INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 06 Issue 11 November 2023

DOI: 10.47191/ijmra/v6-i11-31, Impact Factor: 7.022

Page No. 5230-5240

The Design and Simulation of a Stand-Alone Solar Inverter with Improved Efficiency and Power Quality for Home Appliances

Md. Shaharier Hasan

Department of Electrical and Electronics Engineering, Stamford University Bangladesh, Bangladesh

ABSTRACT: An inverter for solar panels is proposed in this paper. The inverter's various components have been tested with MATLAB Simulink. The output of the inverter has been analysed using MATLAB Simulink to determine whether pure sine waves are being produced. There are two kinds of loads that are employed in-house, inductive and capacitive loads. The outputs of the inverter are connected to the loads, and Irms, THDv, and Vrms have been measured. Additionally, the THDv value can be observed by adjusting the PV array's radiation and temperature. Furthermore, Irms and THDv changes can be accompanied by a change in the load value of inductive capacitance. The inverter's accessories, such as the PV array, Buck Converter, DC-DC, battery charge-controller, and battery connectors, are also tested using MATLAB Simulink. This kind of inverter can be used to illuminate buildings, businesses, and industries. Most household appliances run on alternating current, so to renovate DC to AC, an inverter is rummage-sale.

KEYWORDS: PV Array, DC-DC Buck Converter, Battery Charge Controller, Battery, MATLAB/SIMULINK Model, Inverter

I. INTRODUCTION

Solar energy is a renewable energy source that can be transformed into electrical energy in two dissimilar ways: either by heating a working fluid in an electricity-generating cycle using a thermal process, or by using photovoltaic supplies that produce Electricity when subjected to light (1). Power electronics are vital to these scattered energy systems, since they convert produced electricity into a form that can be used by utilities. However, adding power electronic devices typically increases costs and can lead to reliability issues (2, 3). The demand for a standalone electric power system has recently increased. Turning to the renewable energy (RE) industry has been motivated by the rising demand for reliable power supply and the depletion of fossil resources. One of the renewable energy sources that can help with the extra energy demand is solar energy (4). Using an inverter, solar energy can be converted into electrical energy to power equipment, primarily household ones (5, 6).

A. *CHARACTERISTICS OF AN INVERTER*

Inverters should be choosen based on the following characteristics:

- Use type such as home appliance, in a vehicle, for a portable device, or for backup in an emergency
- Proposed electrical voltages; DC input voltage, the AC output
- voltage, and the frequency of the AC output.
- Power capacity type, such as continuous capacity and surge capacity
- Power quality; a sine wave, a quasi-sine wave, and a square wave are four types of waveforms or
- Internal protections: Overload, surge capacity and low voltage
- shutoff
- Geographical locations: high frequency switching type inverter
- and transformer type inverter
- Productivity curvature
- Battery-charging capability
- Expandable (7)

A block diagram of an efficient design for the of stand-alone solar inverter is presented in Figure 1

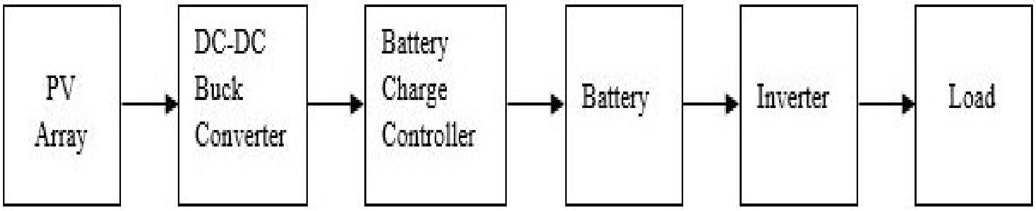

Figure 1: Block Diagram of stand-alone solar inverter

II. METHODS & MODELLING

Each step of work must adhere to a set of guidelines to be completed. The following stages should be performed in this research project to design and simulate a complete system:

Step 1: Design of PV array.
Step 2: Design of DC-DC Buck Converter
Step 3: Design of battery charge-controller & battery connection.
Step 4: Design of pure sine-wave Inverter.

