IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 11, Issue 3, March 2021, ||Series -I|| PP 40-49

PV Self-Consumption Optimization Using Storage System and Demand Side Management

Hamagham Peter Ishaku[1], Polycarp Shizawaliyi Yakoi[2]

[1](Department, of Electrical & Electronics Engineering / Cyprus International University, North Cyprus)
[2](Department, of Computer Engineering/ Cyprus International University, North Cyprus)
Received 18 March 2021; Accepted 02 April 2021

Abstract:
Background: Fossil fuel usage pose a threat to the environmental condition of humans, and coupled with it`s possible depletion, the infusion of renewable energy sources into energy mix has been on the increase for over a decade. Statistics shows that solar PV represents the largest percentage of renewable energy in terms of installations in the world, majorly due to the reduction in price of solar PV in the energy market. However, due to the inconsistency of the solar resource, that is the weather and seasonal changes, there is the challenge of meeting peak demands of consumption, hence the need for energy storage systems and demand side management is necessary in order to meet those peak demands during periods of no energy production.
Materials and Methods: In this study two (2) methods of optimization were taken into consideration, which are the use of energy storage and the demand side management. Simulations were carried out using sunny web design to see the benefit of using storage system over having a PV system without storage. The parameters for the evaluation included the PV system components like the battery types and the inverters. Also the load data incorporated for the simulation was for a five-people household. The factors studied to compare the systems are solar fraction, load shifting and self-consumption.
Results: It showed comparative higher values for solar fraction and load shifting for the system with energy storage and DSM respectively. Also, the result showed that when demand side management is used alongside storage systems, the self-consumption of the system is improved.
Conclusion: This study presents the analysis and evaluation of Solar PV System Optimization using Energy Storage system and Demand Side Management (DSM).
Key Word: Renewable energy; PV system, battery storage, demand side management.

I. INTRODUCTION

Fossil fuel usage pose a threat to the environmental condition of humans, and coupled with it`s possible depletion, the infusion of renewable energy sources into energy mix has been on the increase.

Concept of Energy

Energy is a basic concept in all sciences as well as engineering disciplines around the globe. It's known that energy can neither be created nor destroyed; can only be converted and redistributed from one form to another, for example: from solar energy into electrical energy, or chemical energy to mechanical energy. The current living standards could not be maintained without energy because it is essential to existence.

Recently, with the expanding genuine energy emergency and natural contamination, solar energy and other sustainable energy source, for its plenteous assets provides hope in having cleaner source of energy. Solar energy is the energy from sunlight. Because of the plenitude of daylight, solar energy is said to be the most encouraging sustainable power source for what's to come. Solar energy is drained of carbon outflows; subsequently it has almost no unsafe impact on the earth and human wellbeing.

Photovoltaic (PV) Systems

"Photovoltaic system is an elegant solar energy resource. The fuel source (daylight) is free, plenteous and generally dispersed, accessible to each nation on the planet. At more than 165,000 TW the solar asset predominates the world's present power use of 16 TW or even the anticipated future use of 60 TW (Dunlop, 2012). PV is a solar energy innovation that makes utilization of qualities of specific semiconductors to straightforwardly change over solar radiation to coordinate current (DC) power. PV systems have several advantages when compared to other energy sources. Some of these advantages are:

- PV system is an ecologically friendly technology that produces electricity with basically no noise or pollution. Therefore, operating a PV system makes a statement about shielding the environment and preserving non-renewable energy sources.

- PV systems are supple and can be adapted to numerous different applications. The modular nature of PV arrays and other mechanisms make systems easy to enlarge for increased capacity.
- There are no moving parts, hence PV system are extremely reliable and last an extended time with negligible maintenance.
- PV systems propose energy independence. A grid connected PV system reduces the user's vulnerability to utility power outages and lifelong bills, and a stand-alone system eliminates it.
- Sunlight, which is the energy source for PV systems, is free and voluntarily available during the day time.
- PV system costs are generally decreasing as conventionally produced electricity is predictable to become more expensive, hence PV systems may be used to hedgerow against future energy price upsurges.

Optimizing the rate of self-consumption

Knowing the fact that PV system uses the sunlight which is not readily available during the whole twenty-four hours of the day, this means that it is of paramount importance to optimize the use of the system, or rather use of the electricity produced by the PV system. There are different methods and approaches to optimizing the system but will be discussing two of them which are Demand Side Management (DSM) and using of a storage system.

