Design and Simulation of a DC Microgrid System for a Remote Community in Nigeria

BY
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OUTLINE

- Introduction
- Objective of the Study
- System Sizing and Analysis in Homer Pro for an off grid System
- System components
- Economic And Sensitivity Analysis of Proposed system PV system
- Dynamic Modelling, Simulation and Results
- Summary & Conclusion

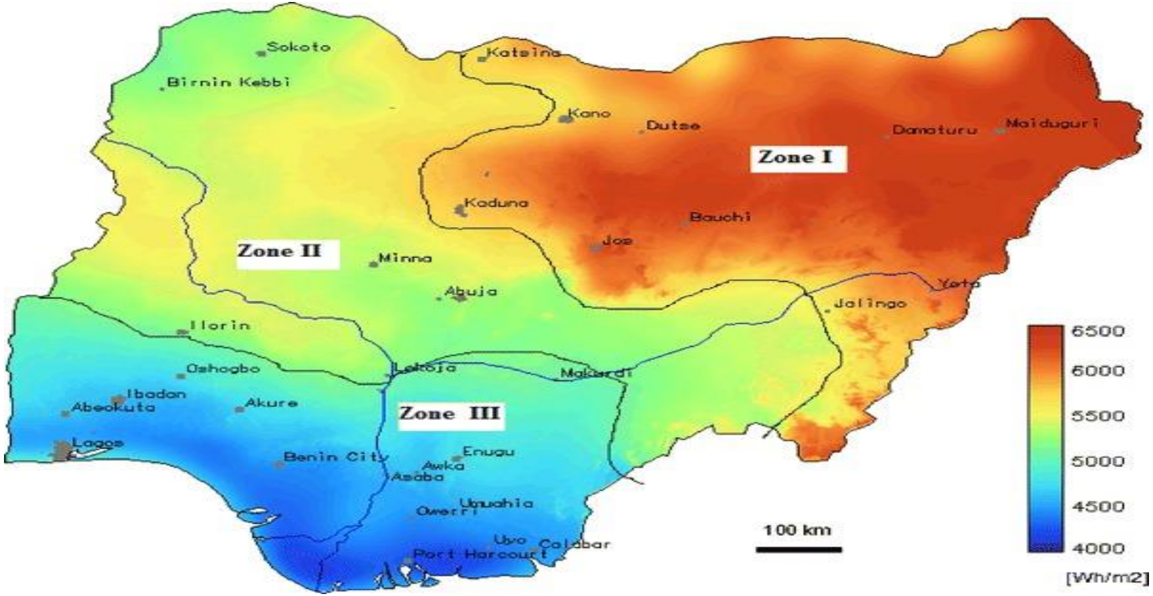
INTRODUCTION

- Nigeria is one of west Africa country with about 206 million population
- Greater population of Nigerians does not have access to Electricity. Hence the need for alternative energy.
- Most remote communities are cut off from the electricity grid
- The selected site is situated in Edo State, Nigeria. The community has 9 houses which are not more than 100m apart

INTRODUCTION

- The average daily direct radiation reach about 4.65kWh/m^2/day in Southern region of the country.

- With this high potential of solar that can be utilized as alternative source to supply part of the energy needs in Nigeria



Solar irradiation in Nigeria

LITERATURE REVIEW

Author	Paper Reviewed
A. Chauhan	A review on Integrated Renewable Energy System based power generation for stand-alone applications
A. Desai	Exploring Technical and Economic Feasibility of a Stand-Alone Solar PV based DC distribution system over an AC for use in houses
A Rajeev	Design of an Off-grid PV system for the rural community
C.B. Muzaffar	Design and analysis of off grid solar system for DC load of a house in Pakistan
A.U Rehman	Design and control of an off-grid solar system for a rural house in Pakistan
Nunu Mazibane	Design of an off-grid PV system for Mapetja rural village.
S. Sini	Techno-economic feasibility analysis of a solar off-grid system for a residential load in an under-developed colony

LITERATURE REVIEW

Author(s)	Paper reviewed
W. Chengshan	Research on several problems of distributed generation energy supply system
L. Huang	Stability analysis of DC microgrid considering the action characteristic of relay protection
M. Ahamed	Modelling and simulation of a solar PV and battery used DC microgrid system
Z. Guorong	Influence of bus voltage on DC load in DC microgrid
M. Tianyi	Modelling and Stability Analysis of microgrid with Multi-converter
Palit and S. Malhotra	Energizing rural india using microgrids

SITE LOCATION

On Google maps the selected site has the following co-ordinates: Latitude: 6° 17'22.2"N, Longitude: 5° 59'31.8"E (6.28949409312645, 5.992154342254569) .

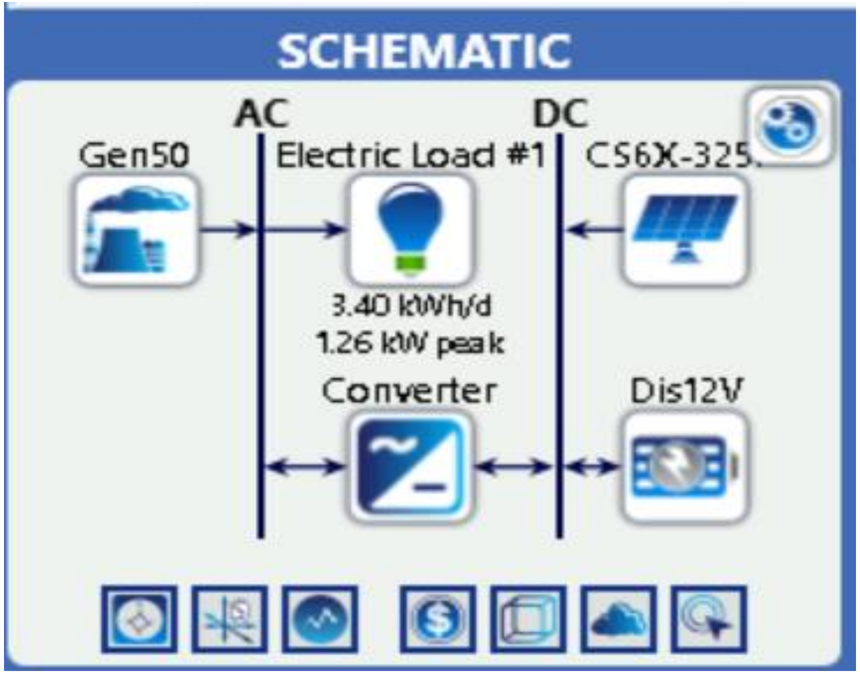
ENERGY CONSUMPTION

Daily energy consumption for a house in remote Edo State, Nigeria

Appliance	Quantity	Power Rating (W)	Total Wattage (W)	Duration (Hours)	Total Energy (kWh)
Ceiling fans	2	60	120	7	0.84
Television	1	50	50	5	0.25
Deep Chest freezer	1	140	140	10	1.4
Water Pump	1	750	750	0.2	0.15
LED bulb	7	8	56	6	0.34
Double arm streetlight	2	70	140	3	0.42
Total load:			1.26kW		3.4kWh

