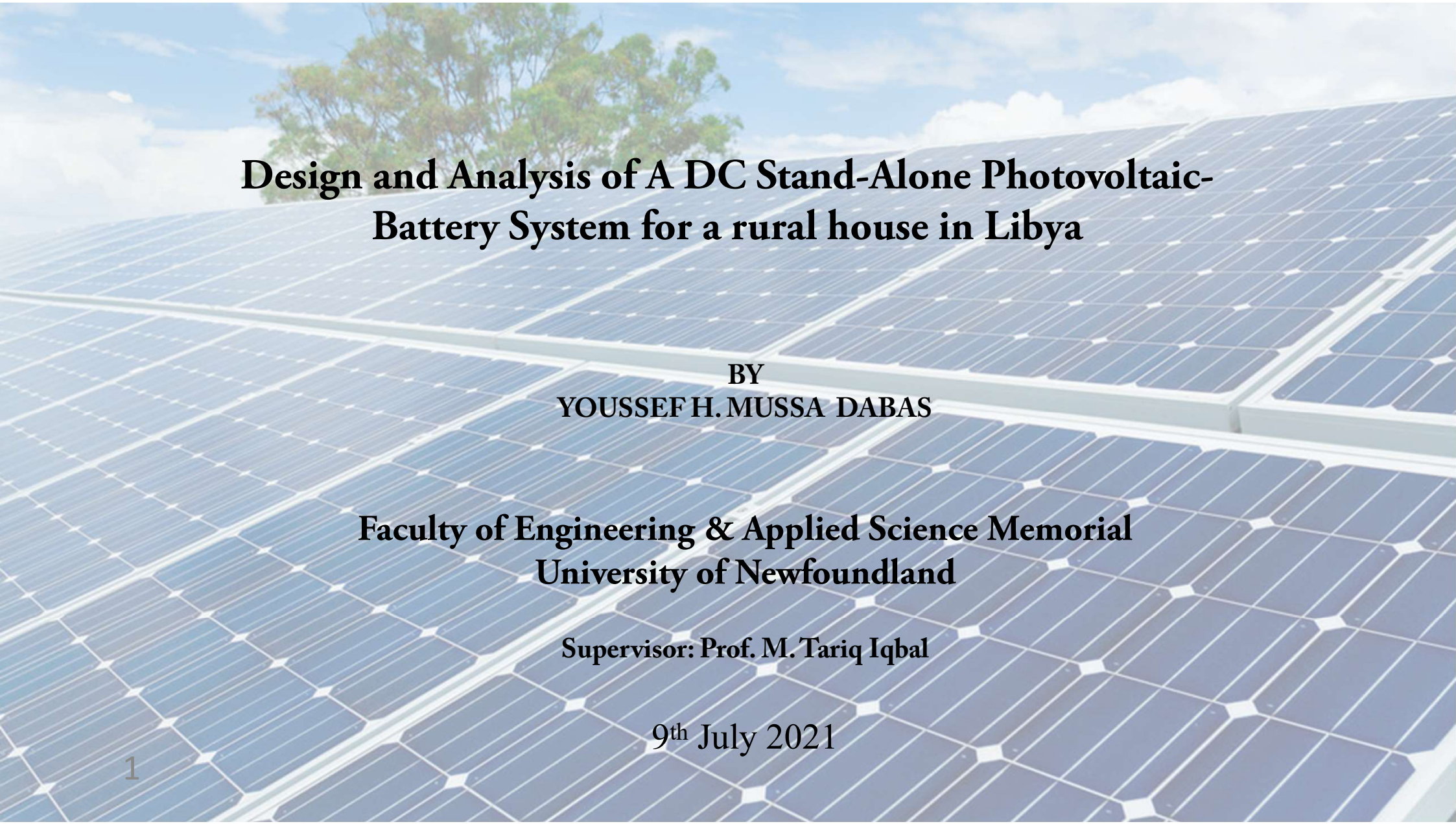

Design and Analysis of A DC Stand-Alone Photovoltaic-Battery System for a rural house in Libya

BY
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Outline

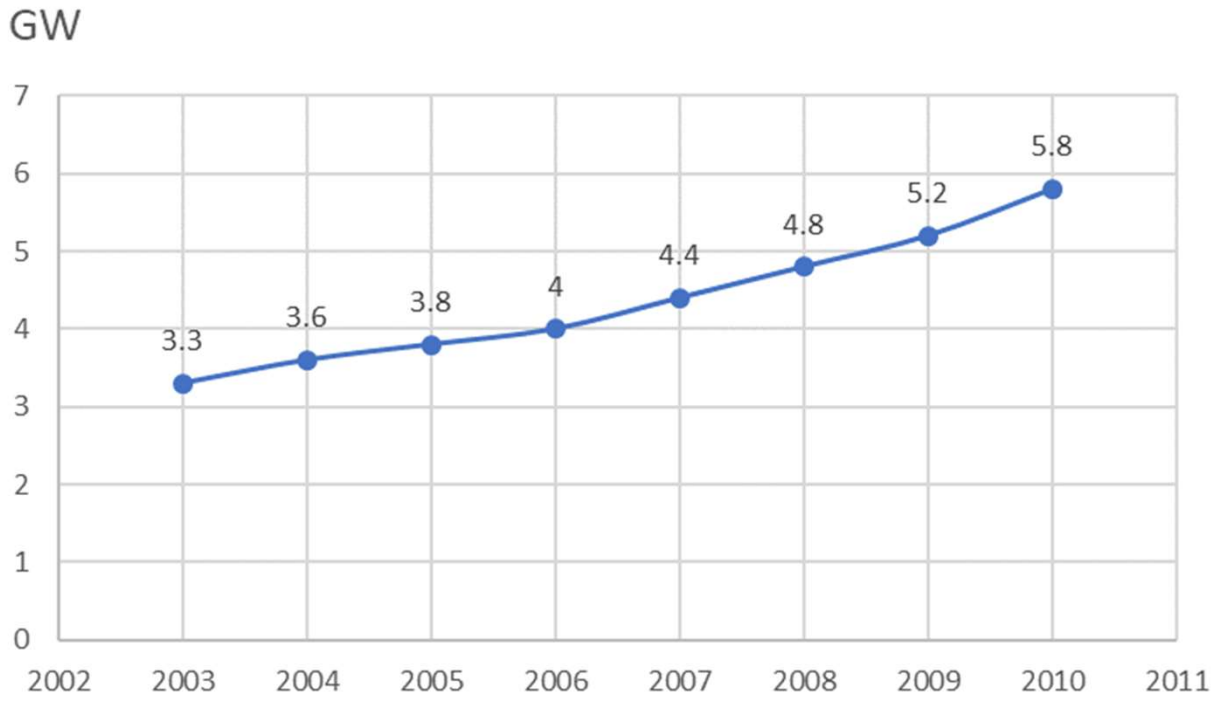
- Introduction
- Objective of the study
- Estimation Of The Energy Consumption and Thermal Simulation
- System Sizing and Analysis in HOMER PRO
- Economic Analysis of The Proposed PV System
- Dynamic Modeling, Simulation, and Results
- Summary & Conclusion

Introduction

- Libya one of north Africa country with about 7 million population & 1,750,000 km2.
- Relies on the oil and natural gas as the source of energy generation.
- Industrial and population growth are causing significant increase in the power demand.
- The household loads consumed about 24% of the total amount of energy .
- Investment in extra installations as power stations, transmission lines and substations.

Introduction

- the power demand will get about 11 gigawatts by 2030.