Demand Side Management (DSM) usually refers to the actions that influences the quantity of energy consumed by users. This can likewise incorporate activities focusing on diminishing of peak demand amid periods when energy supply frameworks are compelled. Demand side management traditionally has been seen as a means of mitigating peak electricity demand. By just reducing the load on electricity network, DSM has other various benefits, including mitigating electrical systems emergencies, reducing the number of blackout occurrence and also increasing the system reliability. Also, it includes the reduction in expensive importation of fuel, reducing energy prices, as well as reducing harmful emission to the environment. DSM reduces high investments in generation, transmission and distribution networks. Therefore, DSM provides significant economic, reliability and environmental benefits.

Owing to the randomness and volatility of solar and wind, the energy storage system is essential in order to have a constant power supply. There are a number of ways to store energy; in this study we will consider using battery, super capacity and a hybrid storage system of both. Hybrid super-capacitor and battery energy storage combines the advantages of power-type energy storage element and energy storage components, to avoid the disadvantages of just a single energy storage system technology (Xiu, Cheng and Chunyan, 2014). In this study, we will be focusing on battery energy storage system.

Objective of this study

The main focus of this study is to optimize PV self-consumption, therefore in the work done, two methods were used for analysis and simulation; these are: demand side management and the use of an energy storage system. The simulation done using sunny web design was to show the important role that use of energy storage plays in a PV self-consumption system and how it improves self-consumption. Simulation of a system with good storage capacity will be performed, another simulation with a lesser capacity will also be done and then a simulation of a PV system without storage system at all will be performed and all the results will be compared and analyzed to see the difference at each of cases. As good as the use of energy storage system is, practicing demand side management alongside is of great advantage as it helps in improving the rate of self-consumption which will also be discussed in this study.

II. TECHNICAL DETAILS OF PV SYSTEM

There are number of ways to which photovoltaic systems can be configured, and that may depend on a number of things like the desired design, capacity, cost, application and other reasons, such as Stand-Alone Systems, Grid-Connected Systems (also known as Utility-Interactive Systems), Grid-Connected Systems with Battery (also known as Bimodal Systems), and Hybrid Systems.

PV System Configuration

There are number of ways to which photovoltaic systems can be configured, and that may depend on a number of things like the desired design, capacity, cost, application and other reasons, such as Stand-Alone Systems, Grid-Connected Systems (also known as Utility-Interactive Systems), Grid-Connected Systems with Battery (also known as Bimodal Systems), and Hybrid Systems.

PV Array Orientation

This refers to the direction, position and angle of PV arrays with regards to the sun. As explained in reference (Dunlop, 2012), the orientation of PV system increases or decreases how much solar radiation can be accessed by a PV system. Two main angles are used to define array orientation: tilt angle and azimuth angle.

The tilt angle is the vertical angle between the horizontal and array surface. Maximum annual solar energy from arrays on a fixed surface is achieved by orienting the surface at a tilt angle nearly the same as the value of the local latitude. Depending on the energy needs, array can be optimized for either summer or winter gain by changing the tilt angle. The azimuth angle is the horizontal angle between a reference direction and the direction an array surface faces. Reference direction is usually due north or south. For fixed mounts, azimuth angle is due south.

In his research with Homer software, Makrides et al. (2008) found that the optimum tilt is different for each months or season of the year for various locations. She found that the yearly average of optimum tilt is equal to the latitude of the site. When the tilt angle and azimuth angle are made to experience continuous changes by following the movement or position of the sun, we have what is called sun tracking. Sun tracking may be classified according to the number and orientation of the axes used to track the sun. This brings significant performance gains over fixed surfaces. Single-axis tracking are primarily used for flat plate systems, and sometimes with concentrator systems. Dual-axis tracking rotates two axes independently to exactly follow the position of the sun. This further maximizes the amount of solar energy received, though the gain over single axis tracking is smaller than the gain of single-axis tracking over fixed surfaces. Dual-axis tracking are primarily used with PV concentrators.

PV System Performance

In order to categorize the performance of a PV system, the performance parameters have been specified by International Energy Agency (IEA); the total energy yield, specific yield, and performance ratio (PR) are the important parameters which provide information about the overall system performance, with respect to energy production and system losses (Mitchell et al., 2005). According to U.S. Department of Energy, the most common PV array design uses flat-plate PV modules or panels. These panels can be fixed in a particular position or designed to track the movement of the sun. They have the capacity to respond to either direct or diffuse sunlight. When the sky is clear, the diffuse part of sunlight accounts for between 10% and 20% of the total horizontal surface solar radiation.