A table containing the complete forms of short forms used in journal papers can be found in Table 1.

Table 1: Nomenclature

No	Name	Nomenclature
1	Irms	Root Mean Square Current
2	THDv	Total Harmonic Distortion Voltage
3	Vrms	Root Mean Square Voltage

A. Design of Stand-alone Solar Inverter for Resistive Load using Simulink

Using Simulink software, a stand-alone solar inverter feeding resistive load system is simulated. Figure 2 presents the simulated design of the system.

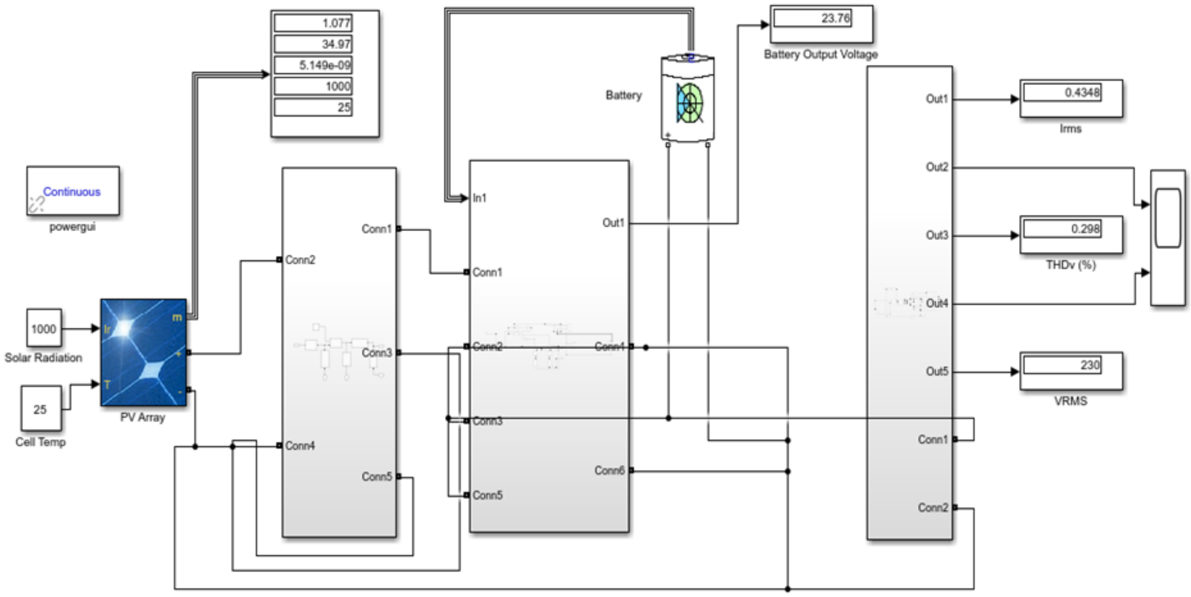

Figure 2: Design and Simulink of Stand-alone solar inverter for resistive load

During an alternating current (AC) circuit, the value of voltage and current is constantly changing. The peak value of an AC waveform represents the maximum value of an alternating waveform. In contrast, the root mean square (RMS) value is the square root of the sum of the squares of the mean values of an alternating current or voltage. The RMS value measures the practical value of a waveform and is used to calculate power in AC circuits (8).

The total harmonic distortion (THD) of power systems should be kept as low as possible. Power systems with lower THD have higher power factor, lower peak current, and higher efficiency.

The output current Irms, THDv and Vrms for resistive load are illustrated in Table 2, while the Simulink output is shown in Figure 3.