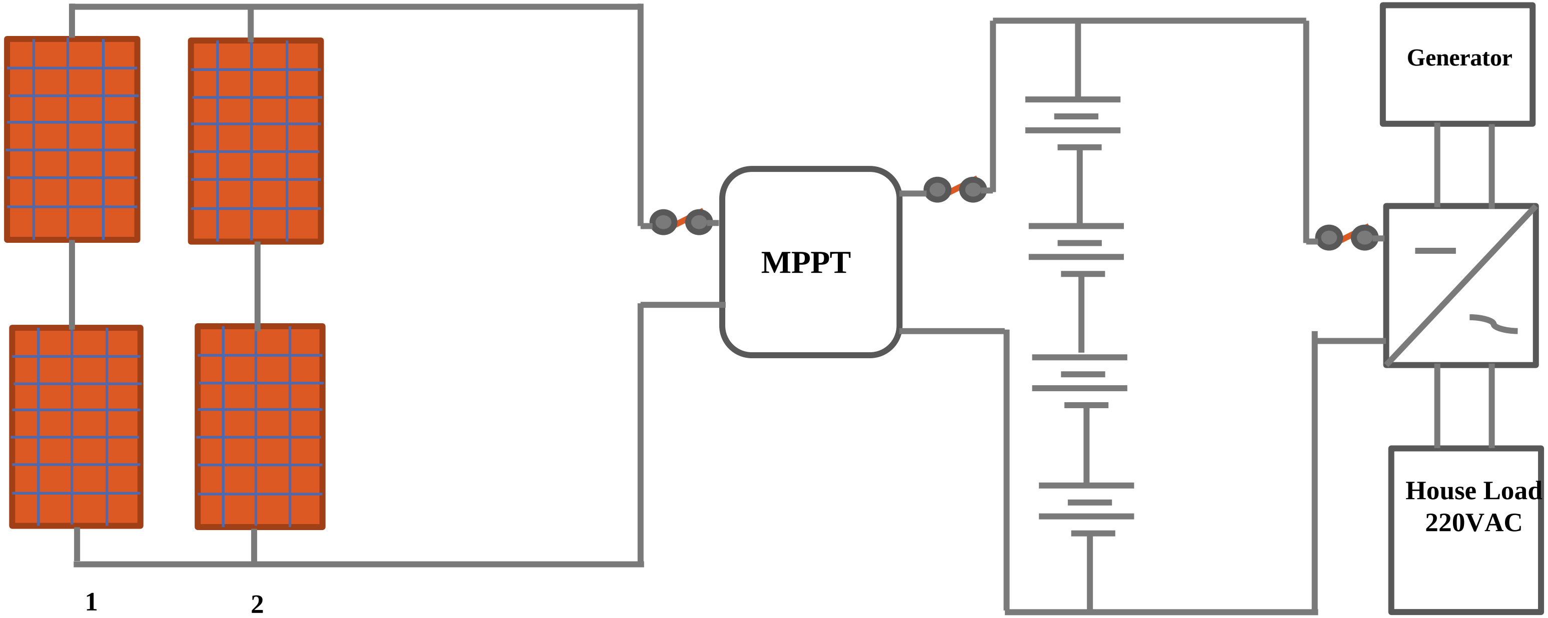
SYSTEM COMPONENTS

All system components were selected using Homer Pro. The figure shows all components in a block diagram. Which consists of 4, 325W PV module, 4, 12V, 350Ahr, 4.8kW generator and 1.6kW inverter.



Homer block diagram of all selected components

SYSTEM COMPONENTS



2 Strings of PV array

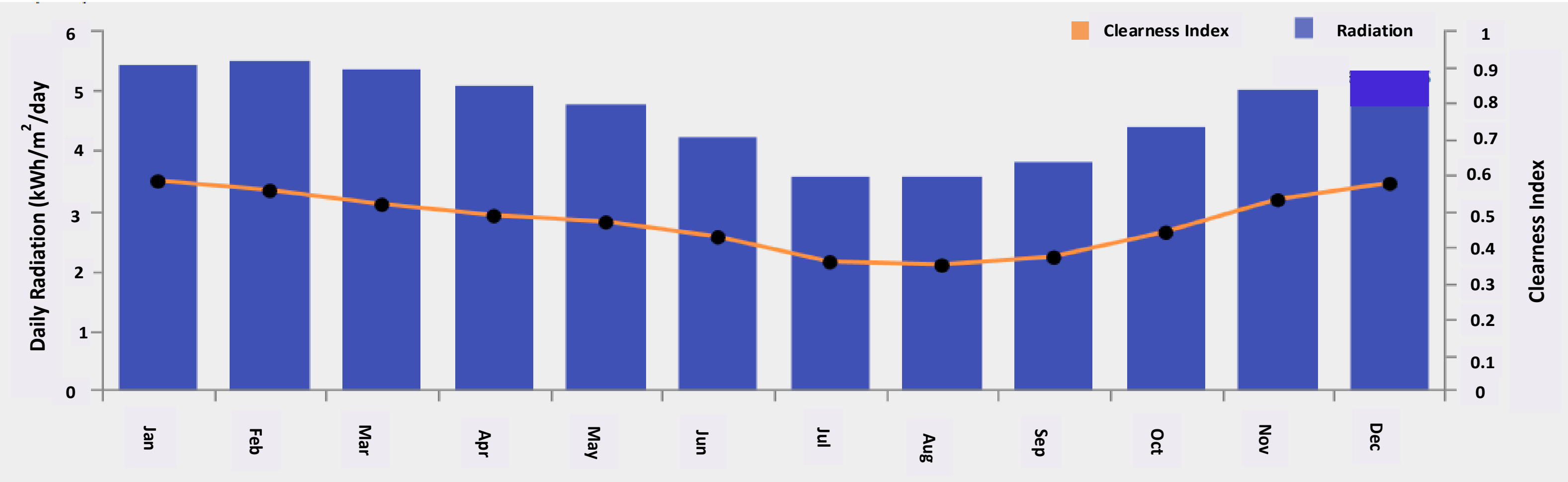
1 String of 12V battery

SYSTEM COMPONENTS

- Using a 48V bus, system is made up of a 1.23kW PV comprised of 4 modules each of 325W (2 series and 2 parallel).
- MPPT
- The DC – DC buck converter
- Permanent magnet synchronous generator for charging the battery when the voltage of the battery goes below 49V due to inconsistency in solar resources.

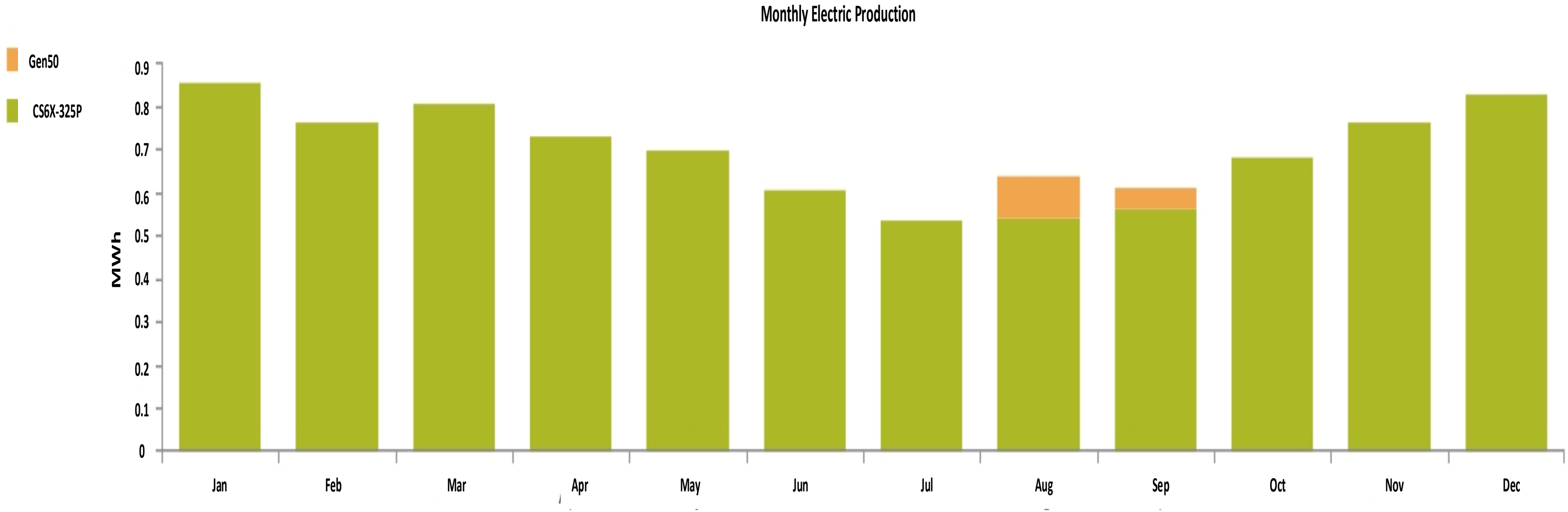
SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID RESIDENCE