PV Self-consumption

Self-consumption can be defined as the possibility of any kind of electricity consumer to connect a PV system with a capacity corresponding to the consumer's consumption. PV Self -consumption can be on/off grid depending on the reasons for installing the system. This could also be in small or large capacity.

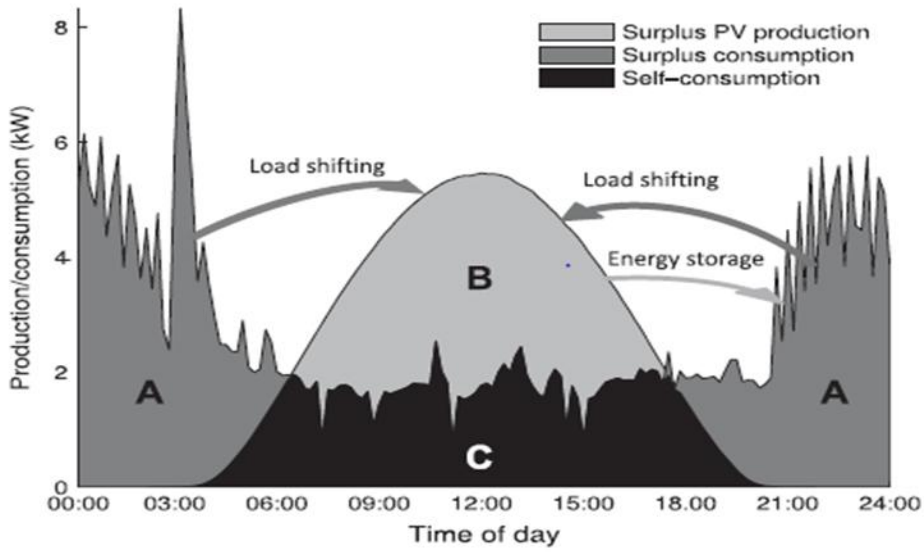

Figure no1: Daily net load, net generation and absolute self-consumption
(Source: Castillo-Cagigal et al, 2011)

Figure no1 shows the power profile of an on-site PV generation and power consumption. Area A and B are the total net demand and generation respectively, area C is the PV power that is utilized directly with the building.

$$\text{Self-consumption} = \frac{C}{B+C} \quad (1)$$

Self-sufficiency $= \frac{C}{A+B}$ (2)

III. METHODOLOGY

This section discusses the various methods used for analysis. Simulations performed based on different storage capacity using Sunny Design Web. Demand Side Management analysis was also performed.

Simulation Using Sunny Design Web

The system design and simulations were split into smaller bits. The configuration of PV system with battery was compared with a PV system without storage capacity. The parts of the PV configuration modelled in the simulation process are the inverter profiles, the battery rating, the Load and consumption data, and PV ratings. In the absence of a grid system, a hydrocarbon generating set is provided to make up the energy demands during peak periods.

To simulate the effects of using battery storage in PV system configuration for off-grid, the scenarios considered are:

- PV system without battery storage
- PV system with battery storage

In the first scenario, which is without the battery storage, the PV output is primarily consumed by the household load and any surplus is lost. In the second scenario, PV system with a simple battery charge, the output from the PV system will first meet the load of the household. In the event of any power surplus, it will be stored in the battery. However, in the event of the battery being full, since there is no grid system, the energy will be lost. If the power from the PV system is not enough to meet the demands from the household, the power from the battery will be used to meet the demand. The peak load is 9.8KW with annual energy consumption of 6200KWh.