Table 2: Output for Resistive Load

No	Name	Value
1	Irms	0.4349 Amp
2	THD_V	0.3707 %
3	Vrms	230 Volt

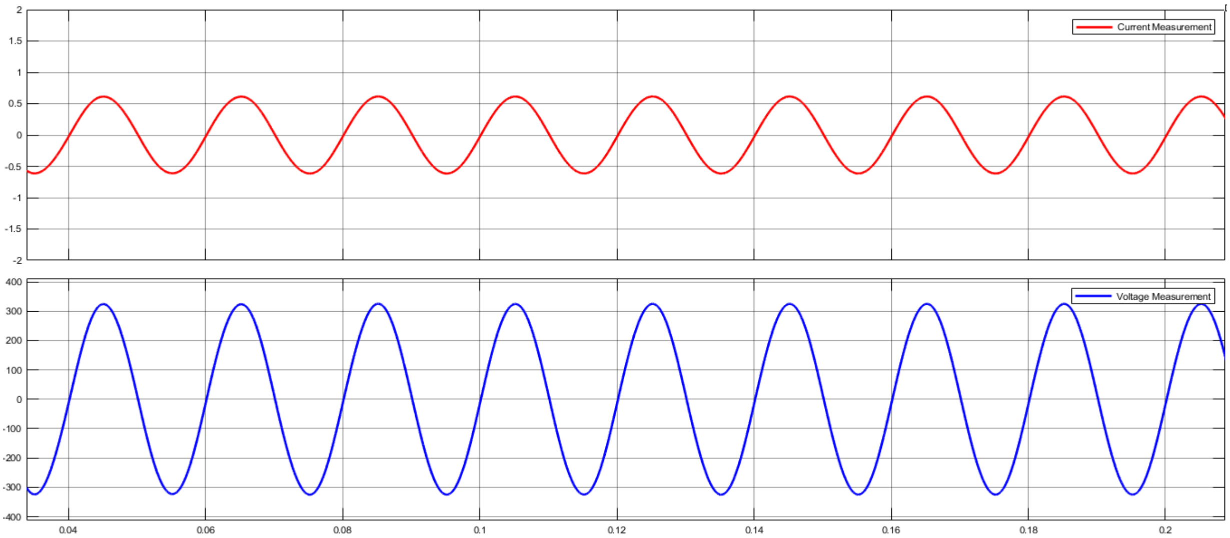

Figure 3: Simulink Output of stand-alone solar panel inverter for resistive load

B. *Design of Stand-alone Solar Inverter for Inductive Load using Simulink*

A resistive load is where the sine waves of current and voltage are in phase. Loads with inductive characteristics are more complex because the voltage and current are out of phase, which results in a secondary voltage opposing the supply voltage.

Figure 4 illustrates the Simulink design of the stand-alone system for inductive load, and Table 3 shows its output. Figure 5 depicts the Simulink output of the inverter in case of inductive load.