- The scaled annual average solar irradiation is 4.63kWh/m^2/day



The monthly average solar irradiance of the selected site

SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID RESIDENCE



SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID RESIDENCE

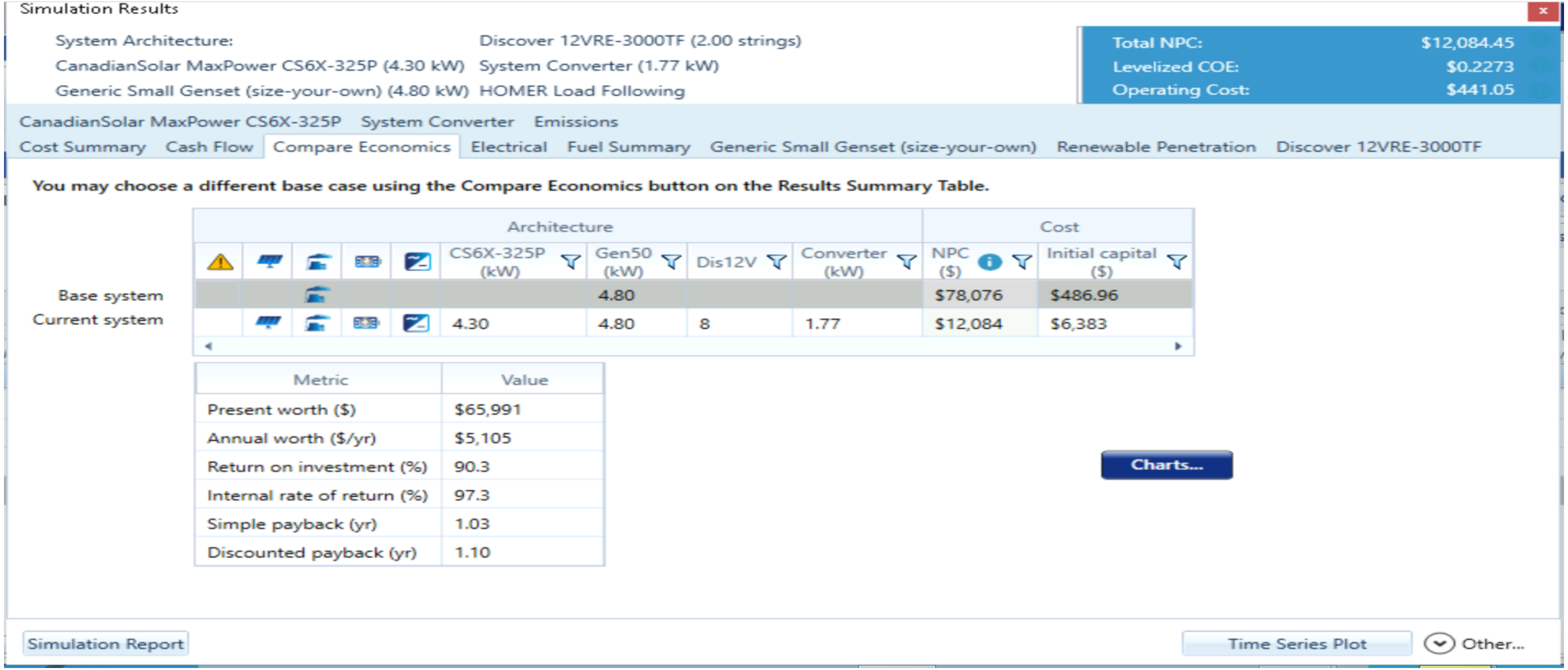
- Solar PV is the prime supply for powering the load and charging the battery
- The battery only operates as backup
- The battery is mostly a source of power supply at night or at rainy or cloudy days
- The emergency generator only operates if both cannot meet the load demand.

ECONOMIC ANALYSIS OF PROPOSED PV SYSTEM

CS6X-325P (kW)	Gen50 (kW)	Dis12V	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)	Hours	Produ (kV
4.30	4.80	8	1.77	LF	$12,084	$0.227	$441.05	$6,383	92.6	103	97	1.0	126	302
8.01		12	1.66	CC	$14,630	$0.275	$386.16	$9,637	100	0	63	1.6		
	4.80	4	1.99	LF	$25,888	$0.487	$1,824	$2,313	0	1,737	244	0.41	2,135	5,124
12.5	4.80		0.969	CC	$62,821	$1.18	$4,265	$7,686	0	4,836	24	4.1	5,944	14,26
	4.80			CC	$78,076	$1.47	$6,002	$486.96	0	7,127			8,760	21,02

ECONOMIC ANALYSIS OF PROPOSED PV SYSTEM

- The diesel generator only system is more expensive than the PV hybrid system



Cost comparison between base and current system

SENSITIVITY ANALYSIS OF PROPOSED PV SYSTEM

FILE | LOAD | COMPONENTS | RESOURCES | PROJECT | HELP

Home | Design | Results | Library | View | Electric #1 | Electric #2 | Deferrable | Thermal #1 | Thermal #2 | Hydrogen | Calculate

RESULTS

Summary | Tables | Graphs | Calculation Report

Export... | Export All... | Compare Economics | Column Choices...

Sensitivity Cases

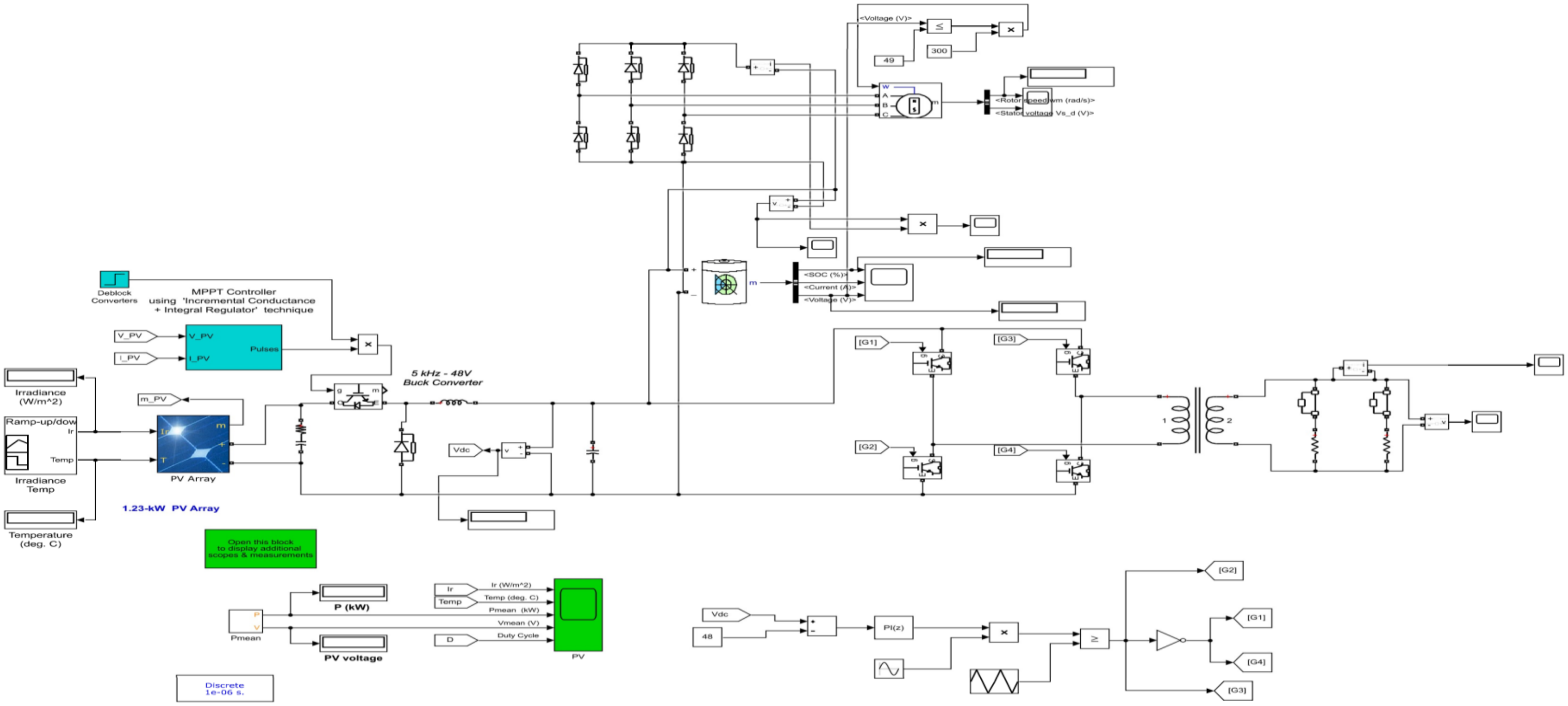
Left Click on a sensitivity case to see its Optimization Results.

Sensitivity		Architecture					Cost				System		
CS6X-325P Derating (%)	Electric Load #1 Scaled Average (kWh/d)	CS6X-325P (kW)	Gen50 (kW)	Dis12V	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hou
77.0	11.3	4.84	4.80	8	1.73	LF	$12,555	$0.236	$453.95	$6,687	92.2	108	133
88.0	11.3	4.29	4.80	8	1.78	LF	$12,092	$0.227	$442.37	$6,374	92.5	104	128
99.0	11.3	4.18	4.80	8	1.81	LF	$11,718	$0.220	$418.05	$6,314	94.5	77.3	95.0
77.0	13.5	5.50	4.80	8	1.79	LF	$14,701	$0.230	$590.61	$7,066	88.7	189	232
88.0	13.5	5.35	4.80	8	1.80	LF	$14,149	$0.222	$554.33	$6,983	91.2	146	180
99.0	13.5	4.76	4.80	8	1.78	LF	$13,691	$0.215	$545.15	$6,644	91.2	146	180
77.0	9.02	4.09	4.80	4	1.86	LF	$10,399	$0.244	$446.36	$4,629	84.9	168	207
88.0	9.02	3.54	4.80	4	1.87	LF	$10,006	$0.235	$439.98	$4,319	84.7	171	210
99.0	9.02	3.78	4.80	4	1.89	LF	$9,685	$0.228	$404.35	$4,457	88.9	124	152

