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Dynamic modeling and simulation of the rooftop PV system for the First Passive House in Newfoundland

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Abstract. This paper presents the design and modelling of a photovoltaic (PV) system for the first house in Newfoundland built under the guidelines of the Passive House Institute United States (PHIUS+2015). The proposed PV system is optimized with the use of HomerPro software to get 9.75kW of PV panels with a battery storage system. Detailed modelling of the system is finally completed in MATLAB/Simulink with the implementation of a charge controller, MPPT controller, and 8kW of single-phase DC to AC converter. The simulation results show the stability of the system and the advantage of the Grid-connected PV system with a battery backup. System design, detailed modelling and some simulation results are included in the paper. Finally, the cost of the designed system has been compared with the electricity bills considering saving and using Homer optimized results; the feasibility of the proposed system is presented.

1. Introduction

With the gradual improvements in renewable energy technologies and increasing concerns related to climate change, there is increasing interest in renewable energy production solutions for the cold climate like Canada. Especially, with a considerable amount of wind resources, it is possible to implement a wind generation system to meet the energy needs of a house in Newfoundland [1]. A micro-hydro power generation system could also be an option depending on the location. The usage of solar resources as a renewable energy generation with the help of the Photovoltaic (PV) systems is also of interest. In this study, all possible solutions for renewable energy production with the focus towards the photovoltaic and effects of snow have been explored and discussed in detail for the First Passive House (PH) built in the cold climate of Newfoundland, Canada. Load analysis and site analysis for the Passive House, along with an appropriate grid-connected renewable electricity generation system, has been performed using computer simulation tools for sizing and optimization.

Considering the extreme need for a low carbon footprint, a transition to efficient housing that uses renewable energy sources can make a considerable contribution. The idea of a substantial reduction of residential energy consumption was developed in 1990, where the first Passive house was built [2], and this idea has been voluntarily followed throughout the world. Although local building code for the selected site offers considerable energy savings but following strict standards of PHIUS can prove to be a vital step towards sustainable living. Furthermore, it is not uncommon for the installation of a PV generation system in cold climates. In some cases, the performance gets better than extremely hot climates [3] because drawing current from solar panel increases temperature hence reduces efficiency [4]. Generally, in cold climates, snow is a big issue for PV energy generation systems, but overall yearly production losses from the snow covering the panels have been found to



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less than 35% [5]. It has also been known that during winter months when the snowfall is at its peak, monthly PV production losses could reach up to 100% [5], which is alarming yet dependent on many factors like:

1. The angle of a solar panel.
2. The outer surface of the PV plates.
3. PV plates frame to hold or allow snow slip from the plate.
4. Fluctuation in variables like temperature, wind and humidity to enable freezing rain or block the area of the plates.

The efficiency of PV panels can be enhanced by either following the principles of self-consumption [6] and manual snow clearing from the PV panels or by implementing snow removal technologies with active heating and snow melting [7] [8]. There are few related examples which use a similar bottom-up approach and comparison with the simulation of the computer-aided model [9], to visualize the overall consumption of a unit throughout the year to build on Net-Zero-Energy-House [10] and also the strategies of retrofitting efficient energy consumption techniques where the climate gets hostile and extremely cold [11]. Still, detailed system design and modelling are required that shows easy steps of designing a complete model.

1.1. Approach and methodology:

Firstly, a detailed site analysis and load analysis of the site had been performed. After that, historically collected load data was inserted into the Homer Pro software, and the sizing of the optimized system was completed with sensitive analysis among the thousands of possible combinations. The optimized system was then verified using PVsyst software, and cost analysis was performed. Finally, the control system for the selected system was designed with MPPT, charge controller, DC boost converter, and tested using MATLAB / Simulink tool with the requirement of according to the Newfoundland powers guideline. Finally, the system was verified by creating a fault in the grid and tested for islanding mode. In other words, the system should not produce any electricity if the grid was shutdown.