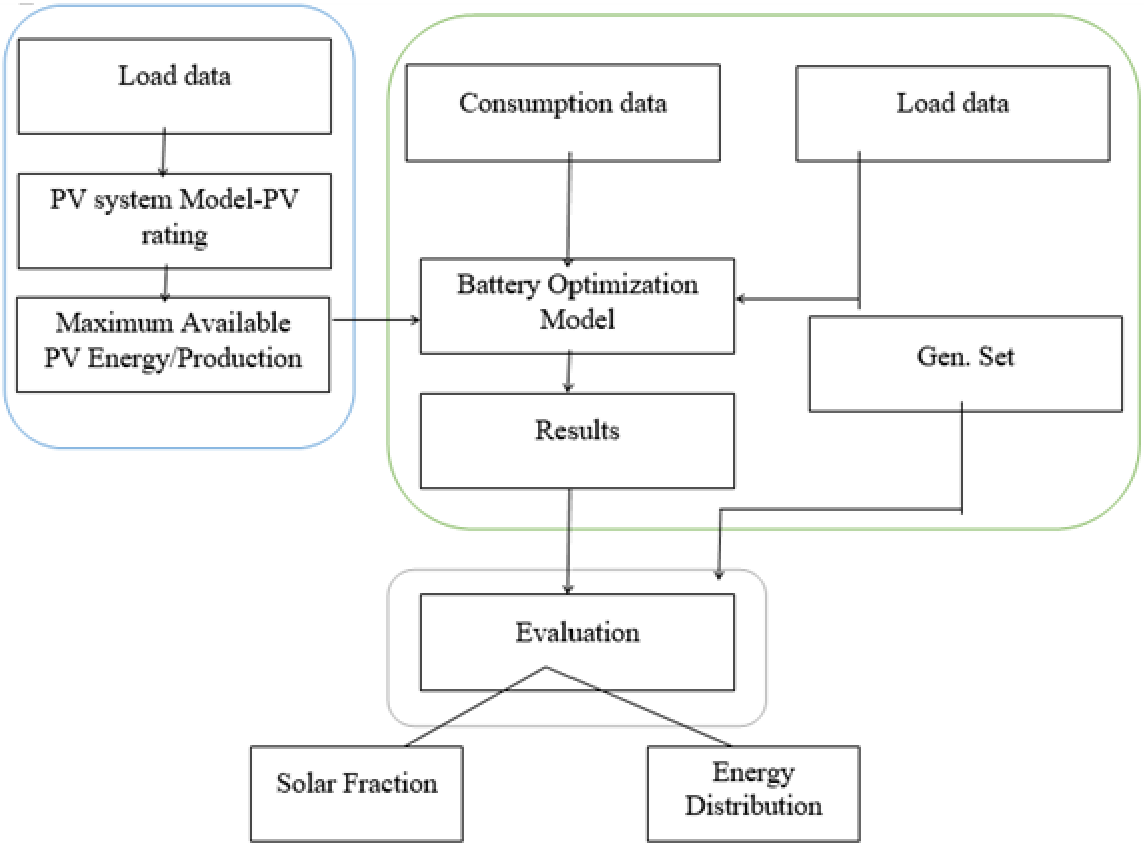

Figure no2: Daily net load, net generation and absolute self-consumption

Simulation performed with the use of Storage System

In this section a simulation using sunny web design was conducted of a PV system that works with a battery storage system and the total overview of the system simulation is what is discussed below and the location used is Yola, Adamawa State, in the north-east part of Nigeria with latitude 9.2035°N.

Table no1 presents the general PV system with a storage system overview of the components types, power, capacity and percentages. In determining the tilt angle, the latitude 9.2035°N was multiplied by 0.87 to give 8° as it is less than 25° (optimum tilt angle, 2018).

Table no1: System Overview.

PV module	10*A.M.P. Solar: AMM 240W
Tilt angle	8°
Peak power	2.40 KWp
Inverter	1* SB3.0- 1AV -40
Storage	3* Sunny Island 4.4M lead battery
Total nominal capacity	30.75 KWh
Of which can be utilized	24.60 KWh
Genset active power	7.9 KW
Average energy efficiency	3.50 KWh/1
Nominal AC power of inverter	3.00 KW
AC active power	3.00 KW
Active power ratio	125%
Max. available PV energy	4,315.95 KWh
Energy usability factor	100 %
Spec. energy yield	1798 KWh/KWp
Unbalanced load	3.00 KVA
Consumed PV energy	4,282.35 KWh
Consumed PV share	99.2 %
PV share of the energy supply	114.1%
The a verage annual solar fraction	60.2 %

Another simulation was carried out with all the data is same with the previous except for the storage capacity that is reduced from total nominal capacity of 30.75 KWh to 18 KWh in order to analyze the effect of reduced battery capacity.

Table no2: PV system section 1 parameters.