SENSITIVITY ANALYSIS OF PROPOSED PV SYSTEM

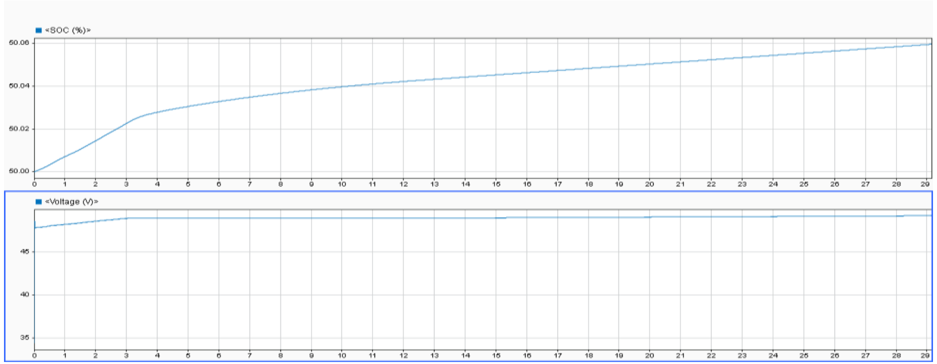
- Sensitivity analysis is used to determine the adaptation of the system
- For this design, Sensitivity analysis was performed on Solar PV variation of 10% and load input variation of 20%
- Environmental factor such as cloudy weather, suspended dust could affect the efficiency of the PV
- Optimization result shows best configuration for optimal cost for the house in these conditions

DYNAMIC SIMULATION AND RESULT

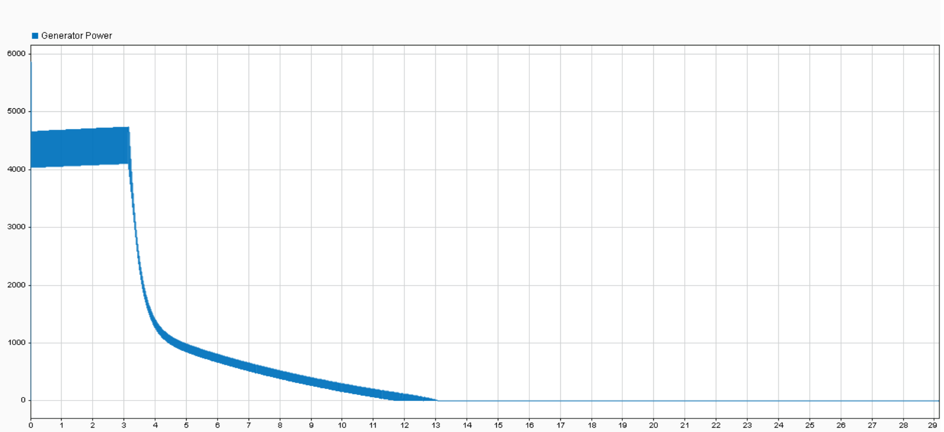


PV-battery-generator hybrid system in Simulink

DYNAMIC SIMULATION AND RESULT

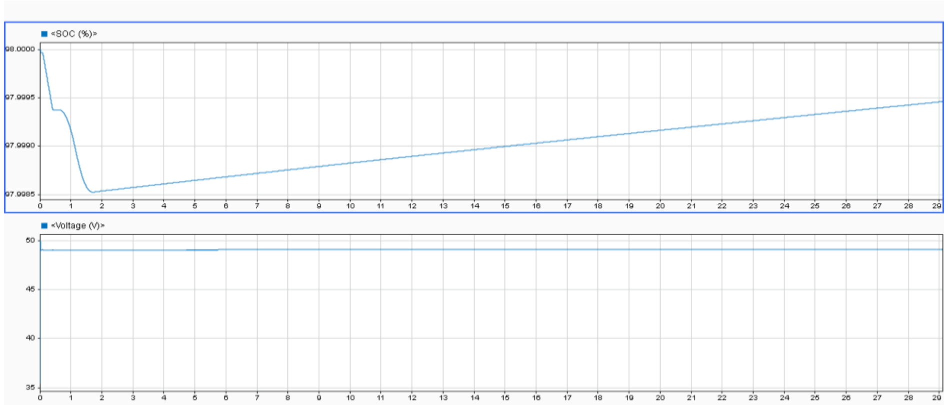


Battery SOC and Voltage at half load and 50% SOC

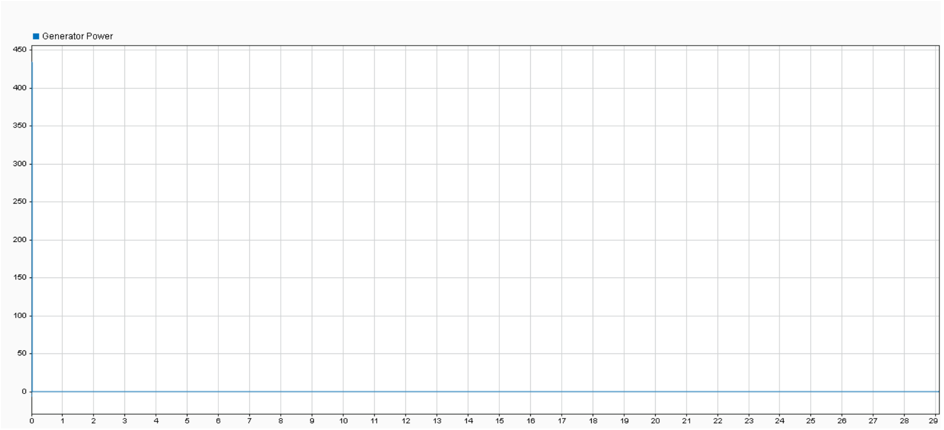


Generator Power at half load

DYNAMIC SIMULATION AND RESULT



Battery SOC and Voltage at full load and 98% SOC



Generator Power

SUMMARY

The performance of the system is evaluated under various conditions in MATLAB/SIMULINK. During this search, it became clear that the proposed stand-alone PV hybrid system with battery and emergency backup generator is stable, and it can fully meet the needs of the house load.

SITE LOCATION

On Google maps the selected site has the following co-ordinates: (6.182863, 5.933505) Latitude:6°10'58.3"N Longitude: 5°56'00.6"E.

Site photo

ENERGY CONSUMPTION

Daily energy consumption for a house in remote Edo State, Nigeria

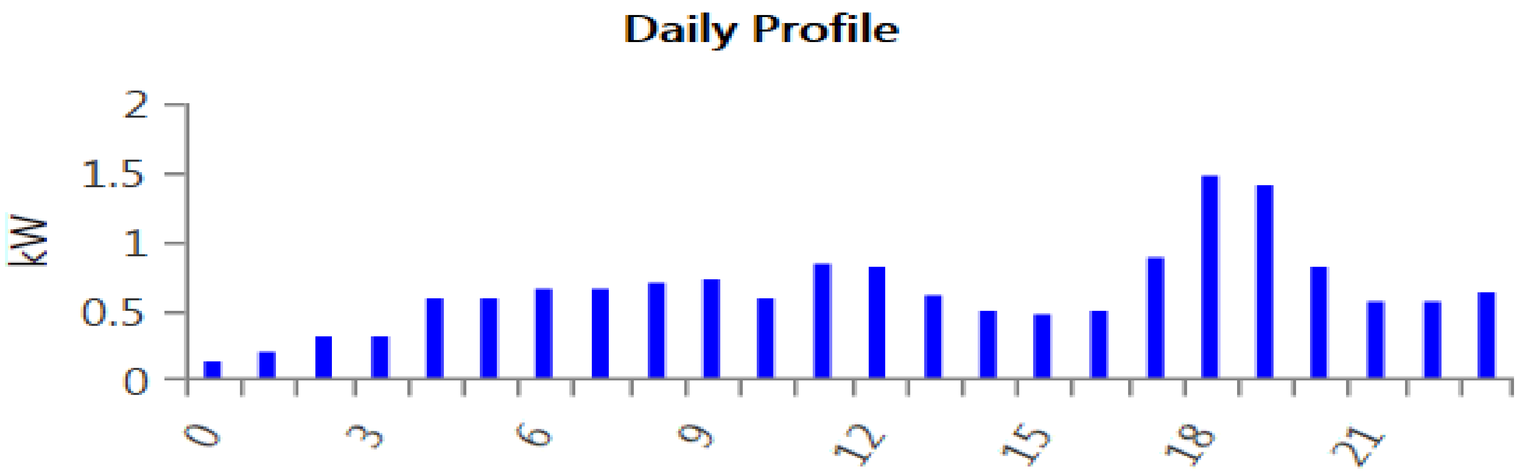
Appliances	Quantity	Wattage (W)	Total Wattage (W)	Daily usage (hours)	Energy (Wh/day)
LED bulb	3	18	54	10	540
Fan	2	10	20	9	180
Radio/cell phone	1	5	5	8	40
Television	1	30	30	8	240
Total:			109		1000