Libyan load growth

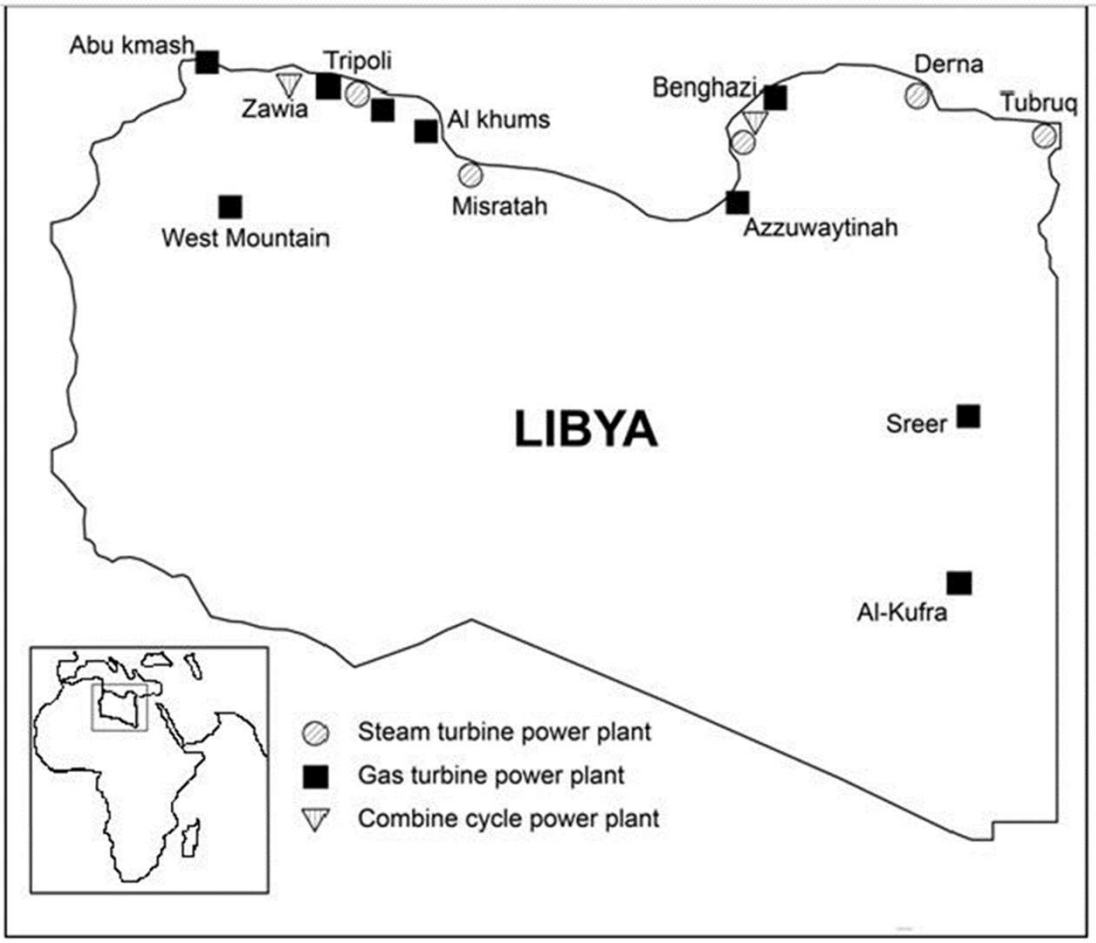
Introduction

- Political instability in Libya since 2011 causes several wars to take place in different regions of the country.
- Critical damage in the infrastructure of the electrical grid and delayed the maintains of some generation plants.
- Forcing the engineers of the control center to load shedding to keep the system from breakdown.

the damage in electricity grid

Introduction

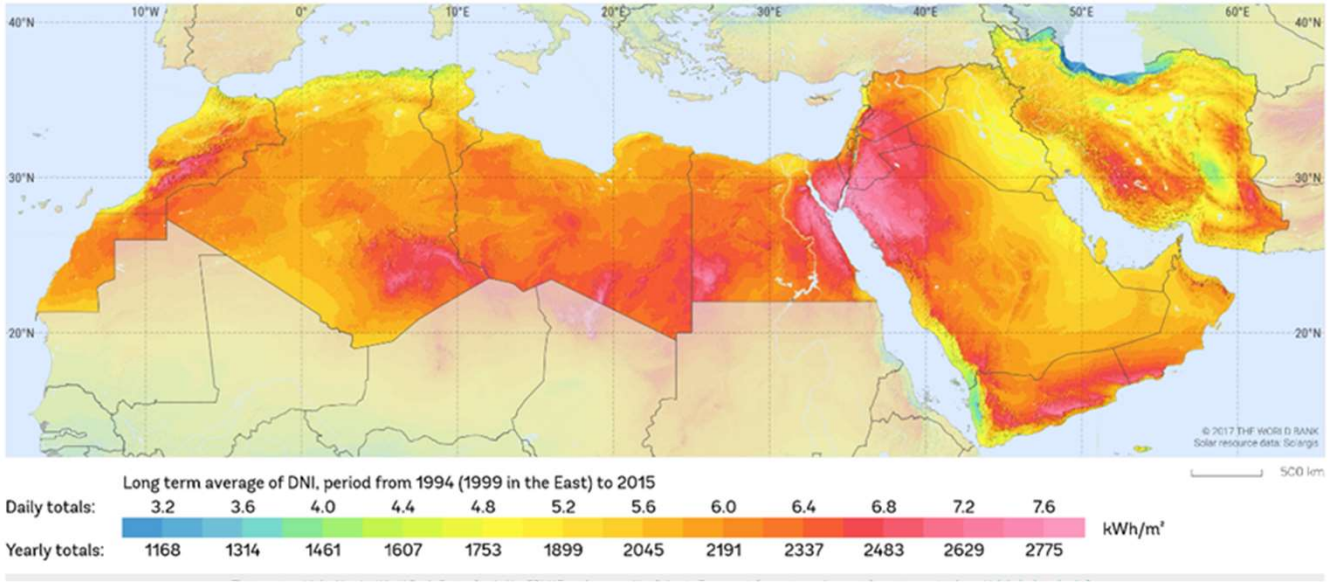
- About 80 % of Libya's area located in the Sahara Desert.



Power plant's locations in Libya

Introduction

- The average daily direct radiation reach to about 8.1 kWh / m2 / day in the southern region of the country.
- With this a high potential of solar that can be utilized as alternative source to supply a part of the energy needs in Libya



Direct average irradiation Middle East and North Africa

Literature Review

- Literature reviewed regarding solar energy system utilization ,sizing ,design and dynamic molding.

Paper reviewed	Comments
A. Asheibe	The renewable energy in Libya: Present difficulties and remedies
F. Mosbah	Design and analysis of a hybrid power system for Western Libya
A. Iqbal	Design and Analysis of a Stand-Alone PV System for a Rural House in Pakistan
A. Demirbas	Energy sources, part A: recovery, utilization, and environmental effects
M. Ben Jebli	The role of renewable energy and agriculture in reducing CO2 emissions: Evidence for North Africa countries
I. M. S. I. Al-Jadi	Photovoltaic in Libya applications, and evaluation
Y. Aldali	Evaluation of A 50MW two-axis tracking photovoltaic power plant for AL-Jagbob, Libya

Literature Review

- Literature reviewed regarding DC distribution for residential networks & economic analysis

Paper reviewed	Comments
K. Shimomachi	Comparison between DC and AC microgrid systems considering ratio of DC load
O. Technology	LOW-TECH MAGAZINE Renewed Interest in DC Power More Solar Power for Less Money
K. Siraj	Dc distribution for residential power networks—a framework to analyze the impact of voltage levels on energy efficiency
A. Oulis Rousis	Design of a Hybrid AC/DC Microgrid Using HOMER Pro: Case Study on an Islanded Residential Application
M. Almaktar	Revitalizing operational reliability of the electrical energy system in Libya: Feasibility analysis of solar generation in local communities,
K.Y. Lau	Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions

Research Objectives

- Sizing and design a stand-alone PV system with battery to meet the load of the proposed house.
- A 48 V DC is chosen instead of 220 V AC to supply the house.
- Present an economic feasibility analysis by using HOMER software.
- Dynamic analysis by using MATLAB / Simulink to assess the performance of the proposed system .

Estimation of the Energy Consumption, Thermal Simulation, And Analysis in BEopt

- A house on the farm in Benghazi was selected to represent the pattern of energy consumption for remote areas loads.