	Atorvastatin 40 mg (before)	Atorvastatin 40 mg (After)	Percentage Change	P value
Lipids, mg/dL				
Total Cholesterol (TC)	224.3±30.8	150.7±22.2	-32.81%	<0.001
LDL-C	158.3±22.6	83.9±15.1	-46.99%	<0.001
HDL-C	37.5±2.70	38.8±3.5	+3.46%	0.003
Triglyceride	165.8±30.8	141.4±22.6	-14.71%	<0.001
Non-HDL-C	180.6±31.2	113.2±18.1	-37.32%	<0.001
Glucose and HbA1C				
FBG, mg/dL	142.5±25.7	90.95±7.9	-36.17%	<0.001
HbA1c, %	5.82±0.2	5.71±0.3	-1.89%	0.198

Table no2: Shows the system's parameters and their corresponding values and capacities.

Simulation performed without the use of Storage System

In this section a simulation using sunny web design was conducted of a PV system that works with no battery storage system and the total overview of the system simulation is discussed below and the location considered is Yola, Adamawa State, in the north-east part of Nigeria. Table no3 shows the climatic data and Table no4 presents the general PV system overview of the components types, power, capacity, and percentages ratings.

Table no3: Shows Climate Data**.**

Annual Extreme temperature	14°
Average high temperature	32°
Annual extreme high temperature	45°

Table no4: Shows System Overview**.**

PV module	10*A.M.P. Solar: AMM 240W
Tilt angle	8°
Peak power	2.40 KWp
Inverter	1* SB3.0- 1AV -40
Storage	3* Sunny Island 4.4M lead battery
Total nominal capacity	0 kWh
Genset active power	7.9 KW
Average energy efficiency	3.50 KWh/1
Nominal AC power of inverter	3.00 KW
AC active power	3.00 KW
Active power ratio	125%
Max. available PV energy	4,315.95 KWh
Energy usability factor	100 %
Spec. energy yield	1798 KWh/KWp
Unbalanced load	3.00 KVA
Self-consumption	2,136 kWh
Performance ratio	80.2 %
Self-sufficiency quota	34.5 %
Average annual solar fraction	7.2 %

Demand Side Management

DSM is basically initiatives that encourages consumers minimize their use of energy. In this section the ways and benefits of DSM in a PV system will be discussed. Table no5 is a result of previous work where by DSM was applied to a load profile and analysis was performed to obtain the result in the table, where N is the self-consumption factor

Table no 5: Electrical energy flows during the sample days and measured weeks with battery capacity of 5.4 kWh.

Parameter	Day without DSM	Day with DSM	Week without DSM	Week with DSM
E_{PV} (Wh)	23,501	23,760	159,332	165,222
E_{load} (Wh)	10,643	10,965	74,735	76,932
$E_{PV,load}$(Wh)	3427	6329	23,151	43,799
$E_{Grid,E}$(Wh)	20,074	17,431	136,181	121,423
$E_{Grid,I}$(Wh)	7216	4636	51,584	33,133
N (%)	32.2	57.7	30.9	56.9

(Source: Castillo-Cagigal et al, 2011)

EPV: Energy produced by PV system
ELoad: Energy consumed by load
EPV, Load: Energy produced by PV which is directly consumed by the load
EGrid, E: Energy exported to the grid
EGrid, I: Energy imported from the grid

It can be seen in Table no5 that EPV, Load is much larger when DSM is used than when DSM is not used because more energy from the PV system is being preserved, saved and eventually used, therefore the energy imported from the grid is less when DSM is being used which is also same in the table. Finally, the self-consumption factor.

Table no6: Average PV self-consumption with and without load shifting.

PV system size (KWp)	Absolute self-consumption (MWh/year)	
	Without DSM (load shifting)	With DSM (load shifting)
3	1.8	2.0
6	2.6	2.8
9	3.1	3.3
12	3.4	3.6

(source: EnerNex, 2018)

Load shifting which is a form of Demand Side Management was used and the result is shown in table 3.6 where values gotten for use of the DSM method in self-consumption were all greater than values gotten without the use of DSM.