OBJECTIVE

- **Design of a DC microgrid system for a remote community using a 48V bus system**
- **Optimization of the system for economic feasibility using Homer Pro**
- **Dynamic simulation of the System to determine Stability and power quality**

SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID COMMUNITY

- ➢ Annual energy consumption estimated using Homer Pro
- ➢ The daily average energy consumption is 1kwh/day



SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID COMMUNITY

System Architecture: HOMER Cycle Charging
Generic flat plate PV (0.417 kW)
PowerStar (1.00 strings)

Scaled Average (0.60 kWh/d)

Total NPC: $2,406.62
Levelized COE: $0.8508
Operating Cost: $108.49

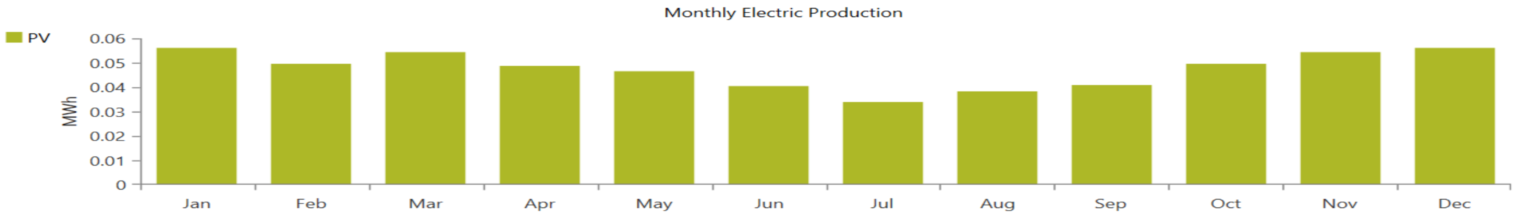
Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | PowerStar | Generic flat plate PV | Emissions

Production	kWh/yr	%
Generic flat plate PV	569	100
Total	569	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	219	100
Deferrable Load	0	0
Total	219	100

Quantity	kWh/yr	%
Excess Electricity	321	56.4
Unmet Electric Load	0.182	0.0833
Capacity Shortage	0.208	0.0949

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	4,806	%

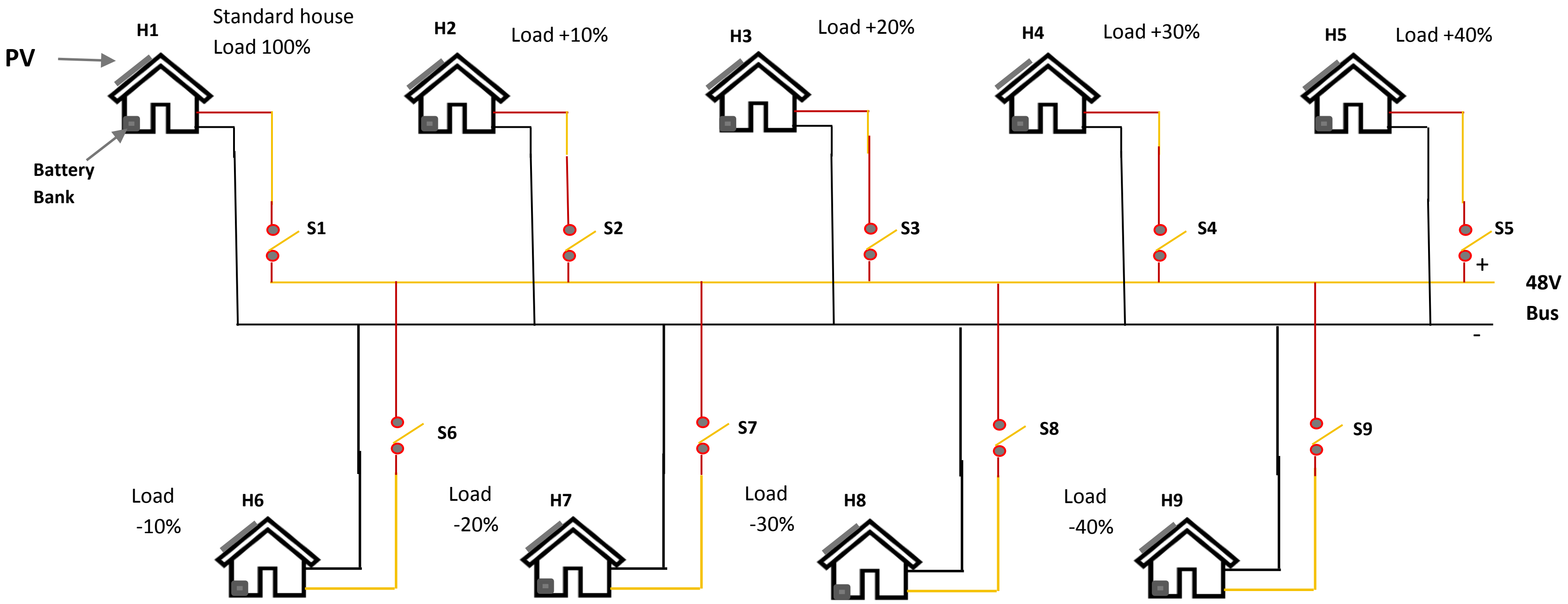


Electrical output

SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID COMMUNITY

- Solar PV is the prime supply for powering the load and charging the battery
- The battery only operates as backup
- The battery is mostly a source of power supply at night or at rainy or cloudy days
- Excess energy produced from a PV is feed back into the microgrid

SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID COMMUNITY



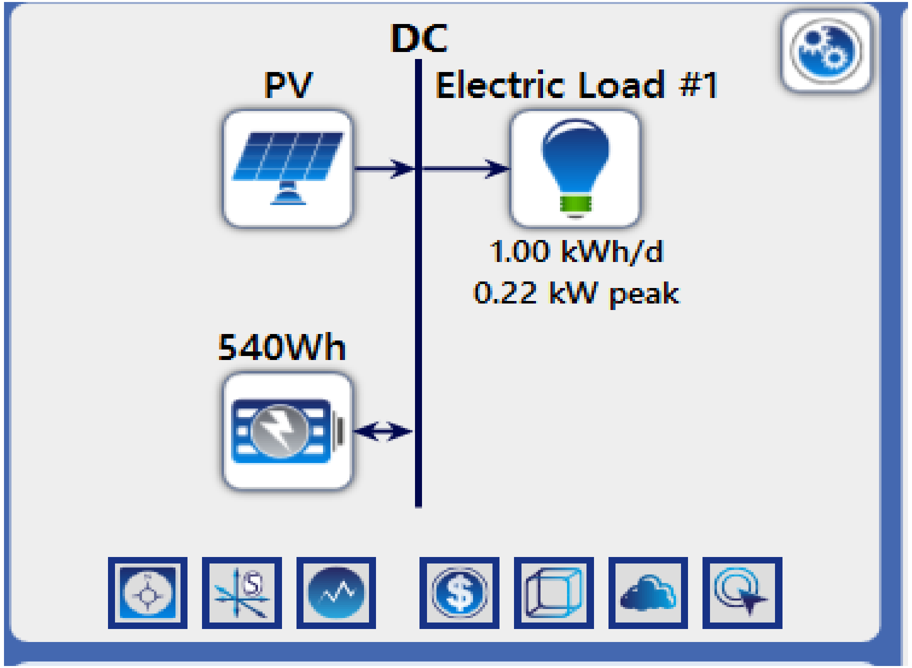
block diagram showing load distribution of households in the community

SYSTEM SIZING AND ANALYSIS FOR AN OFF-GRID COMMUNITY

- The Figure above shows Load distribution of the 9 households in the community
- Each house has a PV system, battery bank
- Each house has a Switch to connect/disconnect to or from the microgrid.
- House 1 having an energy consumption of 1kWh/day is used as a reference
- Using house 1 as reference, a load variation of 10%, is used for load distribution from house 1 to house 9.