2. Site analysis

This study focuses on cold climate areas like Newfoundland winter gets extremely cold, and yearly snowfall reaches more than 250cm [12]. The first step is to study the options for alternative energy, and only micro-hydro, wind, and solar energy have been found to be feasible [13]. Occasional high winds in the area increase the risk factor and public safety concerns in the residential area [13]. So, one of the most suitable alternative energy production options is the PV system due to its affordability and ease of use. There are three main types of photovoltaic power system for residential electricity generation:

1. A grid-tied solar power unit
2. Grid-tied solar power unit with battery backup
3. Stand Alone or off-grid solar power unit

All solar power systems are designed as per the requirement of the user. A grid-connected system is designed with battery backup to make it failsafe against local grid failure [14]. Furthermore, a modular system has been designed and presented [15], which can be expanded later on. This system is also tested according to the guideline of the local grid-tie handbook.

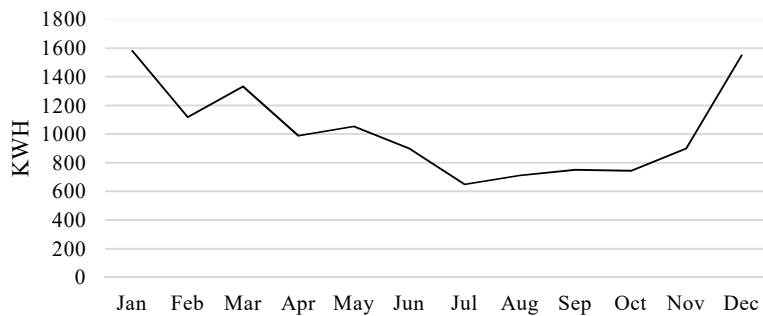


Figure 1. Average monthly power consumption of selected site.

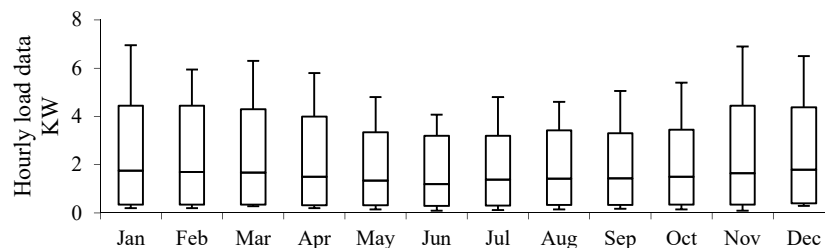


Figure 2. Approximated seasonal load data for the apartment.

2.1. Load analysis:

By looking at the average of the last two years' energy consumption data for the selected site, as shown in Figure 1, it is visible that the peak months are January and December. Figure 2 shows the hourly seasonal load data approximated using the reports generated by the smart meter. It also shows similar trends in peak load values in the winter season when solar irradiance is lower than the yearly average [1]. For this reason, the Grid-tie inverter system is going to prove useful where excess energy can be sold back to the grid in summer. The main consumption of electricity is for water heating and other home appliances. Currently, a combination of wood and electric heating system is being used for the Passive House. A separate study can be completed for solar water heating systems or sub-soil heating for more sustainable living.

2.2. System optimization and cost analysis:

For the first step towards the system sizing, HomerPro software has been used for steady-state system optimization and analysis. This software gives the user the flexibility to have multiple sensitivity analyses at the same time while the ability to quickly see the impact of each variable for all possible scenarios. Figure 3 shows the overall proposed system. For simulation purposes, CanadianSolar (CS1H-325MS) has been selected where an estimated cost of solar panels has been selected to be \$12,990. For Battery backup, one string of 4 batteries with 12V-220Ah rating has been used with an average cost of \$3,600. Overall converter cost with installation has been selected \$11,500 in HomerPro for optimization, and Studer Xtender XTH 8000-48 has been selected for the HomerPro optimization. After adding up all the costs, average operation/maintenance costs and replacement costs in the HomerPro a final cost of \$40,084 has been estimated with yearly operating costs around \$611. Now, by selecting an optimized system cost and dividing it with the estimated electricity bill saved. The payback period of the system is calculated to be 21.5 years while the system can meet 64.5% of electricity needs. The expected life of the system is 25 years and the cost estimates include operation and maintenance cost also replacement costs.