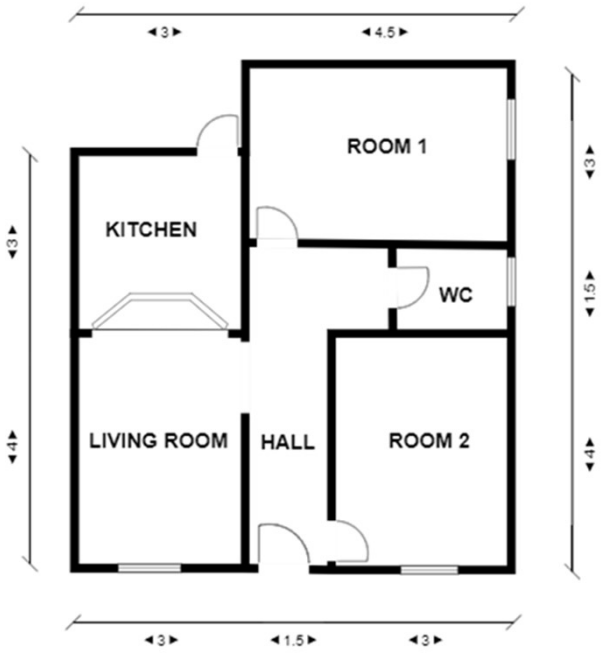
The house facade of the case study

Estimation of the Energy Consumption, Thermal Simulation, And Analysis in BEopt

- The total area of the case study's house is about 59 m2.
- it consists of three rooms, a kitchen, a bathroom, and a small hall.

load estimation of a typical rural house in Libya

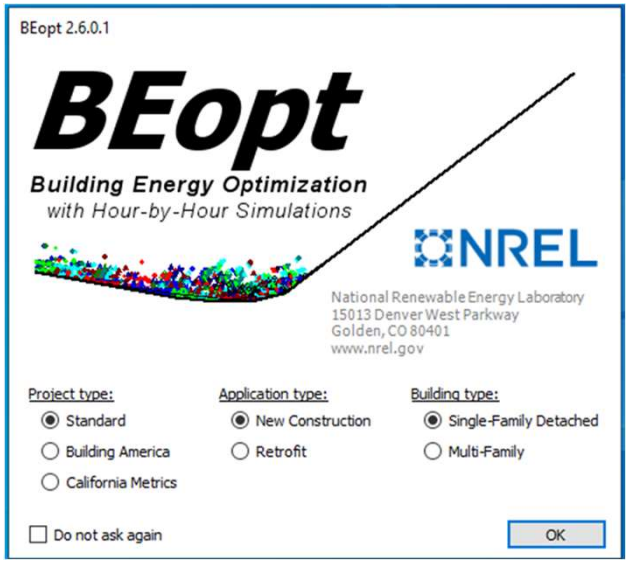
#	items	number	power(W)	total power(W)	hours/day
1	LED lamp	10	7	70	12
2	fan	3	20	60	18
3	water heater	1	450	450	10
4	fridge	1	100	100	8
5	TV	1	49	49	8
6	others	3	100	300	2



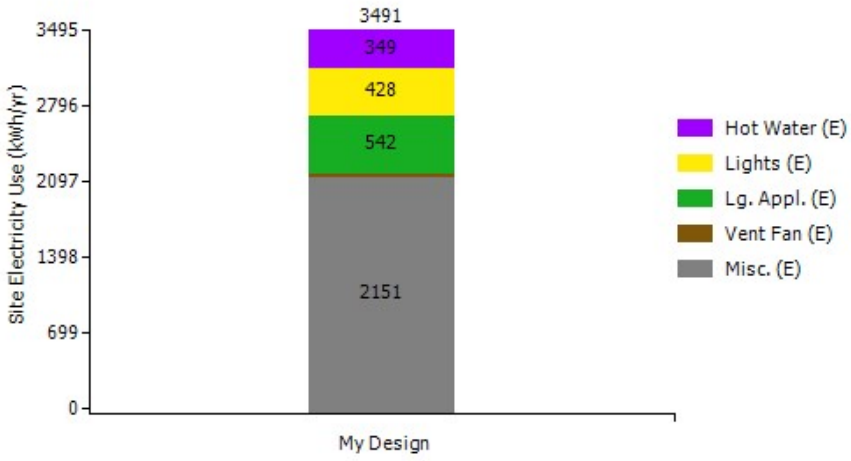
Floor Plans of the house

Estimation of the Energy Consumption, Thermal Simulation, And Analysis in BEopt

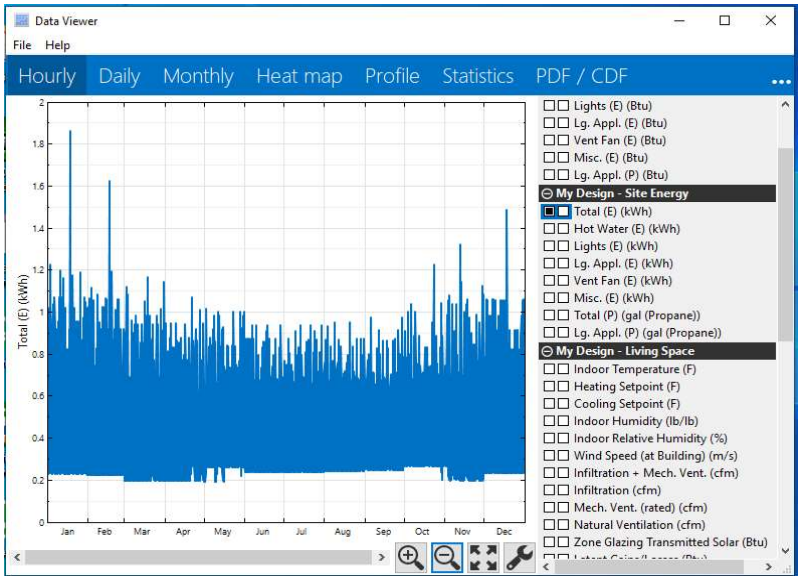
- Building Energy Optimization Software BEopt is an easy-to-use program to perform simulation on a residential model.
- It is considered among the programs that give reliable results in energy modeling.
- It uses parameters such as the orientation of the building, thermal mass, walls' thickness, windows' shading, etc. addition to the weather data for selected site.



Estimation of the Energy Consumption, Thermal Simulation, And Analysis in BEopt



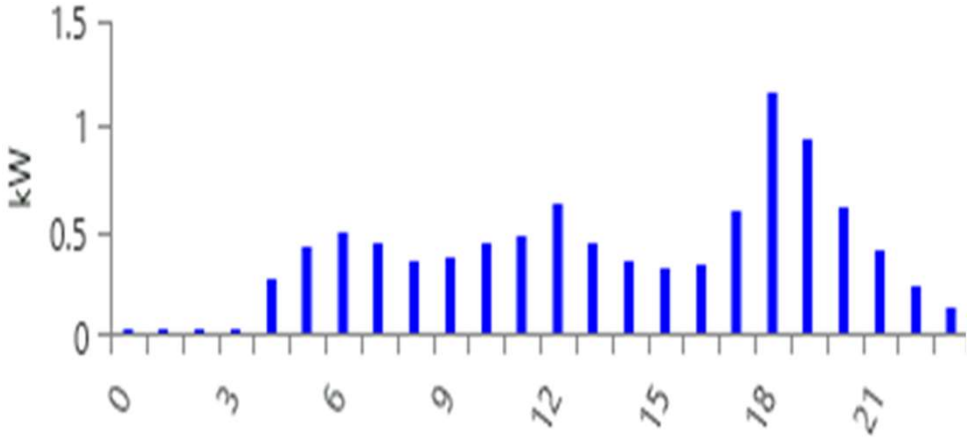
The geometry of the house in BEopt software



The hourly load profile for a year in BEopt

System Sizing and Analysis in HOMER PRO

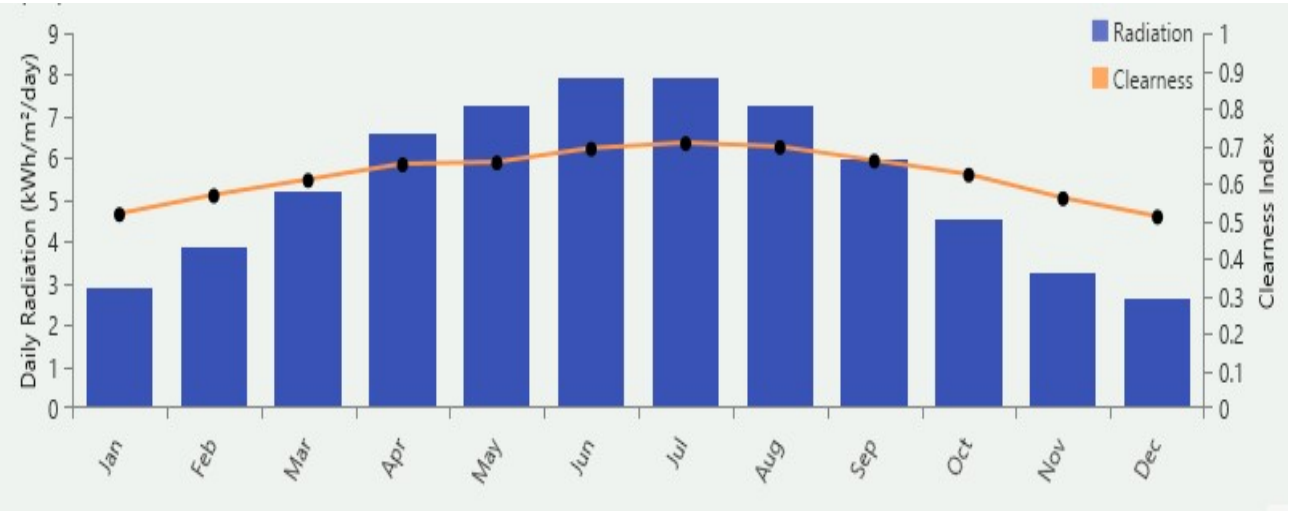
- Annual energy consumption was estimated by BEopte software.
- the daily energy consumption is 9.6 kWh/day .