IV. RESULTS AND DISCUSSION

As discussed, and analyzed through the work done, it can be noted that the benefits and reasons why demand side management is necessary through the following ways:

- Cost reduction- the major benefit and reason to use of DSM is to reduce the cost of power production and also cost of power consumption.
- Environmental and social improvement- demand side management reduces the use of energy therefore leading to reduced greenhouse gas emissions.
- Network issues and reliability- Improving and/or avoiding problems in the electricity framework through reducing the demand in ways which maintains systems reliability in the immediate time and also over a longer term defers the need for network augmentation.
- Improved market- short term reactions to electricity market situations, particularly by mitigating loads during periods of high market prices basically cost by the reduced generation or network capacity.
- Reduction in costumer energy consumption bills
- Reduction in the need for a new power plant, transmission and distribution networks.
- Stimulation of the economic development and advancement
- Creation of more jobs due to new innovations and technologies
- Increase in the competitiveness of the local enterprises
- Reduction in air pollution
- Mitigates dependency on foreign energy sources
- Reduction in the peak power prices for electricity.

Results of simulation performed with sunny web design

Figure no3 shows the energy distribution of the PV system with storage capacity. It presents the self-consumption, the energy stored and the energy taking from the grid/genset.

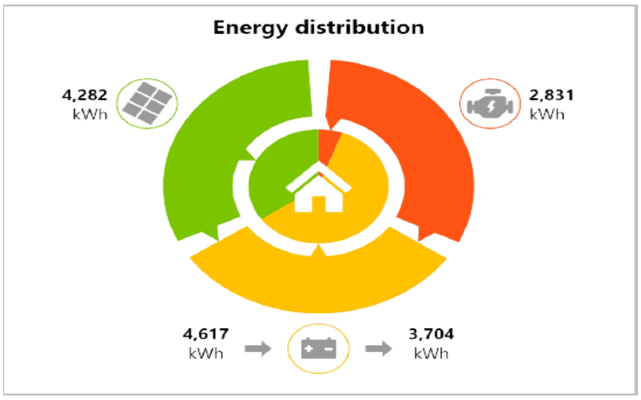

Figure no3: Energy distribution chart

Figure no4 shows the energy distribution of the PV system without storage capacity. It presents the self-consumption, the energy yield, the energy taking from the grid/genset and grid feed in.

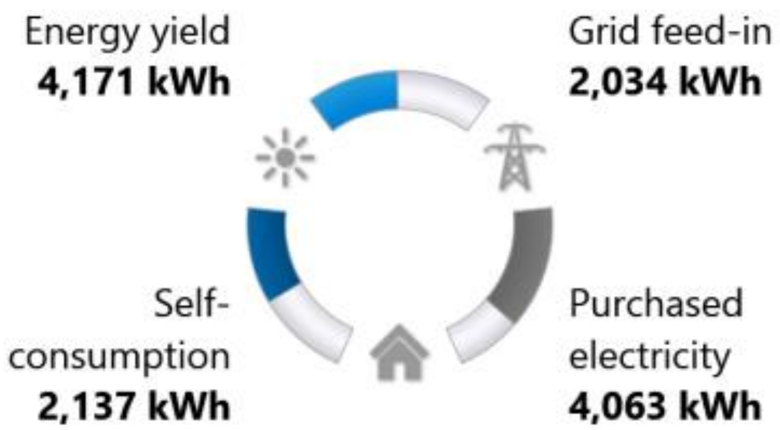

Figure no4: The energy distribution

Difference between a system with or without storage capacity

Solar saving fraction also known as solar fraction (f) which is the total amount of energy provided by the solar technology divided by the total energy required by the load profile. Also, the solar fraction for simulation with battery is way higher than that of simulation without the use of battery, showing how important the storage system is to the whole PV system. The average annual solar fraction of the simulation with battery is 60.2% and that of the simulation without the use of storage system is just 7.2% which is very low. The difference between the two simulations is shown in Table no7.

Table no7: Result differences between the two simulations

System properties & parameters	With battery	With lesser Bat. Cap.	Without battery
Power reserve	-0.3 KW	-0.2 KW	-10.9 KW
Energy deficit	O KWh	O KWh	2.3 KWh
Useable storage capacity	24.6 KWh	14.4 KWh	0 KWh
Autonomous time	1.3 d	0.8 d	----
Annual average solar fraction	70.2 %	52.4 %	7.2 %
Used PV energy	4,282 KWh	4,032 KWh	2,137 KWh
Annual energy generated by genset/grid	2,831 KWh	2,856 KWh	4,063 KWh