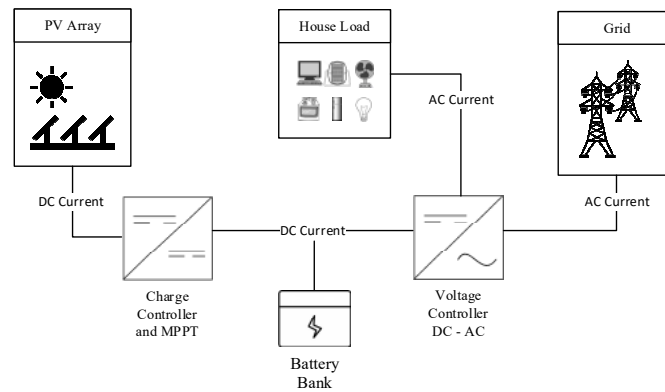


Figure 3. System dynamics of the proposed system.

3. Detailed system design

After a detailed analysis of the system, analyzing similar system dynamics [16][17][18], a controller has been designed similar to [19], also shown in Figure 3. Previously, it has been concluded that the most optimized solution, as shown in Figure 4, is to have a Grid-Tie system with MPPT and battery controller. The system is connected to the grid, and the most challenging part is to have a controller designed to match the frequency of the grid, THD should be less than 0.1%, so, for this purpose, a generalized study helps implement ways to reduce error and to reduce harmonics[20]. Conclusively, a hybrid PV inverter, is going to feed the local load and the grid. As the system used an AC circuit breaker for anti-islanding protection. This system can be further integrated for DC coupling if the grid has turned off, eventually using the leftover energy for the critical loads.

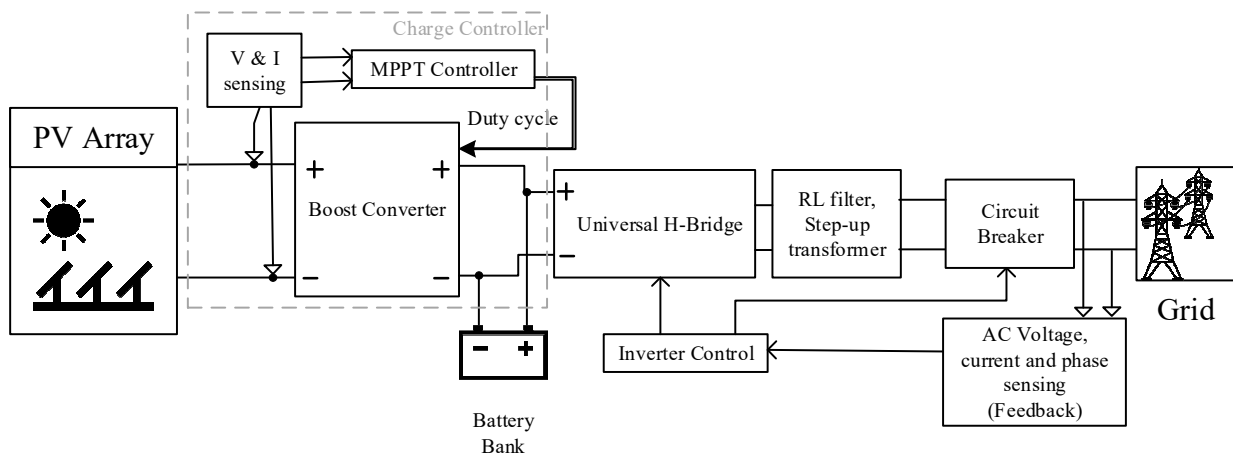


Figure 4. Complete model of proposed system as simulated in Simulink.