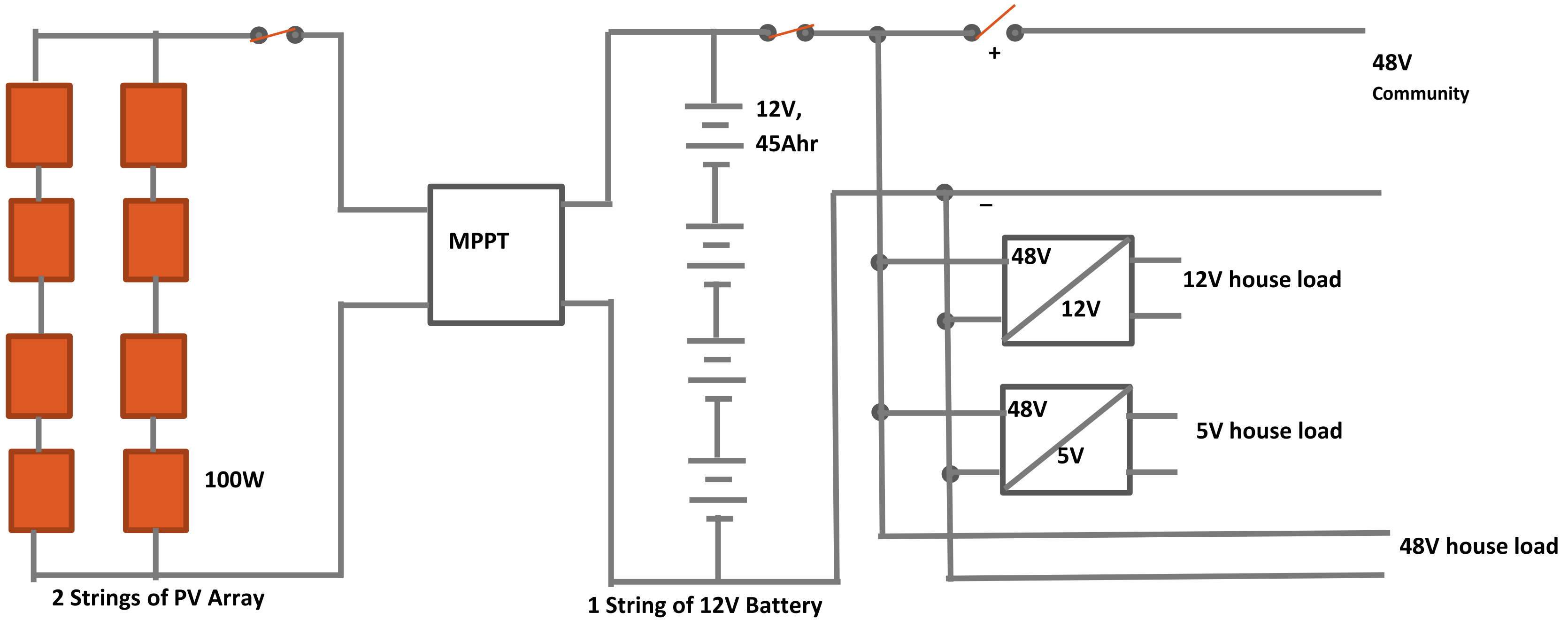
SYSTEM COMPONENTS

All system components were selected using Homer Pro. The figure shows all components in a block diagram. Which consists 100W PV module, 12V, 45Ahr.



Homer Pro system block diagram

SYSTEM COMPONENTS



System component in a House

SYSTEM COMPONENTS

- House appliances such as lights, fans, refrigerators run on either 48V, 12V or 5V.
- DC-DC converters are used to convert bus voltages to house load voltage
- The System comprises of a 100W Solar Panel, battery of 12V, 45Ahr all connected to the 48V bus
- There is no inverter in the system
- Maximum Power Point Tracking (MPPT) ensures the PV reaches delivers maximum power

EXAMPLE OF DC APPLIANCES

12V,7W, LED bulb

12v Large Ceiling Fan

12V DC TV

48V DC Refrigerator

ECONOMIC ANALYSIS OF PROPOSED PV SYSTEM

Sensitivity	Architecture			Cost				System		PV		540Wh	
Electric Load #1 Scaled Average (kWh/d)	PV (kW)	540Wh	Dispatch	NPC (US$)	COE (US$)	Operating cost (US$/yr)	Initial capital (US$)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (US$)	Production (kWh/yr)	Autonomy (hr)	Annual Throughp (kWh/yr)
0.600	0.417	4	CC	$2,407	$0.851	$108.49	$1,004	100	0	304	569	51.8	131
0.700	0.323	8	CC	$3,780	$1.15	$165.90	$1,636	100	0	236	440	88.9	160
0.800	0.396	8	CC	$3,928	$1.04	$173.22	$1,689	100	0	289	540	77.8	182
0.900	0.863	4	CC	$3,310	$0.780	$153.13	$1,330	100	0	630	1,178	34.6	191
1.10	1.21	4	CC	$4,015	$0.774	$188.00	$1,585	100	0	885	1,654	28.3	231
1.20	0.827	8	CC	$4,799	$0.848	$216.29	$2,003	100	0	603	1,128	51.8	263
1.30	0.958	8	CC	$5,066	$0.827	$229.47	$2,100	100	0	700	1,308	47.9	283
1.40	0.759	12	CC	$6,226	$0.943	$276.33	$2,654	100	0	554	1,036	66.7	314
1.00	0.576	8	CC	$4,293	$0.911	$191.27	$1,821	100	0	421	787	62.2	223

System design for each house in the community

ECONOMIC ANALYSIS OF PROPOSED PV SYSTEM

- Homer Pro performs economic analysis to determine the feasibility of implementing a system based on financial constraints.
- Result shows detailed breakdown of cost both installation and operation of the system which includes capital, Replacement, O&M cost, e.t.c.
- The total cost of all the components gives the Net Present Cost (NPC) of the system per household.
- For the house with a Load of 0.6kWh/d, result shows an NPC of $2,407, Capital cost of $1,004, O&M cost of $108.49

SENSITIVITY ANALYSIS OF PROPOSED PV SYSTEM

Export... Export All...

Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

Compare Economics Column Choices...

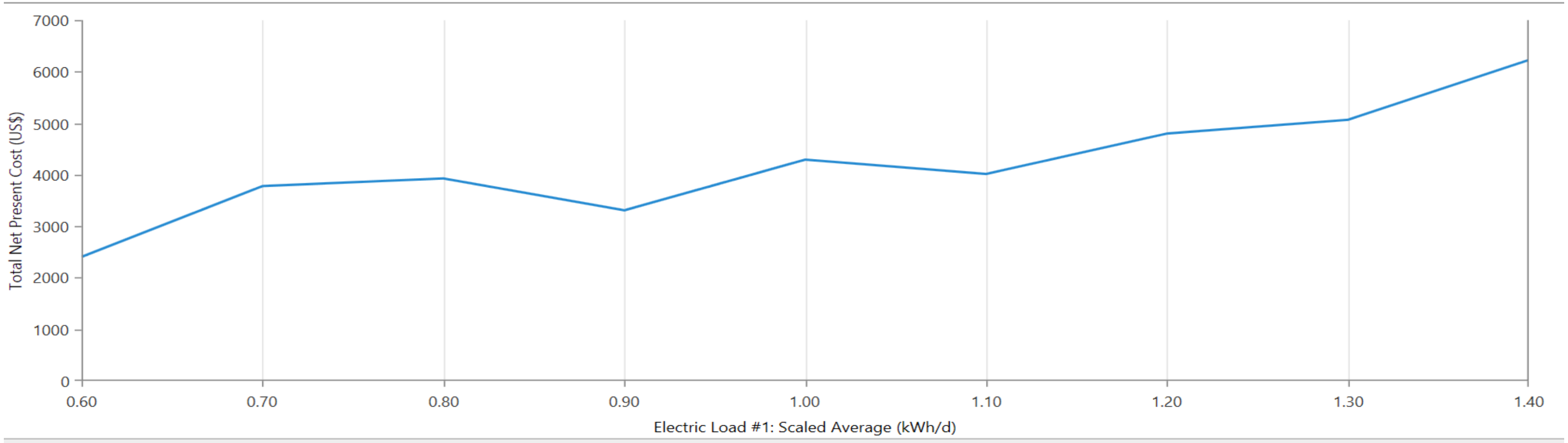
Sensitivity		Architecture				Cost				System		PV		
Electric Load #1 Scaled Average (kWh/d)	Solar Scaled Average (kWh/m²/day)	PV (kW)	540Wh	Dispatch	NPC (US$)	COE (US$)	Operating cost (US$/yr)	Initial capital (US$)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (US$)	Production (kWh/yr)	Autonon (hr)
0.600	4.14	0.469	4	CC	$2,512	$0.888	$113.69	$1,042	100	0	342	571	51.8
0.600	4.63	0.417	4	CC	$2,407	$0.851	$108.49	$1,004	100	0	304	569	51.8
0.600	5.00	0.385	4	CC	$2,343	$0.828	$105.34	$981.18	100	0	281	568	51.8
0.700	4.14	0.364	8	CC	$3,865	$1.17	$170.07	$1,666	100	0	266	444	88.9
0.700	4.63	0.323	8	CC	$3,780	$1.15	$165.90	$1,636	100	0	236	440	88.9
0.700	5.00	0.299	8	CC	$3,732	$1.13	$163.50	$1,618	100	0	218	440	88.9
0.800	4.14	0.437	8	CC	$4,011	$1.06	$177.31	$1,719	100	0	319	532	77.8
0.800	4.63	0.396	8	CC	$3,928	$1.04	$173.22	$1,689	100	0	289	540	77.8
0.800	5.00	0.364	8	CC	$3,865	$1.02	$170.07	$1,666	100	0	266	537	77.8
0.900	4.14	0.530	8	CC	$4,199	$0.990	$186.62	$1,787	100	0	387	645	69.1
0.900	4.63	0.863	4	CC	$3,310	$0.780	$153.13	$1,330	100	0	630	1,178	34.6
0.900	5.00	0.450	8	CC	$4,037	$0.951	$178.59	$1,728	100	0	328	663	69.1
1.10	4.14	0.777	8	CC	$4,699	$0.906	$211.32	$1,967	100	0	567	946	56.6
1.10	4.63	1.21	4	CC	$4,015	$0.774	$188.00	$1,585	100	0	885	1,654	28.3
1.10	5.00	0.650	8	CC	$4,443	$0.857	$198.68	$1,875	100	0	475	959	56.6