Daily profile of the residential load

System Sizing and Analysis in HOMER PRO

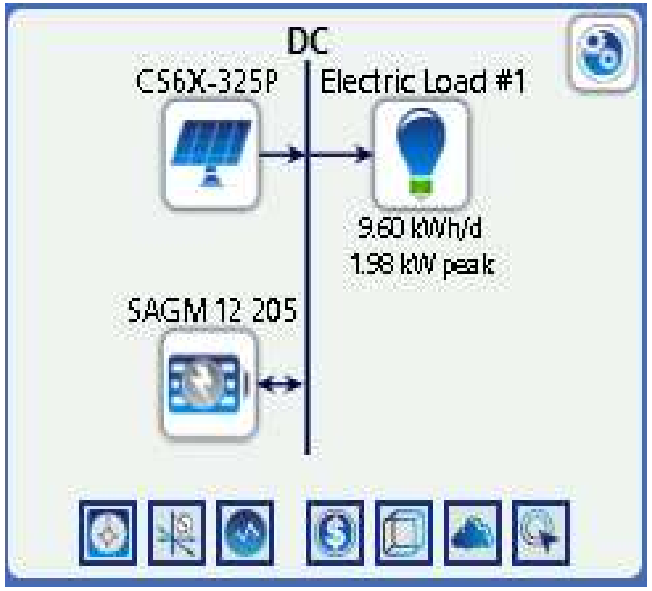
- The scaled annual average solar irradiation is 5.44 kWh/m2/d.



The monthly average solar radiation at the selected site

System Sizing and Analysis in HOMER PRO

- HOMER Pro software was used and provided with the proposed system's parameters to analyze and study the feasibility of utilizing PV systems in supplying direct DC loads.



Schematic diagram of the proposed PV-battery system

System Sizing and Analysis in HOMER PRO

- A 48 V DC bus was chosen for several factors, including:

I. Almost household devices these days run internally on DC power.

II. PV systems produce DC power, thus avoiding AC to DC conversion losses that can reach 30%.

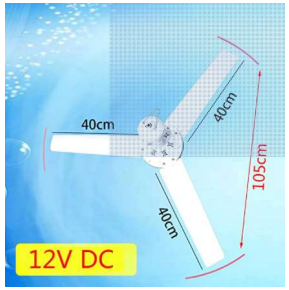
III. The lack of need for an inverter reduces the capital cost.

IV. 48V DC is good solution among other DC voltage levels due to due to it is high efficiency, safe, and capable of running most of the house load.

Examples of DC appliances

- DC appliances are commonly available in the market these days.

12V,7W, LED bulb



12v Large Ceiling Fan

12V DC TV

48V DC Refrigerator

System Sizing and Analysis in HOMER PRO

- HOMER Pro considers different solar panels and batteries to reach the optimize system.
- the most cost-effective and suitable solution to cover the target load listed at the top and followed by the least efficient one, and so on.

Architecture			Cost				System		CS6X-325P	
CS6X-325P (kW)	SAGM 12 205	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
3.59	12	LF	$15,070	$0.333	$613.85	$7,135	100	0	2,035	6,413
3.59	12	CC	$15,070	$0.333	$613.85	$7,135	100	0	2,035	6,413
3.62	12	LF	$15,099	$0.334	$615.09	$7,148	100	0	2,048	6,454
3.62	12	CC	$15,099	$0.334	$615.09	$7,148	100	0	2,048	6,454
3.62	12	LF	$15,107	$0.334	$615.40	$7,151	100	0	2,051	6,464
3.62	12	CC	$15,107	$0.334	$615.40	$7,151	100	0	2,051	6,464
3.64	12	LF	$15,132	$0.334	$616.49	$7,163	100	0	2,063	6,500
3.64	12	CC	$15,132	$0.334	$616.49	$7,163	100	0	2,063	6,500
3.65	12	LF	$15,140	$0.334	$616.83	$7,166	100	0	2,066	6,512
3.65	12	CC	$15,140	$0.334	$616.83	$7,166	100	0	2,066	6,512
3.70	12	LF	$15,201	$0.336	$619.43	$7,193	100	0	2,093	6,597
3.70	12	CC	$15,201	$0.336	$619.43	$7,193	100	0	2,093	6,597
3.74	12	LF	$15,259	$0.337	$621.90	$7,219	100	0	2,119	6,679
3.74	12	CC	$15,259	$0.337	$621.90	$7,219	100	0	2,119	6,679
3.75	12	LF	$15,265	$0.337	$622.17	$7,222	100	0	2,122	6,688

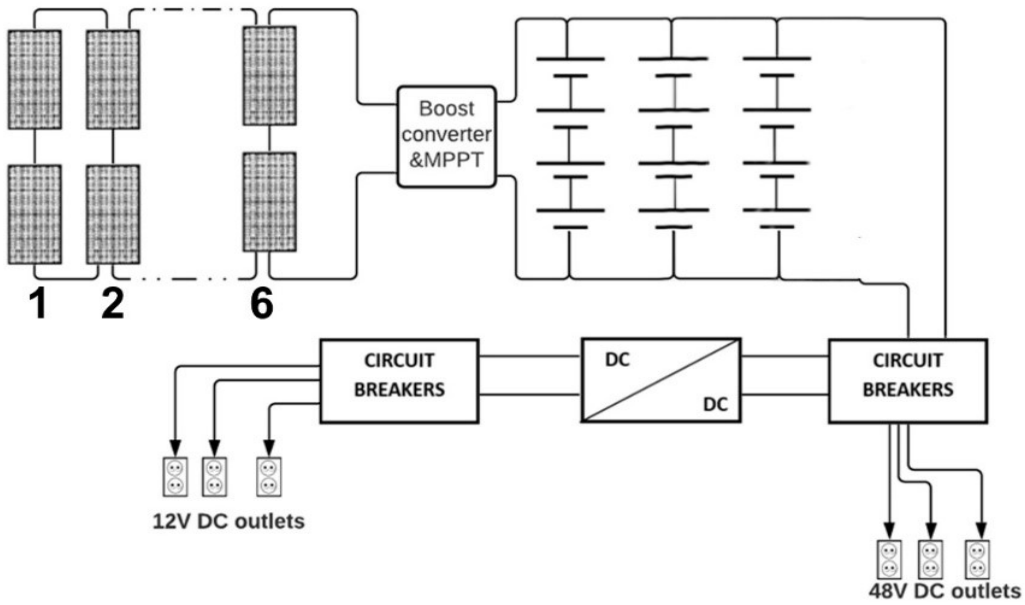
Optimization Results in HOMER PRO software

System Sizing and Analysis in HOMER PRO

- The desired system components that produce 3.59 KW consist of 12 PV panels 325 W each.
- 12 lead-acid battery banks 12 V, 219 Ah to store excess generated electricity and feed the load at night and in bad weather.

The layout of the proposed system and the DC distribution in the house

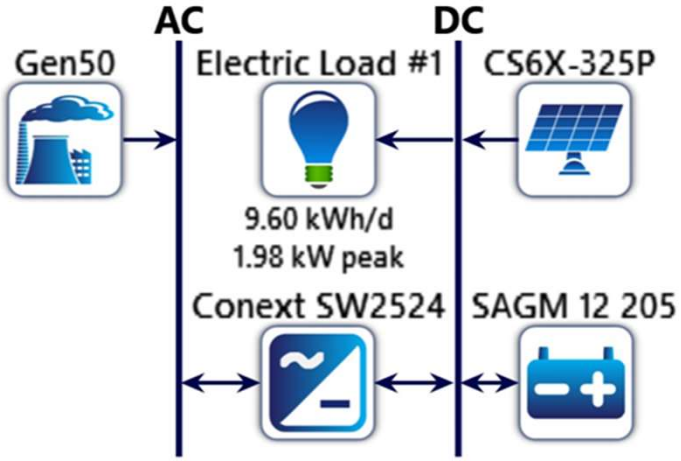
- House appliances such as refrigerator, freezer, water pump, and water heating are coupled to 48 V DC.
- A buck converter steps a voltage down to 12 V DC to supply light bulbs and small electronic loads such as TV, fans, etc.