3.1. System presentation:

The presented system model of PV solution, composed by:

- CS1H-325MS PV module with the parameters is shown in Table 1 and the total available power to the maximum of 9.75kW as optimized in HomerPro.

- Boost converter system have been presented to step-up the voltage of the PV system to 48VDC, which makes the system scalable for future usage with multiple sub-systems and loads.
- Feedback and Phase-locked loop system with self-filter output.
- A single-phase coupling system with anti-islanding protection.
- Controller blocks have been used to track maximum power point and to control the magnitude, frequency, and total harmonics disturbance with VLL = 240Vrms and the grid frequency to be 60Hz.

Figure 4 represents the flow that has been simulated in Matlab/ Simulink. The system has all the blocks mentioned above, with the flow of each block representing the respective module explained below. Table 1. Provides some PV specifications.

Table 1. Canadian Solar (CS1H-325MS)

Parameters	Index	Values
Maximal power	Pmax	325 W
Open circuit voltage	Voc	45.5V
Short circuit current	Isc	9.34A
Voltage at MPP	Vmp	37V
Current at MPP	Imp	8.78A
Weight	W	42lbs
Type	Polycrystalline	16.94% efficiency
Dimension	L x W x H	76.9'' x 38.7'' x 1.57''

3.2. The PV system modelling and maximum power utilization:

Photovoltaic panels are inherently a DC power source and composed of a lot of small PV cells that assemble up to become a PV panel. The equivalent circuit of a single photovoltaic module is shown below in Figure 5. This power source can be indicated by a current source in anti-parallel with a diode, and other non-idealities, as shown in Figure 5, are indicated by Rs and Rsh. PV arrays are composed of several PV modules to produce the desired level output. Equation 1 shows the I-V characteristics of the PV panel[21].

$$I = I_{pv} - I_0 \left[\exp\left(\frac{qv}{akT}\right) - 1 \right] \quad (1)$$

PV array has been represented in Figure 4, and the MPPT controller has been represented, giving duty cycle signals. At only one-point PV panel is supplying maximum output power, which is dependent on the load and current and voltage sensing going to help determine that. To get maximum out of the panels, Incremental Conductance based MPPT algorithm has been implemented, which provides robust power point tracking. The algorithm is illustrated in Figure 6, which basis on dI/dV at Maximum Power Point (MPP) should be zero. Voltage and Current are sampled and plus width modulation is regulated to calculated dI and dV . The MPPT regulates the duty cycle and PWM for the control signal until the condition $dI/dV + (I/V) = 0$ is satisfied [21].

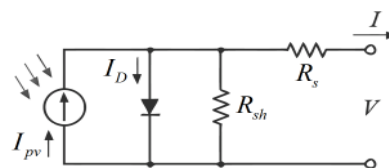


Figure 5. Photovoltaic module equivalent circuit.

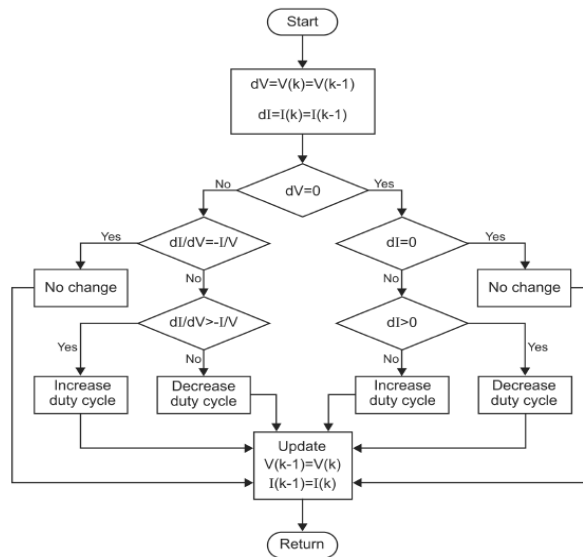


Figure 6. Flowchart of incremental conductance algorithm [21].