SENSITIVITY ANALYSIS OF PROPOSED PV SYSTEM

- Sensitivity analysis is used to determine the robustness of a design
- For this design, Sensitivity analysis was performed on Solar irradiation using a range of 4.14kWh/m^2/day to 5kWh/m^2/day
- Due to climate change solar irradiation could increase or decrease which conversely affecting PV efficiency
- Optimization result shows best configuration for optimal cost for each house in these conditions

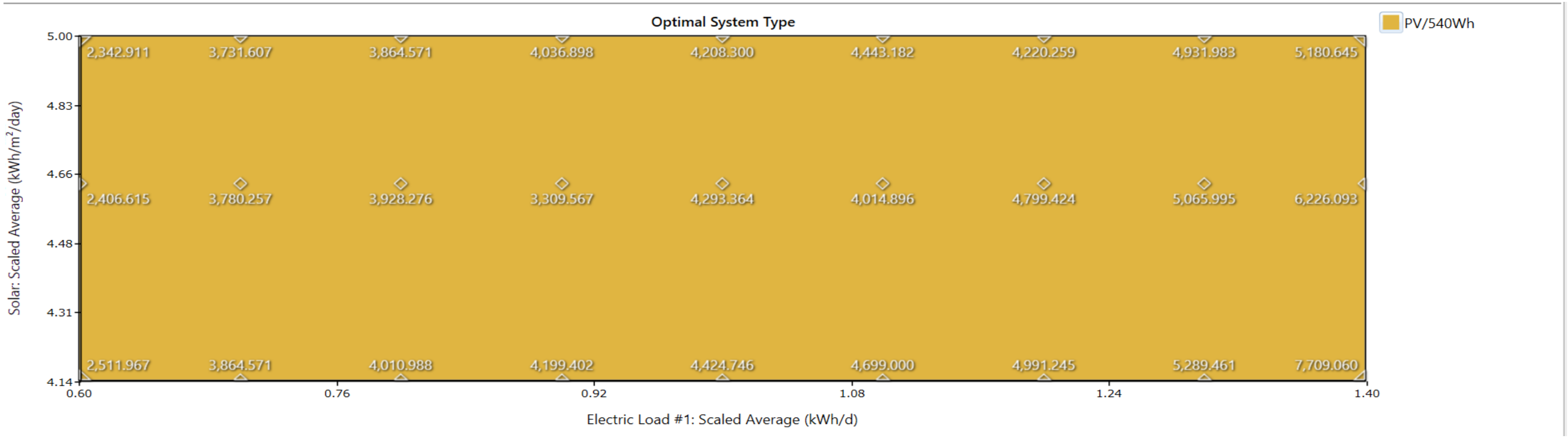
SENSITIVITY ANALYSIS OF PROPOSED PV SYSTEM

- Optimization surface plot with NPC and COE superimposed for remote Edo community for 4.145kWh/m^2/day solar scaled average

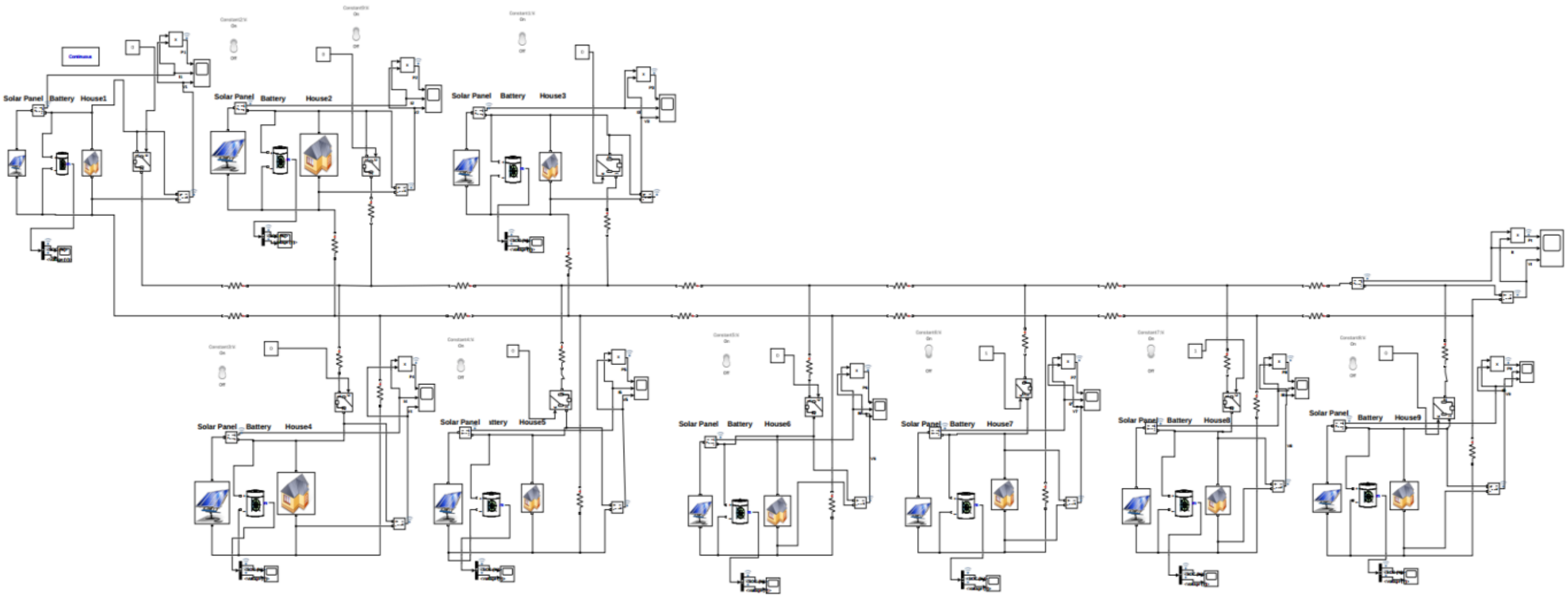


SENSITIVITY ANALYSIS OF PROPOSED PV SYSTEM

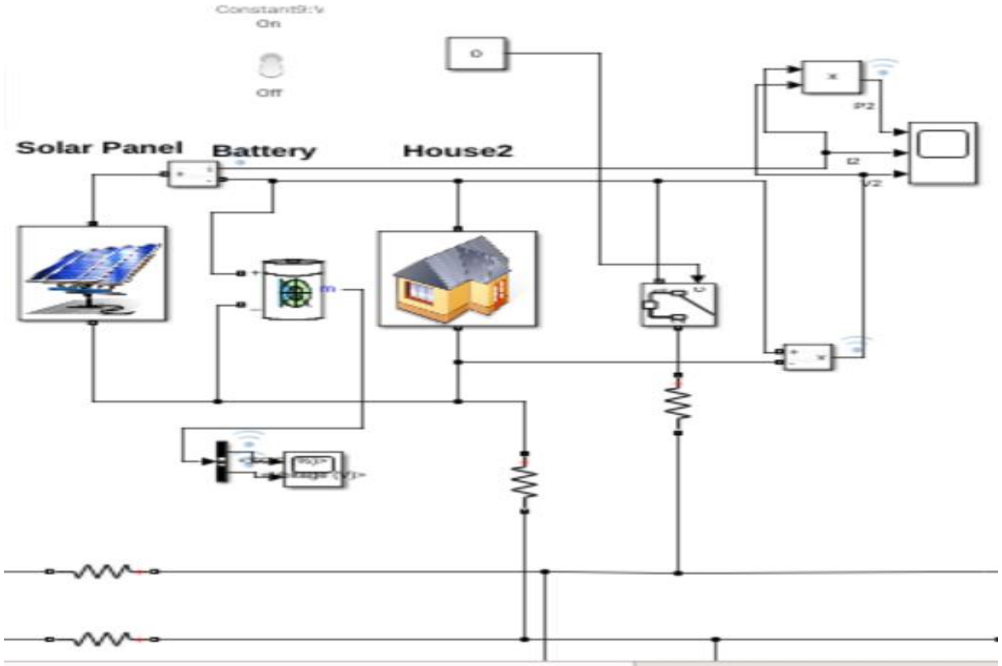
- Optimization surface plot with NPC and COE superimposed for remote Edo community for 5.00kWh/m2/day solar scaled average