PV System diagram and the DC distribution in the house

Economic Analysis of the Proposed PV System

- To study the economic feasibility varies solutions were compered by using HOMER PRO .



Schematic diagram of the hybrid system

Economic Analysis of the Proposed PV System

Technical and economic characteristics of system's components

Component	Rating	#Of items	Cost /unite	Total
PV	325 W	12	$184	$ 2,208
Battery	12V, 219 Ah	12	$425	$5,600
Convertor	3KW	1	$1500	$1500
Diesel generator	3KW	1	$500	$500

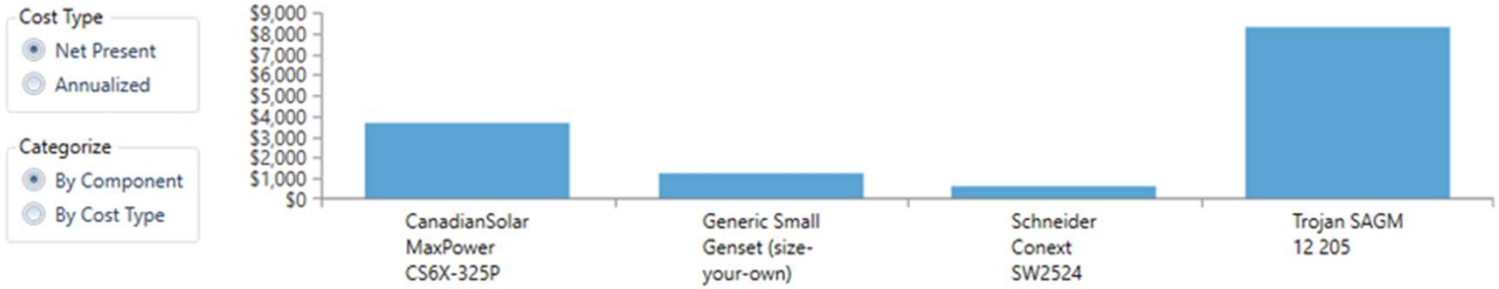
Economic Analysis

Architecture									Cost				System		Gen50	
					CS6X-325P (kW)	Gen50 (kW)	SAGM 12 205	Conext SW2524 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)
					2.71	4.00	8	0.808	LF	$13,895	$0.307	$623.20	$5,838	95.7	60.8	150	150
					3.59		12		CC	$15,070	$0.333	$613.85	$7,135	100	0		
						4.00	4	1.57	LF	$32,319	$0.714	$2,269	$2,986	0	1,669	4,094	4,135
⚠					6.35	4.00		1.93	CC	$50,040	$1.10	$3,479	$5,063	0	2,561	6,256	6,357
						4.00		1.97	CC	$57,332	$1.27	$4,320	$1,484	0	3,590	8,760	8,916

Optimization results for the investigated systems

Economic Analysis

- The Hybrid PV/Diesel System with Battery offers the least NPC .

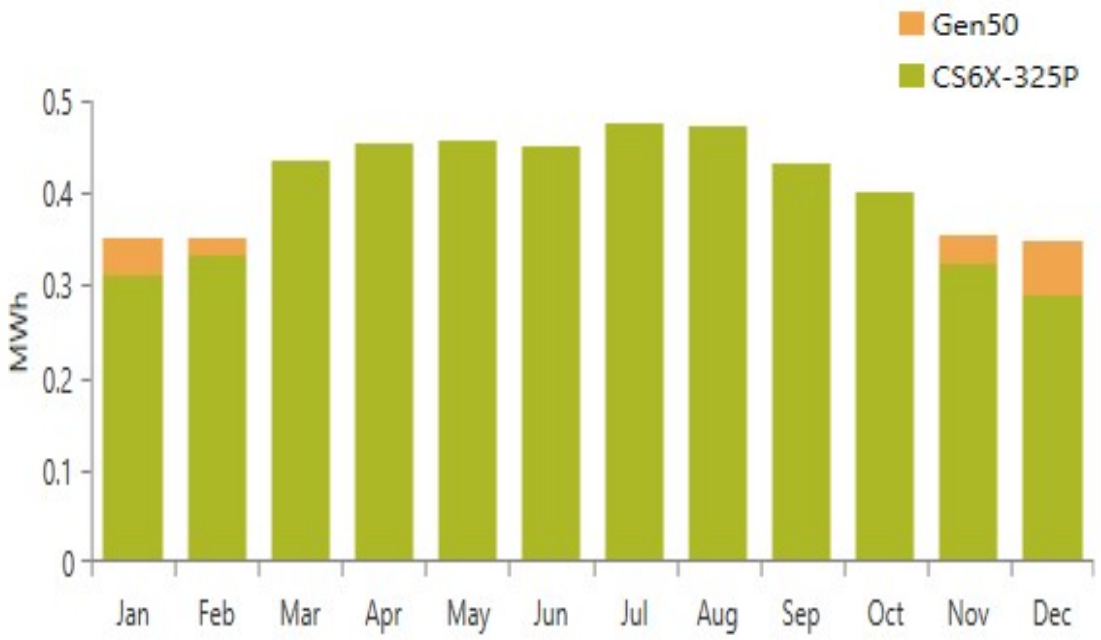


Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6X-325P	$1,534.24	$0.00	$2,155.86	$0.00	$0.00	$3,690.10
Generic Small Genset (size-your-own)	$500.00	$0.00	$58.17	$816.76	($89.83)	$1,285.10
Schneider Conext SW2524	$403.87	$285.43	$0.00	$0.00	($38.70)	$650.60
Trojan SAGM 12 205	$3,400.00	$3,013.21	$2,068.40	$0.00	($212.82)	$8,268.80
System	$5,838.11	$3,298.65	$4,282.44	$816.76	($341.36)	$13,894.60

Cost summary of hybrid PV-Gen-Batt system

Economic Analysis

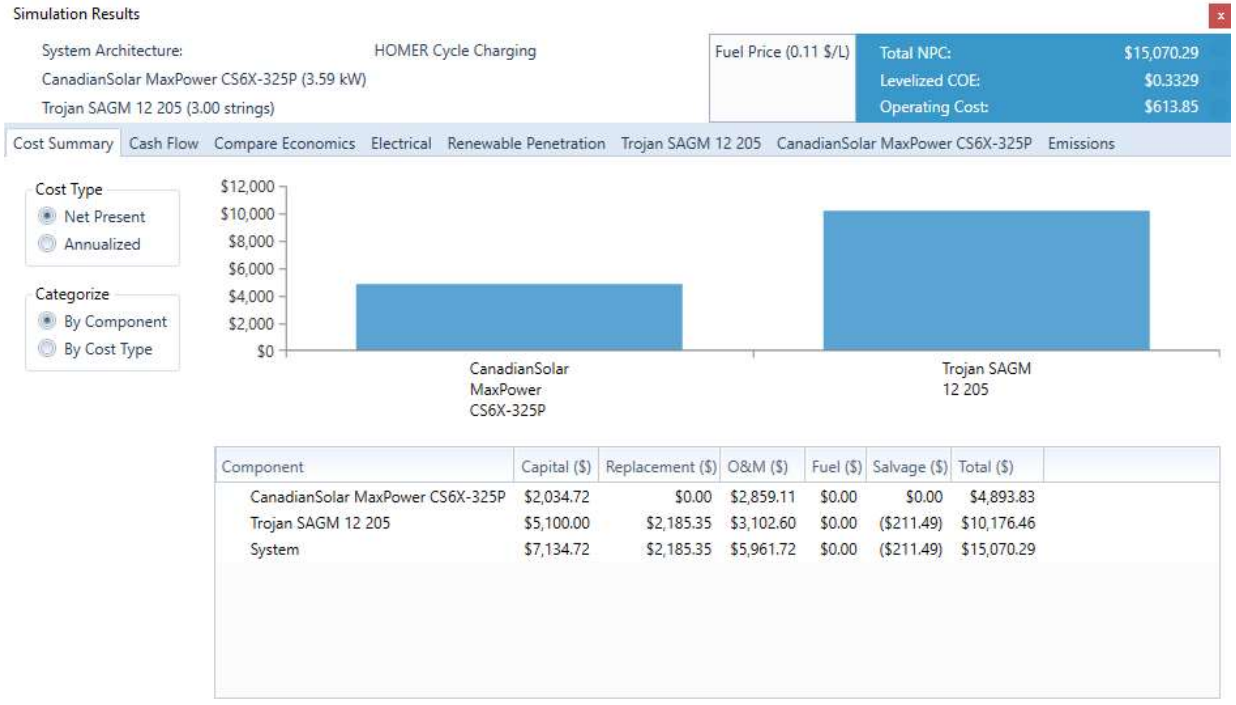
- Solar panels produce most of the electrical energy in the hybrid system.
- PV array considered as prime supply to feed the essential loads and charge the battery bank.
- The battery bank is the prime power resource on cloudy days and night-time.
- A diesel generator will operate only as a backup power supply if both cannot meet the load demand in the winter months when solar radiation reducing