Following is the quick explanation where the maximum power point is achieved when:

$$\frac{dP}{dV} = \frac{d(V * I)}{dV} = I + \frac{d(V)}{dV} = 0 \tag{2}$$

$$\frac{dI}{dV} = \frac{-I}{V} \tag{3}$$

where $P = V * I$

dI, dV = components of I and V ripples measured with respect to time and I, V = mean values of V , and I measured with a sliding time to supply the adjusted duty cycle to track maximum PowerPoint.

3.3. Boost converter:

In this system, diode and IGBT have been used for voltage setup. The average inductor current is higher than the average output current in boost converter [22]. When the switch is on, the inductor starts to store the energy with the increasing flow through the inductor, and the stored energy is dispatched when the IGBT switch is closed. Consequently, the average voltage across the load is higher than the supplied input voltage. Figure 7 shows a diagram of the boost converter implemented.

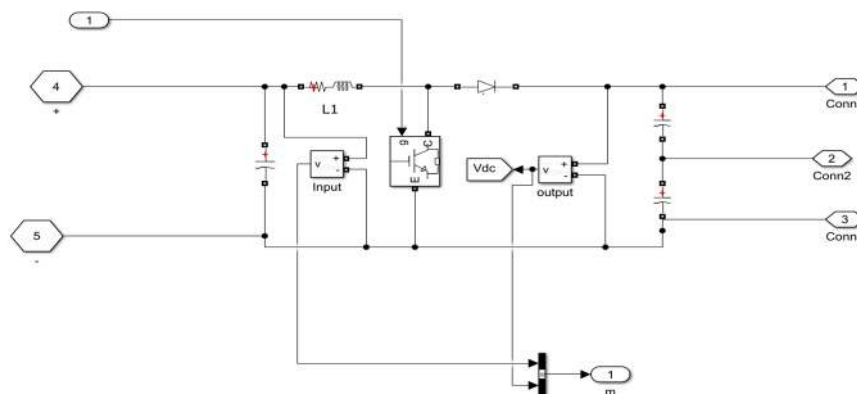


Figure 7. Boost converter as simulated in Simulink.

3.4. DC-AC controller:

To feed current to the grid, DC current supplied by the PV system is to be converted into V_{ac} that must have exact parameters as the grid. V_{ac} converts 48 VDC into AC pure sine wave. It consists of two feedback control loops:

- An external control loop that regulates DC link voltage to 48V bus.
- An internal control loop that regulates grid currents.
- The control system uses a sample time of 100 microseconds for voltage and current controllers.

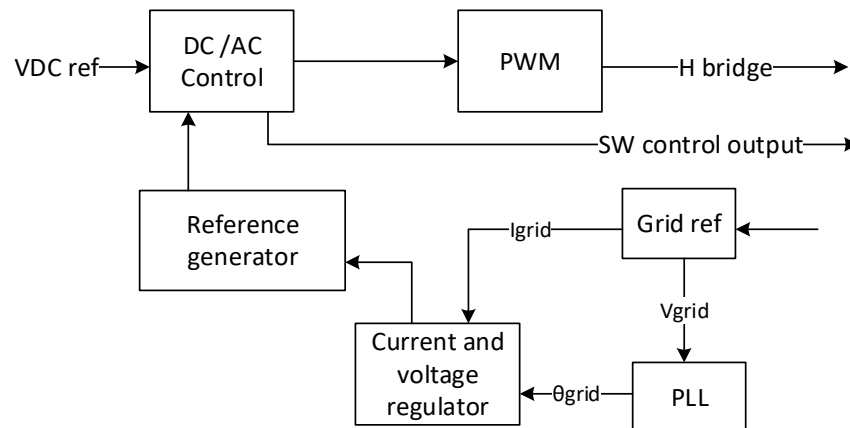


Figure 8. Block Diagram of inverter control.