DYNAMIC SIMULATION AND RESULTS

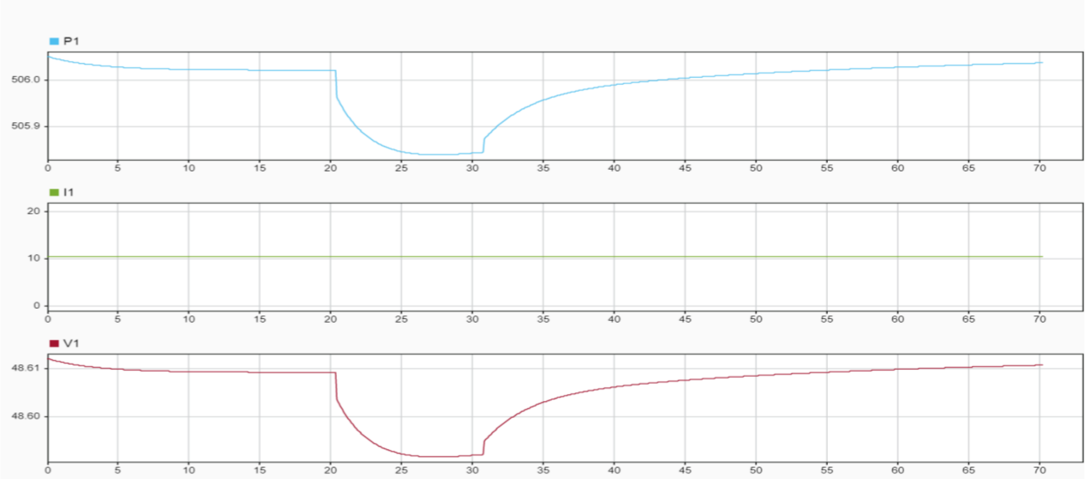


Design of communal microgrid system in Simulink

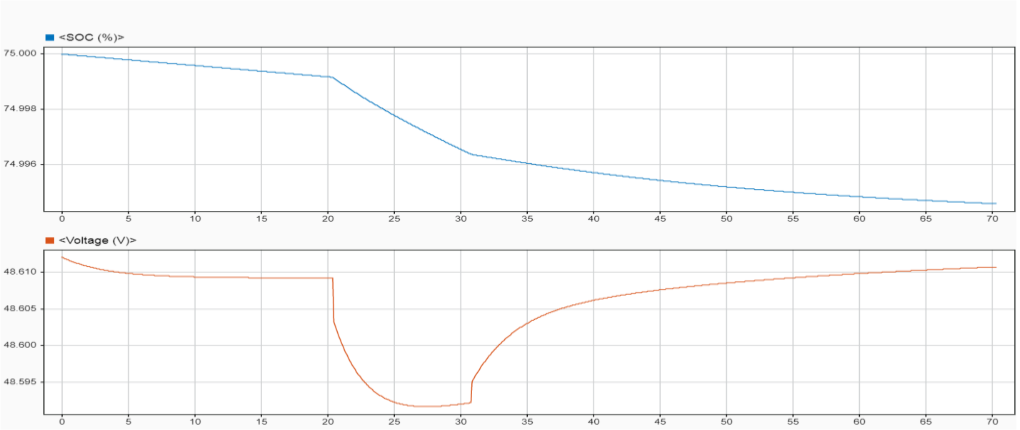


Design connection of House 2 to Microgrid

DYNAMIC SIMULATION AND RESULT

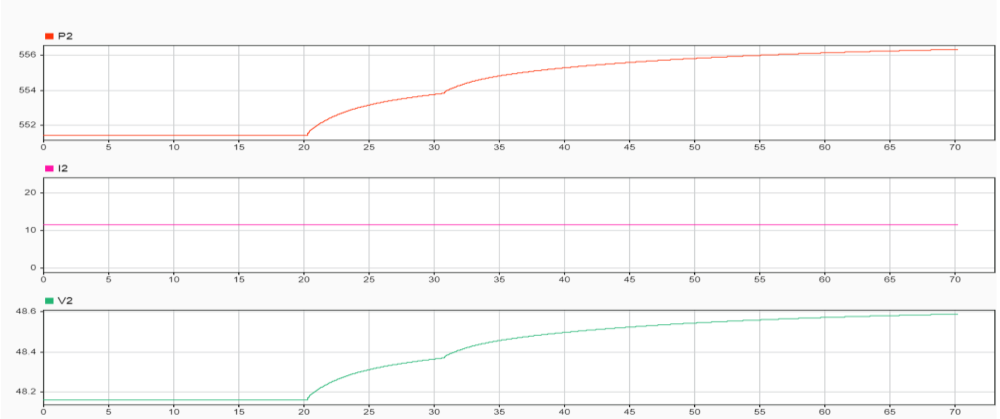


Power, Current of voltage of house 1.

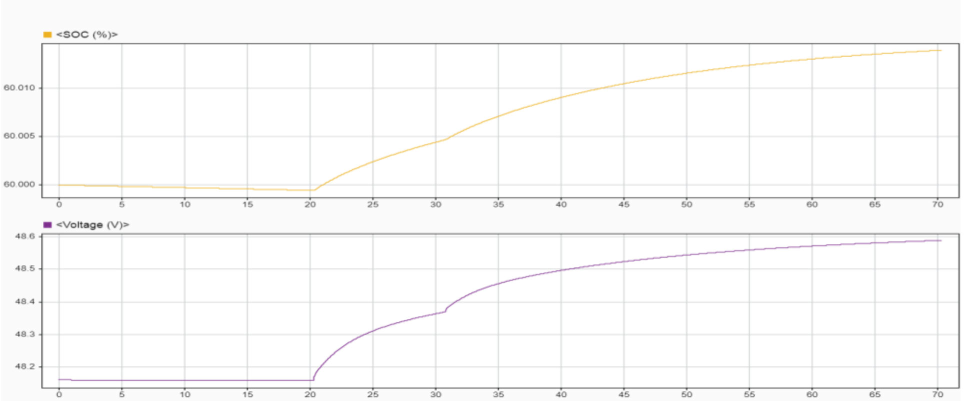


The SOC of the battery and voltage.

DYNAMIC SIMULATION AND RESULT



Power, current and load voltage of House 2.



Battery Voltage and SOC of house 2

CONCLUSION

- A 48V DC bus system were used for the communal microgrid
- Modelling, sizing, and optimization for an off-grid PV-battery microgrid with DC load have been presented.
- A detailed economic and sensitivity analysis was done.
- The performance of the system is evaluated under various conditions in MATLAB/SIMULINK.
- During this search, it became clear that the proposed off grid PV-battery is stable, demonstrated power sharing , and can fully meet the needs of the community load.

RESEARCH CONTRIBUTIONS

- A complete sizing and design of off grid PV system to supply power to remote areas in Edo State, Nigeria
- DC microgrid Power sharing system for remote community
- Use of DC bus system instead of AC
- Detailed economic and sensitivity analysis for various conditions
- Dynamic modelling of DC microgrid to show system stability and power sharing

FUTURE WORK

- Addition of low cost open-source SCADA system for small scale renewable energy system.
- Application of wind energy system especially in Northern Nigeria where there is high wind energy and solar resources
- DC Microgrid renewable energy system for Northern Nigeria in areas with spatial residential/communities.
- Large Scale Grid-tied Hybrid system implementation in Nigeria.
- Implementation of Solar farms and Solar water pumps for communities in Northern Nigeria for agricultural and ranching purposes for improved agricultural experience and development in the agricultural sector.

PUBLICATIONS

- J.C. Ozogbuda and M.T. Iqbal “Dynamic Simulation of a Standalone Photovoltaic Hybrid System of a Remote house in Nigeria”. *2021 IEEE 12th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*. 10.1109/IEMCON53756.2021.9623160
- J.C. Ozogbuda and M.T. Iqbal “Dynamic Simulation of an Off Grid Photovoltaic System with backup battery and generator for a Remote house in Nigeria”. 30th IEEE NECEC conference Nov. 18, 2021.
- J. C. Ozogbuda and M. T. Iqbal “Design of a DC Microgrid System for a Remote Community in Nigeria” (Vol 5, No 6, 2021) https://doi.org/10.24018/ejece.2021.5.6.376.
- J. C. Ozogbuda and M. T. Iqbal “ Sizing and Analysis of an Off-Grid Photovoltaic System for a House in Remote Nigeria”, *European Journal of Electrical Engineering and Computer Science* Vol.8 No.1. 2022.

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