Electrical simulation results for the hybrid PV-Gen-Batt system

Economic Analysis

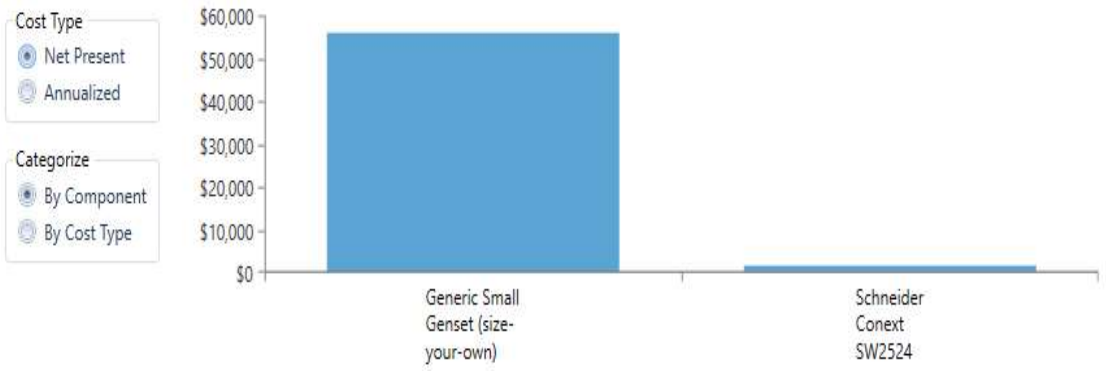
- The second optimal solution matches an isolated PV _battery system .



Cost summary of an isolated PV system with battery

Economic Analysis

- The diesel generator-only system is the most expensive solution than other investigated systems.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic Small Genset (size-your-own)	$500.00	$3,627.34	$3,397.35	$48,269.94	($47.91)	$55,746.72
Schneider Conext SW2524	$984.38	$695.71	$0.00	$0.00	($94.33)	$1,585.76
System	$1,484.38	$4,323.04	$3,397.35	$48,269.94	($142.24)	$57,332.47

Cost summary of stand-alone generator

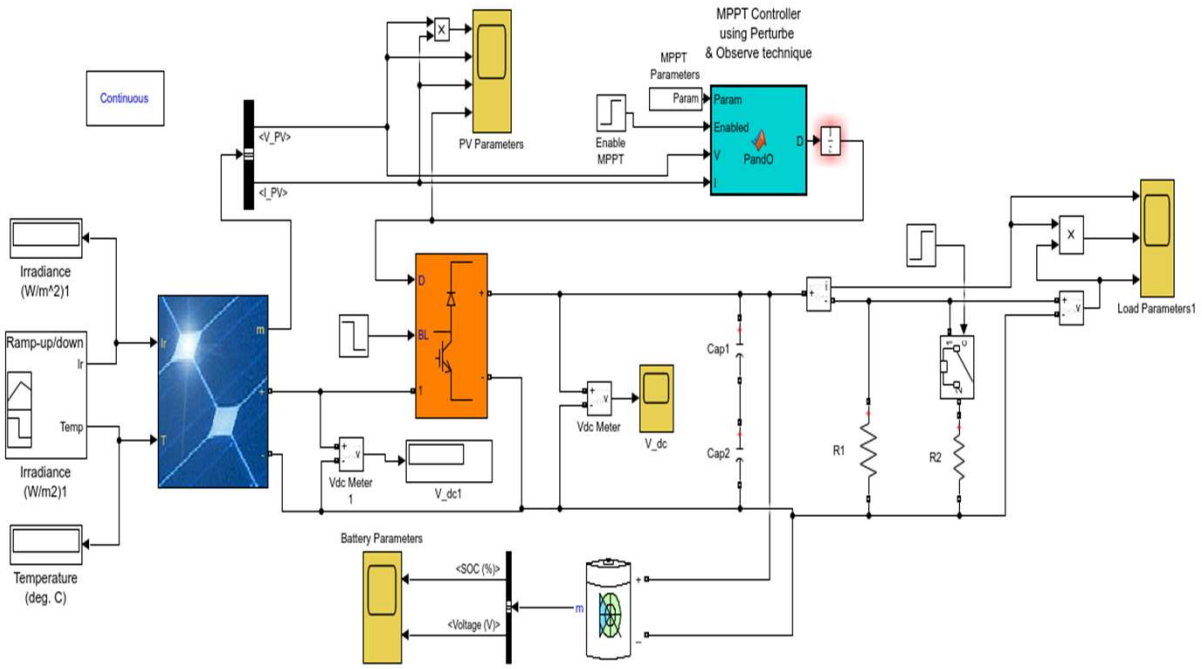
Results and Discussion of Economic Analysis

- The investigation was focused on studying different scenarios of independent systems.
- About 97% of annual electricity produced by solar panels in the hybrid system.
- a slight difference in cost in favor of the hybrid system, which is not that much for 25-year project lifetime.
- instability of prices, and availability of diesel fuel in Libya.
- the benefit of using noise free and purely renewable system .
- The solar energy system with battery is the most appropriate in the Libyan case.

Dynamic Modeling, Simulation, and Results

- Model-Based Design (MBD) is one of these popular methods these days.
- The dynamic model is represented by using computer-aided design (CAD) tools.
- the simulation of the model instead of a performing a physical test.
- MATLAB /Simulink environment was used for modeling the proposed PV battery system.