DC to AC converter aims to produce a sinusoidal wave AC output with controllable magnitude and frequency. As can be seen in Figure 8, inverter control takes input from VDC reference and reference signal generator and generates a pulse width modulation (PWM) to control H-bridge. It also takes feedback from the grid to match the phase and regulates voltage and current. Finally, it generates the corrected PWM, which eventually contributes to synchronizing the inverter to the connection of the main grid.

Boost converter and V_{ac} converters use pulse width modulation, and fast sample time to achieve appropriate resolution of PWM waveforms [24]; on the other hand, islanding is a phenomenon when PV generated, and grid-connected inverter system delivers power to the load and the grid even the grid has been shut down after failure. This power injection to the grid may cause harm to the workers working on-site [25]. So, according to Canadian and European standards (VDE 0126-1-1) [26], the detection of the Islanding and PV system is expected to disconnect from the grid in case of grid lost the power. High-speed AC circuit breakers [27] are capable of disconnecting circuit PV generation systems from the main grid [28].

4. Simulation results and discussion

As represented in Figure 4, the simulation of the system has been performed through MATLAB / Simulink software R2020a. PV panels consist of 15 parallel and two plates in series, which is then stabilized at 48V with battery array. This PV energy produced is fed to closed-loop controller sync up with the grid eventually. Figure 10 and Figure 11 shows the power being supplied to the grid with the 3kW of the load as a standard operating condition. Figure 9 shows the variable solar irradiance provided, and a constant operating temperature of 15 degrees Celsius is feed to the PV array. Figure 10 shows the maximum power supplied to the grid at the conditions mentioned.

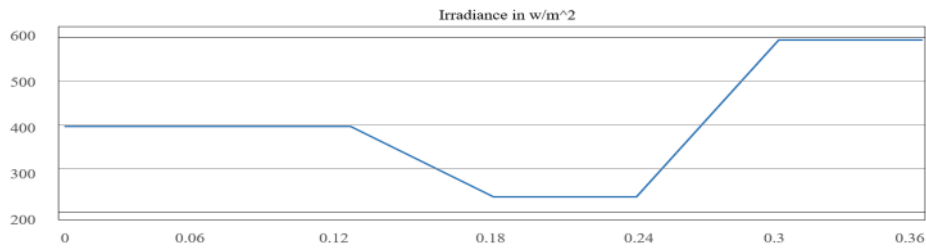


Figure 9. Solar irradiance input.

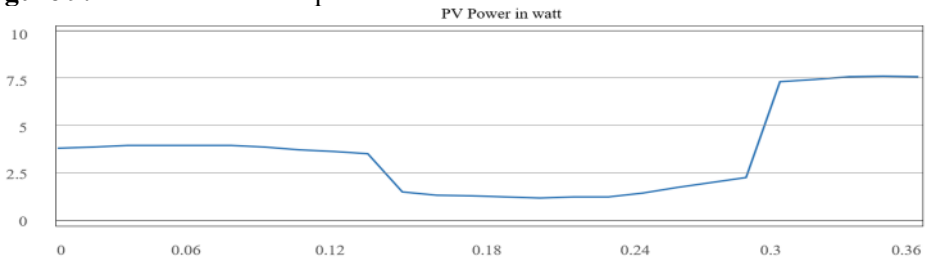


Figure 10. Output power supplied from the PV array.

Figure 11 shows the output sinusoidal waveform of the inverter output. After there is a fault in the grid, and the switch control output is activated with the help of Active Frequency Drift [25], and power flow is controlled with the use of a responsive circuit breaker; hence the inverter is disconnected. Figure 12, shows the dynamic response and the output at the point of common coupling.