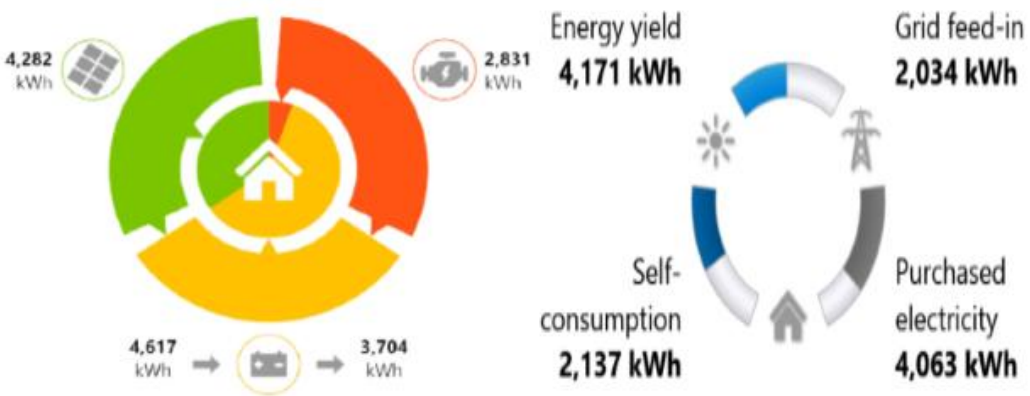

Figure no5: Energy distribution difference between the 2 simulations

In Figure no5, we can see in the energy distribution of the system with battery that the energy from the battery to the load is 3,704 KWh and energy from the genset/grid is 2,831 KWh while in the one without storage is 0 KWh therefore the energy taken from genset/grid is 4,063 KWh in order to meet the required demand.
Table no8 shows the result of an analysis with and without the use of demand side management and also the percentage difference in the values obtained. And it can be seen that there is an improvement in the quantity of self-consumption.

Table no8: Average PV self-consumption with and without load shifting and percentage difference.

PV system size (KWp)	Absolute self-consumption (MWh/year)		
	Without DSM (load shifting)	With DSM (load shifting)	% difference
3	1.8	2.0	10%
6	2.6	2.8	7.14%
9	3.1	3.3	6%
12	3.4	3.6	5.56%

In as much as the use of just storage system alone or use of demand side management different both have advantages and are efficient for PV system optimization, the use of both optimization methods together gives a better advantage and more efficiency as we have seen in the discussions, figures and tables in the chapter.

As the market for solar PV keeps increasing due to higher demand of cleaner energy, it is necessary that ways to optimize the self-consumption of PV system should be improved. Self-consumption is the share of PV production that is consumed directly by the user. This work discussed two techniques of self-consumption optimization, which are battery storage and the demand side management (DSM). In this work, a review of some previous researches in the aspect of self-consumption optimization of PV systems and also a simulation analysis was performed with sunny web design on using battery as storage system, also another simulation was performed without the use of storage system and the both results were analysed and compared. In the simulation a five (5) person apartment was considered in the region of Yola Adamawa state, Nigeria.

The solar fraction of the PV system with battery storage and without battery storage was compared to analyse the solar energy utilisations of both systems. The result showed that the average annual solar fraction of the PV system with battery is 60.2% and 7.2% for a system without battery. This shows that in order to increase the solar savings fraction, energy conservation measures should be employed. The results also show that for the system with battery storage excess produced electricity is stored and used in other periods of the day but in a system where by there's no storage capacity excess energy will be wasted if it is not grid connected in order to send that excess energy to. In terms of energy purchased for the system with storage capacity only 2,831 KWh is required from the grid or the genset, but in the system with no storage capacity 4,063 KWh is required to be purchased, that is to say extra 1,232 KWh of energy is required to be purchased in the case where energy storage system is not used.

It was obviously noticed that the use of storage system is much more benefiting in self-consumption in the sense that it reduces wasted of energy and also reduces cost of purchasing energy and in addition the practice of demand side management alongside the storage system only improves the rate of self-consumption.

V. CONCLUSION

As the market for solar PV keeps increasing due to higher demand of cleaner energy, it is necessary that ways to optimize the self-consumption of PV system should be improved. Self-consumption is the share of PV production that is consumed directly by the user. This work discussed two techniques of self-consumption optimization, which are battery storage and the demand side management (DSM). In this work, a review of some previous researches in the aspect of self-consumption optimization of PV systems and also a simulation analysis was performed with sunny web design on using battery as storage system, also another simulation was performed without the use of storage system and the both results were analysed and compared. In the simulation a five (5) person apartment was considered in the region of Yola Adamawa state, Nigeria.