Dynamic Modeling, Simulation, and Results

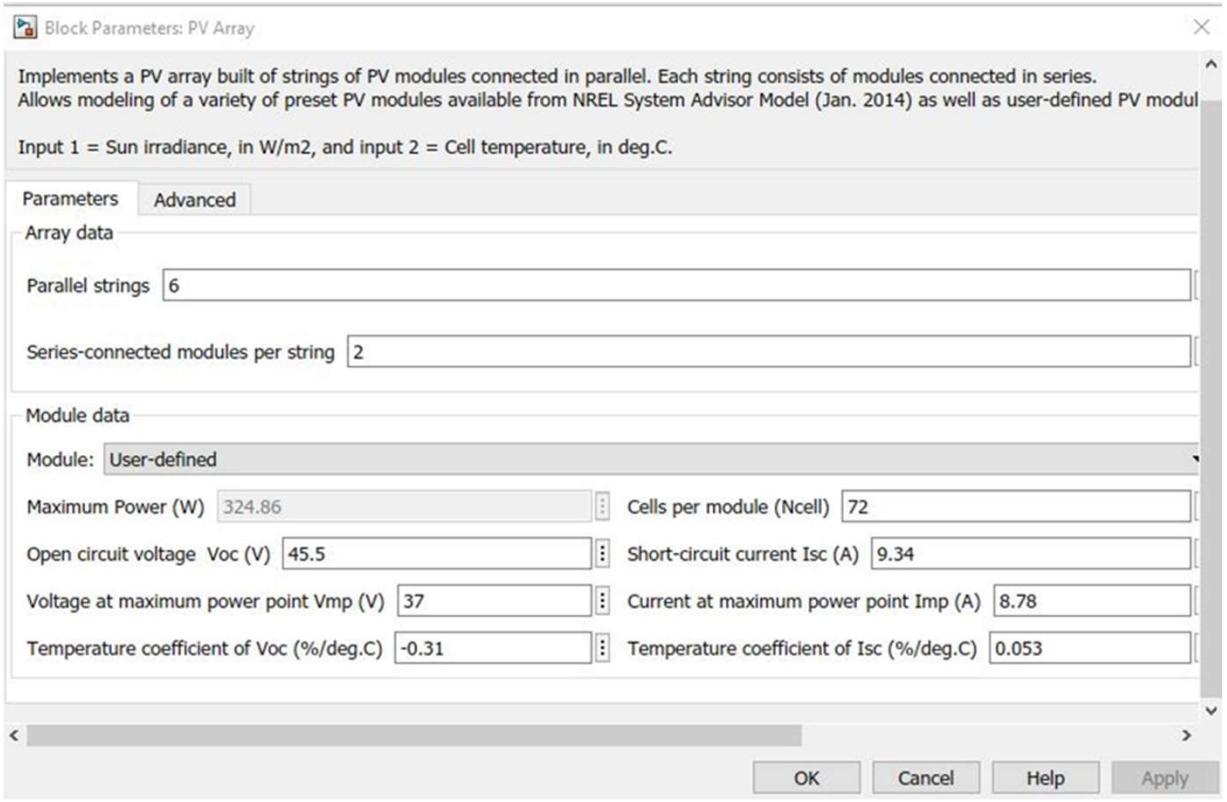


MATLAB/Simulink model of the PV-battery system

The PV array Characteristics

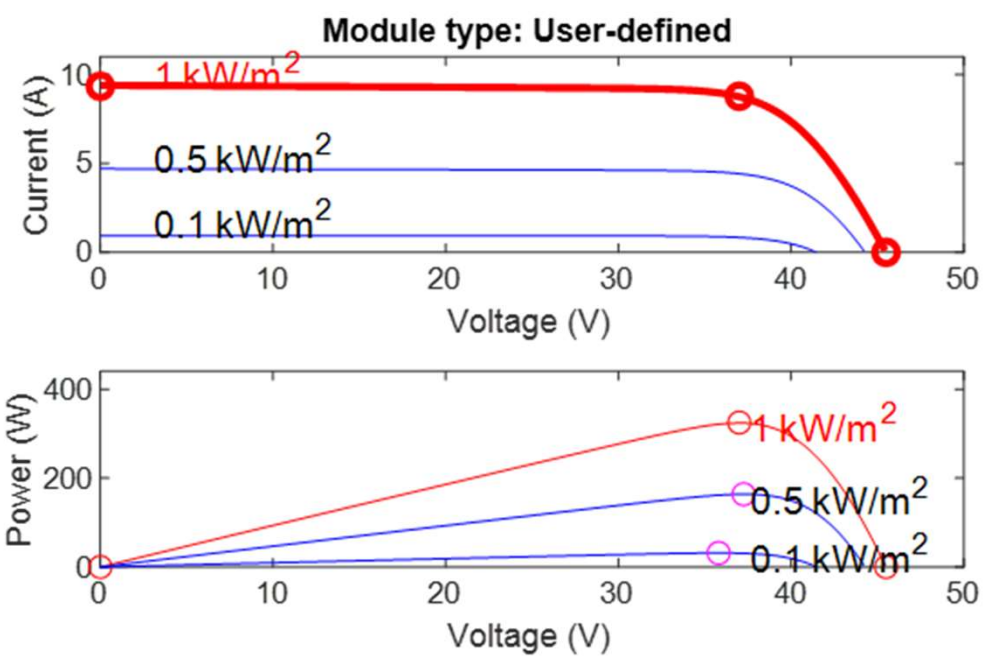
- The proposed system consists of

  12 PV panels 325W each.

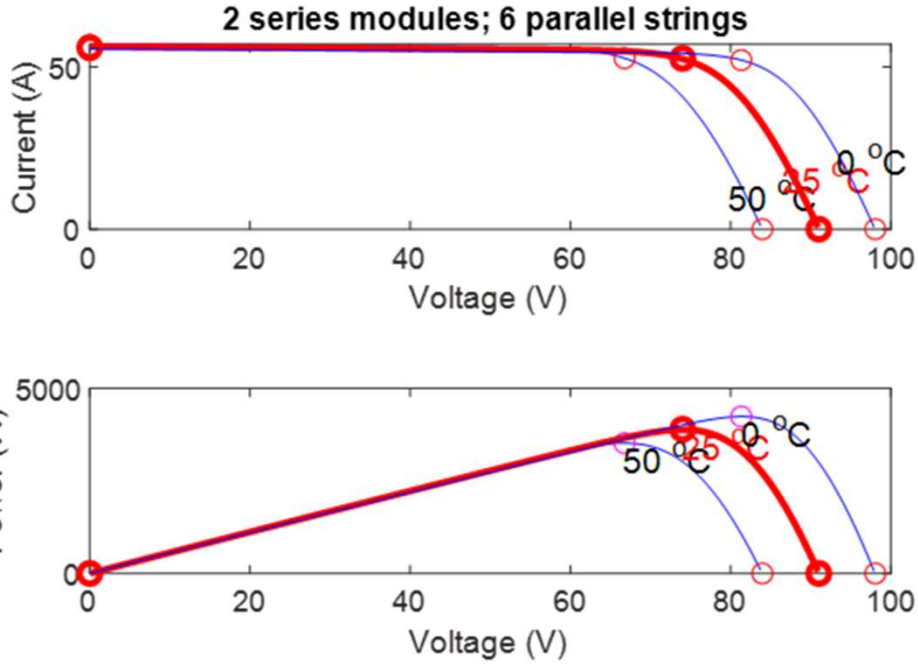


PV array parameters of the proposed system

The PV array Characteristics



PV array characteristic curves with various solar radiations

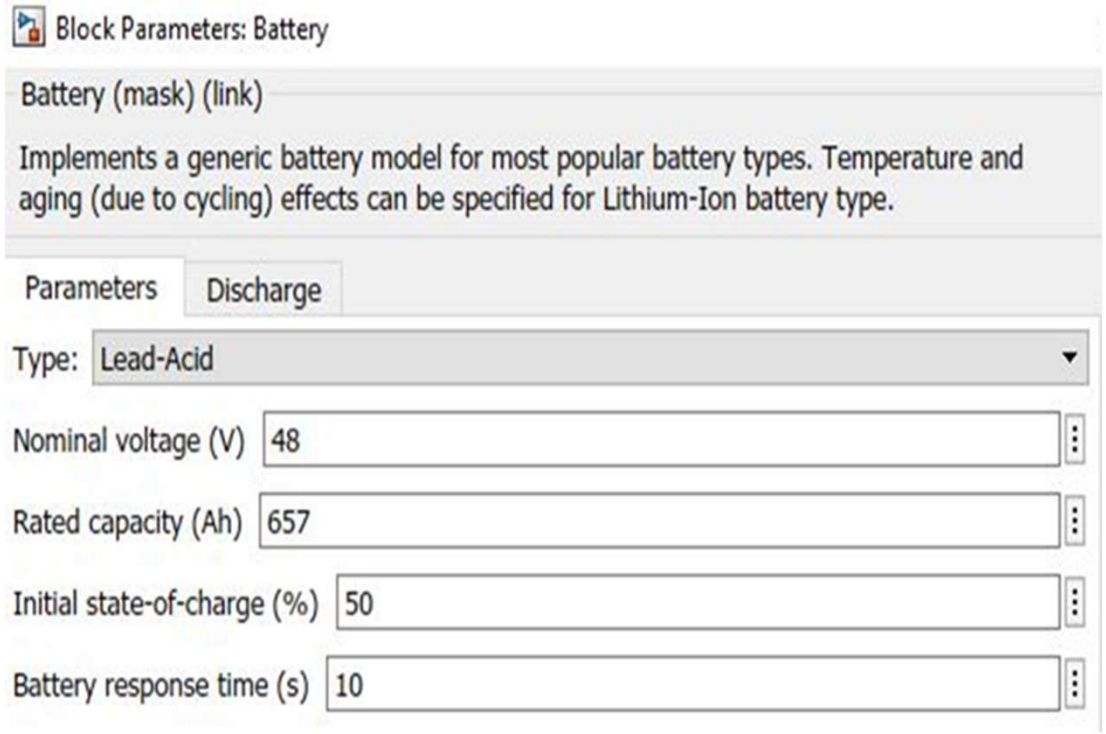


PV array characteristic curves with various temperatures

Battery storage system

- The battery system consist of 12 batteries

, 12 V -219Ah, string size 4, and 3 in parallel .