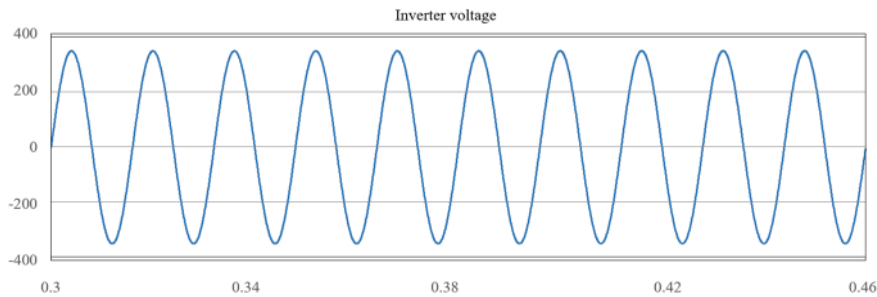


Figure 11. Voltage supplied to the grid.

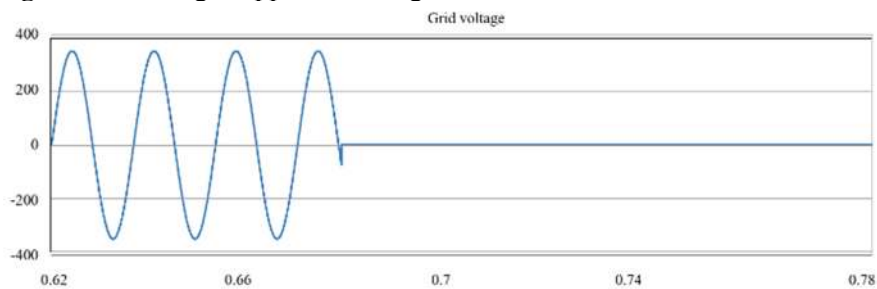


Figure 12. Voltage at the point of common coupling upon grid failure.

5. Conclusion and future work

For the Passive House understudy, this renewable system is going to add exceptional value in terms of sustainable living. As the net-metering rules for Newfoundland in place and being able to use solar resources for low carbon footprint, this system can self-produce up to 64% electricity as an added advantage. The payback period is going to be 21.5 years, including operation cost as optimized in

HomerPro. This system is an essential part of the modern standards of futuristic sustainable house models despite having some limitations, including snow clearing and uncertain solar resources.

This study gives detailed dynamic modelling, load analysis, sizing and optimization of a single-phase, grid-tie, and islanding protected PV electricity generation system. This unique feature can be utilized with distributed generation systems as well as coupling with stand-alone systems. After disconnecting from the grid, this system has the battery bank, which can be used to power up critical loads. In the given case study, reach up to high value and battery bank is not enough to provide long term backup. So, either a backup generator or a larger battery bank can be added with this, which may add an extra cost to the system.

