the system. Solar PV, grid, and battery were considered as generating units. Capacity outage probability tables (COPTs) of each generating unit were utilised to calculate reliability indices (LOLP, LOLE, and ELL) through their corresponding probabilities and failure rates. The binomial expansion was utilised to determine individual probabilities. Tables 5, 6, and 7 show COPT for each generating unit.

Table 5 The COPT (three units of 3 kW solar panel)

Units out	*Capacity out (kW)*	*Capacity in (kW)*	*Bionomial expansion (p+q)³*	*Probability*
0	0	9	p^3	$(0.97)^3 = 0.912673$
1	3	6	$3p^2q$	$3(0.97)^2(0.03) = 0.084681$
2	6	3	$3pq^2$	$3(0.97)(0.03)^2 = 0.002619$
3	9	0	q^3	$(0.03)^3 = 0.000027$

Where q represents the failure rate or unit unavailability of the solar PV given by 0.03 or 3%. p represents the unit availability given by 0.97 or 97%.

Table 6 The COPT (Two battery units of 4 kW)

Units out	*Capacity out (kW)*	*Capacity in (kW)*	*Bionomial expansion (p+q)²*	*Probability*
0	0	8	p^2	$(0.96)^2 = 0.9216$
1	4	4	2pq	$3(0.96)^2(0.04) = 0.0768$
2	8	0	q^2	$3(0.96)(0.04)^2 = 0.0016$

Where q represents the failure rate or unit unavailability of the battery given by 0.04 or 4%. p represents the unit availability given by 0.96 or 96%.

Table 7 The COPT for the Malawi's grid

Units out	*Capacity out (kW)*	*Capacity in (kW)*	*Bionomial expansion (p+q)1*	*Probability*
0	0	999999	p	0.327
1	999999	0	q	0.673

Where q represents the Failure rate or unit unavailability of the grid given by 0.673 or 67.3%. p represents the unit availability given by 0.327 or 32.7%.

Table 8 Summary of reliability results

Reliability index	*Value*	*Units*
Design peak load	0.7482	kW
Loss of load probability (LOLP)	6.746E-10	%
Loss of load expectation (LOLE)	2.462E-09	day/year
	5.9097E-08	hours/year
Total expected load loss (ELL)	0.000504756	Watts

Reliability results summary are presented in Table 8. The results were obtained using COPT from HOMER simulated results. The monthly average number of outages and average duration of outage on the national grid in Malawi were 7.4 and 3.6 hours respectively. Thus, comparing these results with outages on the grid, the results are very small hence more dependable. A similar study for a rural community in Nigeria was carried out and values of LOLP, LOLE, and ELL obtained were 5.76×10^{-8}, 5.0457×10^{-4} hrs/year and 0.025344 Watts respectively making this system viable for the community (Esan et al., 2019). Thus, comparing this study with that of the community in Nigeria, reliability indicators obtained in this work are very small making this designed system more reliable.

6 Conclusions

This paper presented the concept of net metering at a household level. HOMER software was utilised for technical sizing and economic analysis of the system. Additionally, the power outage pattern for Malawi was randomly generated for the entire year with respect to mean outage frequency and mean repair time. Net metering was incorporated to understand its effect on bills and increased access. Results illustrated that for a household of the annual average energy of 8.943kWh/day, required 9 kW solar PV with the initial capital cost of $11,350. The COE on grid in Malawi for residential houses was 0.14 $/kWh while the proposed system with net metering was 0.0131 $/kWh representing an 86.9% decrease. The monthly average energy sold to the grid for one house of the proposed system was 1,009.8 kWh. Therefore, if more houses are selling excess energy to the grid through net metering, excess electricity generated can be available for other users like industries and households. Malawi's poor electrification rate with frequent power outages can partially be solved using a net metering system. These energy distributed systems are also beneficial in so many ways. The first advantage is the difficulty for a utility company to invest in a large solar power plant due to lack of funds. Power plant maintenance will also be eliminated. Additionally, these distributed systems will ensure the availability of power in some locations if part of the grid is down. Therefore, Malawi should consider coming up with a net metering policy and encourage people to mount solar PV systems on their roofs.

The results from HOMER software for the designed system's reliability were further assessed using the COPT. Reliability indices were calculated using FOR. The calculated results for LOLP, LOLE, and ELL were 6.746×10^{-12}, 2.462×10^{-9} days/year and 0.000504756 Watts respectively. These results were also compared with a system for a rural community in Nigeria and reliability indicators obtained in this work are very small making the designed system more reliable.

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