The solar fraction of the PV system with battery storage and without battery storage was compared to analyse the solar energy utilisations of both systems. The result showed that the average annual solar fraction of the PV system with battery is 60.2% and 7.2% for a system without battery. This shows that in order to increase the solar savings fraction, energy conservation measures should be employed. The results also shows that for the system with battery storage excess produced electricity is stored and used in other periods of the day but in a system where by there's no storage capacity excess energy will be wasted if it is not grid connected in order to send that excess energy to. In terms of energy purchased for the system with storage capacity only 2,831 KWh is required from the grid or the genset, but in the system with no storage capacity 4,063 KWh is required to be purchased, that is to say extra 1,232 KWh of energy is required to be purchased in the case where energy storage system is not used.

It was obviously noticed that the use of storage system is much more benefiting in self-consumption in the sense that it reduces wasted of energy and also reduces cost of purchasing energy and in addition the practice of demand side management alongside the storage system only improves the rate of self-consumption.

REFERENCES

[1]. Castillo-Cagigal, M., Caamaño-Martín, E., Matallanas, E., Masa-Bote, D., Gutiérrez, A., Monasterio-Huelin, F., & Jiménez-Leube, J. (2011). PV self-consumption optimization with storage and Active DSM for the residential sector. Solar Energy, 85(9), 2338-2348. http://dx.doi.org/10.1016/j.solener.2011.06.028

[2]. Demand Management as a Stepping Stone to Demand Response - EnerNex. (2018). EnerNex. Retrieved 11 January 2018, from http://www.enernex.com/blog/demand-management-as-a-stepping-stone-to-demand-response-2/

[3]. Dougal, R., Liu, S., & White, R. (2002). Power and life extension of battery-ultracapacitor hybrids. IEEE Transactions On Components And Packaging Technologies, 25(1), 120-131. http://dx.doi.org/10.1109/6144.991184

[4]. Dubey, S., Sarvaiya, J., & Seshadri, B. (2013). Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review. Energy Procedia, 33, 311-321. http://dx.doi.org/10.1016/j.egypro.2013.05.072

[5]. Dunlop, J. (2012). Photovoltaic systems. [Place of publication not identified]: Amer Technical Pub.

[6]. Makrides, G., Zinsser, B., Norton, M., Georghiou, G., Schubert, M., & Werner, J. (2010). Potential of photovoltaic systems in countries with high solar irradiation. Renewable and Sustainable Energy Reviews, 14(2), 754-762. http://dx.doi.org/10.1016/j.rser.2009.07.021

[7]. Makrides, G., Zinsser, B., Schubert, M., & Georghiou, G. (2014). Performance loss rate of twelve photovoltaic technologies under field conditions using statistical techniques. Solar Energy, 103, 28-42. http://dx.doi.org/10.1016/j.solener.2014.02.011

[8]. Martin, N., & Ruiz, J. (2002). Calculation of the PV modules angular losses under field conditions by means of an analytical model. Fuel and Energy Abstracts, 43(4), 269. http://dx.doi.org/10.1016/s0140-6701(02)86350-0

[9]. Mitchell, L., Rich, G., Boyle, K., Hayden, H., Adelstein, J., & Townsend, T. et al. (2005). Performance Parameters for Grid-Connected PV Systems. Washington, D.C: United States. Dept. of Energy.

[10]. Models used to assess the performance of photovoltaic systems. (2009). Washington, D.C.

[11]. National Renewable Energy Laboratory (NREL) Home Page | NREL. (2018). Nrel.gov. Retrieved 18 January 2018, from https://www.nrel.gov/

[12]. Xiu, Y., Cheng, L., & Chunyan, L. (2014). Research on Hybrid Energy Storage System of Super-capacitor and Battery Optimal Allocation. Journal of International Council On Electrical Engineering, 4(4), 341-347. http://dx.doi.org/10.1080/22348972.2014.11011894. (8)

Hamagham Peter Ishaku, et. al. "PV Self-Consumption Optimization Using Storage System and Demand Side Management." *IOSR Journal of Engineering (IOSRJEN),* 11(03), 2021, pp. 40-49.