6. References

- [1] Iqbal M T 2004 A feasibility study of a zero energy home in Newfoundland *Renew. Energy* **29** 277–89
- [2] Passive House Institute US [Online] 2020 Available from: <https://www.phius.org/>
- [3] Andrews R W, Pollard A and Pearce J M 2013 The effects of snowfall on solar photovoltaic performance *Sol. Energy* **92** 84–97
- [4] Alharthi Y Z, Alahmed A, Ibliha M, Chaudhry G M and Siddiki M K 2017 Design, simulation and financial analysis of a fixed array commercial PV system in the City of Abu Dhabi-UAE 2017 *IEEE 44th Photovolt. Spec. Conf. PVSC 2017* 1–4
- [5] Pawluk R E, Chen Y and She Y 2019 Photovoltaic electricity generation loss due to snow – A literature review on influence factors, estimation, and mitigation *Renew. Sustain. Energy Rev.* **107** 171–82
- [6] Luthander R, Widén J, Nilsson D and Palm J 2015 Photovoltaic self-consumption in buildings: A review *Appl. Energy* **142** 80–94
- [7] Rahmatmand A, Harrison S J and Oosthuizen P H 2018 An experimental investigation of snow removal from photovoltaic solar panels by electrical heating *Sol. Energy* **171** 811–26
- [8] Rahmatmand A, Harrison S J and Oosthuizen P H 2020 An innovative method to control surface temperature of a rooftop photovoltaic system *Sol. Energy* **195** 581–91
- [9] Delise V and M S A 2011 Net-zero energy house: Solar photovoltaic electricity scenario analysis based on current future costs *ASHREA conference Monterial* 25- 29.
- [10] Nancy M A and Nabb 2013 Strategies to Achieve Net-Zero Energy Homes: A Framework for Future *NIST Special Publication* 1140
- [11] Chikh A, Member S, Chandra A and Member S 2012 Sizing and Power Management for a Stand-Alone PV System in Cold Climate *PES T&D 2012* 1–6
- [12] Government of Canada Environment and natural resources 2020 Available from: <https://climate.weather.gc.ca/>
- [13] Khan M J and Iqbal M T 2005 Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland *Renew. Energy* **30** 835–54
- [14] Warmann E C and Atwater H A 2018 Designing Tandem Photovoltaics for Energy Production *IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)* 2382–2385
- [15] Khamis A, Mohamed A, Shareef H, Ayob A, Shahrieel M and Aras M 2013 Modelling and Simulation of a Single Phase Grid Connected Using Photovoltaic and Battery Based Power Generation 391–5
- [16] Zaghba L, Terki N, Borni A and Bouchakour A 2014 Intelligent control MPPT technique for PV module at varying atmospheric conditions using MATLAB/SIMULINK *Proc. 2014 Int. Renew. Sustain. Energy Conf. IRSEC 2014* 661–6
- [17] Jazayeri M, Uysal S and Jazayeri K 2014 Evaluation of maximum power point tracking techniques in PV systems using MATLAB/Simulink *IEEE Green Technol. Conf.* 54–60

- [18] Zarkov Z, Demirkov B, Milenov V and Bachev I 2019 Grid connected PV systems with single-phase inverter *2019 Int. Conf. Robot. Signal Process. Tech.* 4–8
- [19] Fekkak B, Mena M and Boussahoua B 2018 Control of transformerless grid-connected PV system using average models of power electronics converters with MATLAB/Simulink *Sol. Energy* **173** 804–13
- [20] Islam A and Chowdhury M I B 2014 A simulink based generalized model of PV cell / array *2014 3rd Int. Conf. Dev. Renew. Energy Technol.* 1–5
- [21] Lokanadham M and Bhaskar K V 2012 Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System *Int. J. Eng. ...* **2** 1420–4
- [22] Siddik A A and Shangeetha M 2012 Implementation of Fuzzy Logic Controller in photovoltaic Power generation using Boost converter and Boost Inverter *International Journal of Power Electronics and Drive System (IJPEDS)* **2(3)** 249-256
- [23] Tina G M and Celsa G. 2015 A Matlab / Simulink Model of a Grid Connected *50th International Universities Power Engineering Conference (UPEC)*
- [24] Benaissa O M, Hadjeri S and Zidi S A 2017 Modeling and simulation of grid connected PV generation system using matlab/simulink *Int. J. Power Electron. Drive Syst.* **8** 392–401
- [25] Yu B, Jung Y, So J, Hwang H and Yu G 2006 A Robust Anti-islanding Method for Grid-Connected Photovoltaic Inverter *Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference* **2** 2242-2245
- [26] Boulahchiche S, Makhloufi S, Semaoui S, Arab A H and Abdeladim K 2018 Experimental Analysis of Grid Connected to PV System According to DIN VDE 0126-1-1 (The 5th International Seminar on New and Renewable Energies At: Unité de Recherche Appliquée en Energies Renouvelables, Ghardaïa – Algeria)
- [27] Jeong Y, Lee H, Lee S and Kim Y 2013 High-speed AC circuit breaker and high-speed OCR *22nd International Conf. on Electricity Distribution (CIRED 2013)*, 10-13
- [28] Zhong QC and Hornik T 2013 Control of power inverters in renewable energy and smart grid integration, John Wiley & Sons