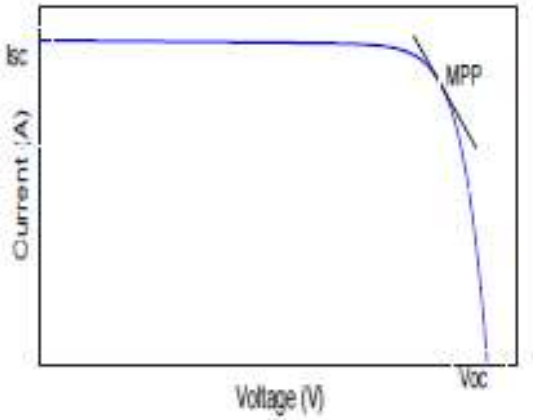
Battey bank parameters of the proposed system

Boost converter and Maximum power point tracking

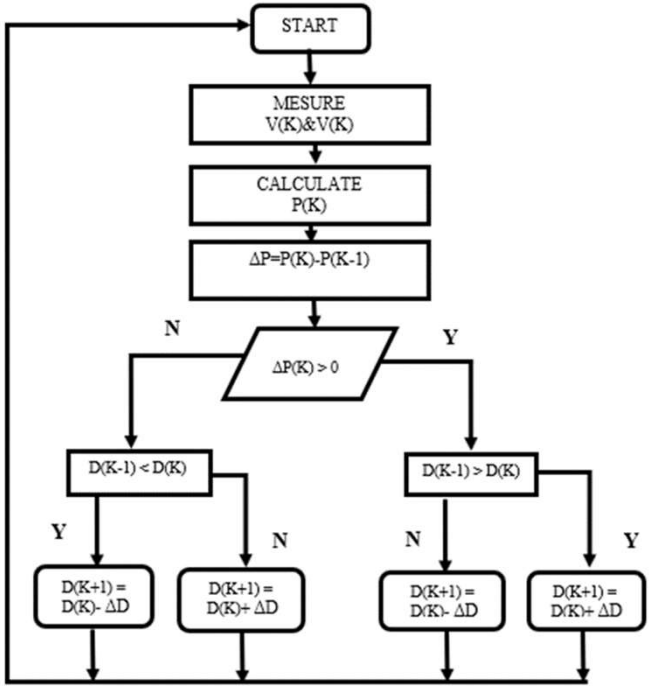
- The DC-DC converter is coupled between a PV module and the load and charge the battery system.
- To enhance and maintain non-linear DC voltage generated by the PV panels.
- The main elements of The DC-DC converter are MPPT, PWM, Inductors, and capacitors.

Maximum Power Point Tracking (MPPT)

- Control the Algorithm is an important stage of an MPPT.
- It raises or reduces the duty ratio that drives MOSFET to ensure the solar panels generate maximum possible power of solar radiations and temperature variations.
- The perturb and observe technique is used in this design .



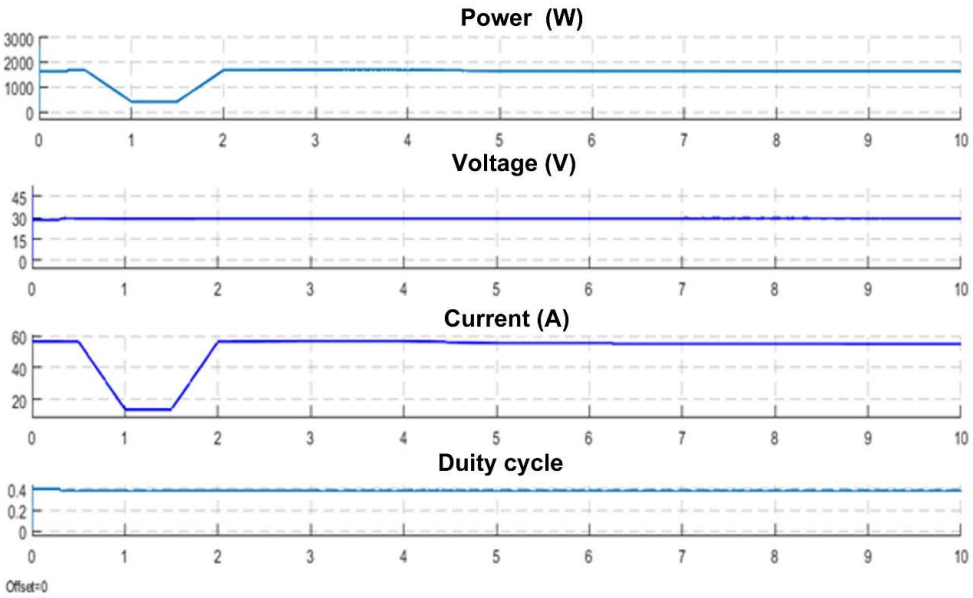
Typical I/V Characteristics of a PV module.



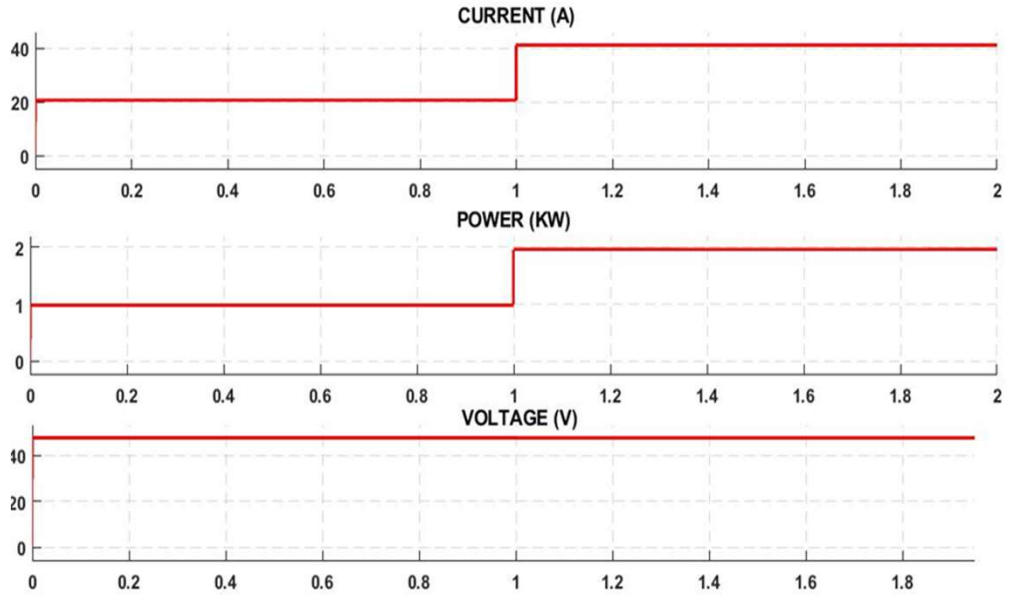
Flow chart of the Perturb and observe Algorithm

Result and Discussion

- To evaluate system stability, the system was tested under half and a full load.



PV array power, voltage, and current



The load voltage, current, and power

Summary and Conclusions

- A 48 DC volts were used as a power supply, chosen after reviewing previous research.
- Complete modeling, sizing, and optimization for the standalone PV-battery system with DC load have been presented.
- A detailed economic analysis was done. Different scenarios were investigated.
- The performance of proposed system is evaluated under various conditions in MATLAB/SIMULINK.
- During this search, it became clear that the proposed stand-alone PV system with battery is stable, and it can fully meet the house load.

Research Contribution

- A comprehensive design and sizing of stand-alone PV system to supply remote area in Libya.
- Proposed for utilization of DC instead of AC as a power source .
- A detailed economic analysis by making a comparison between various systems.
- Dynamic modeling of the PV system to assess the system's performance with different conditions.
- The proposed system consists of 12 PV panels 325 W each and 12 lead-acid battery with $15,070 total cost .

Future Work

- Adding wind turbines to the designed system and studying its effect in reducing dependence on the battery system and thus reducing the cost.
- Study the effects of dust on the photovoltaic system and dust cleaning methods.
- Add SCADA system to monitor various parameters of the hybrid system.

Publications

- Youssef Dabas, M. Tariq Iqbal, "Sizing and Analysis of a DC Stand-Alone Photovoltaic-Battery System for a House in Libya." Jordan Journal of Electrical Engineering. - Volume 7, Number 2, June 2021 .

- Youssef Dabas, M. Tariq Iqbal, Design and analysis of an isolated PV system for a house in Libya, presented at the 28th Annual IEEE NECEC conference St. John's, November 19th, 2019.

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Thank you