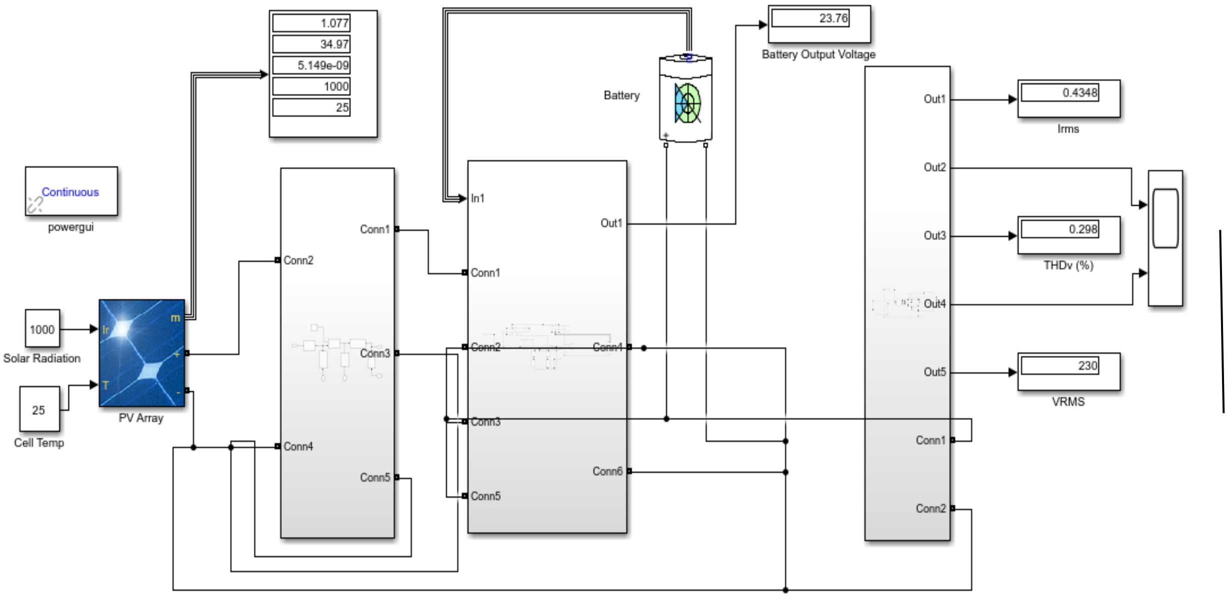

Figure 4: Design and Simulink of Stand-alone solar inverter for Inductive load

Table 3: Output for Inductive Load

No	Name	Value
1	Irms	0.4358 Amp
2	THDv	0.305 %
3	Vrms	230 Volt

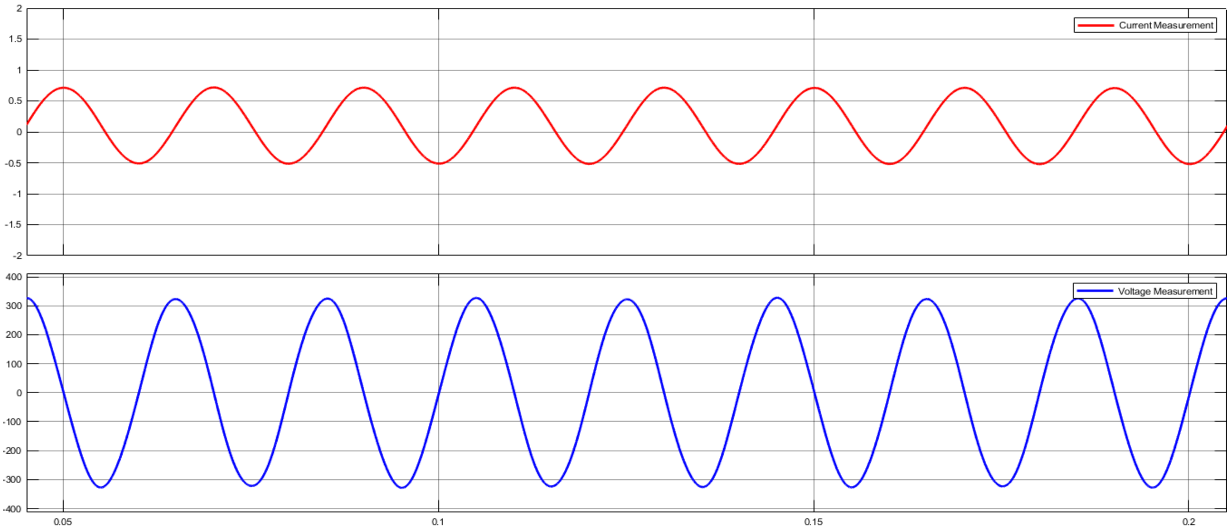

Figure 5: Simulink Output of stand-alone solar panel inverter for inductive load

C. Solar Panel/PV Array

A Solar panel comprises a number of solar cells, and solar arrays are constructed of a number of connected solar panels (9,10, 11). The different types of solar cells are described in the references (12,13, 14). Most manufactured standard PV panels have output voltages of 12V and 24V. PV panels can be wired in series as well as parallel to generate the necessary amount of power (15,16,17). Each work step must follow a set of guidelines.

In the current research project, using a user-define array and one series module, four parallel strings, the system was designed and simulated as mentioned in the following subsections. Figure 6 shows the solar panel PV array, while Figure 7 presents the PV array Power & volt curves.

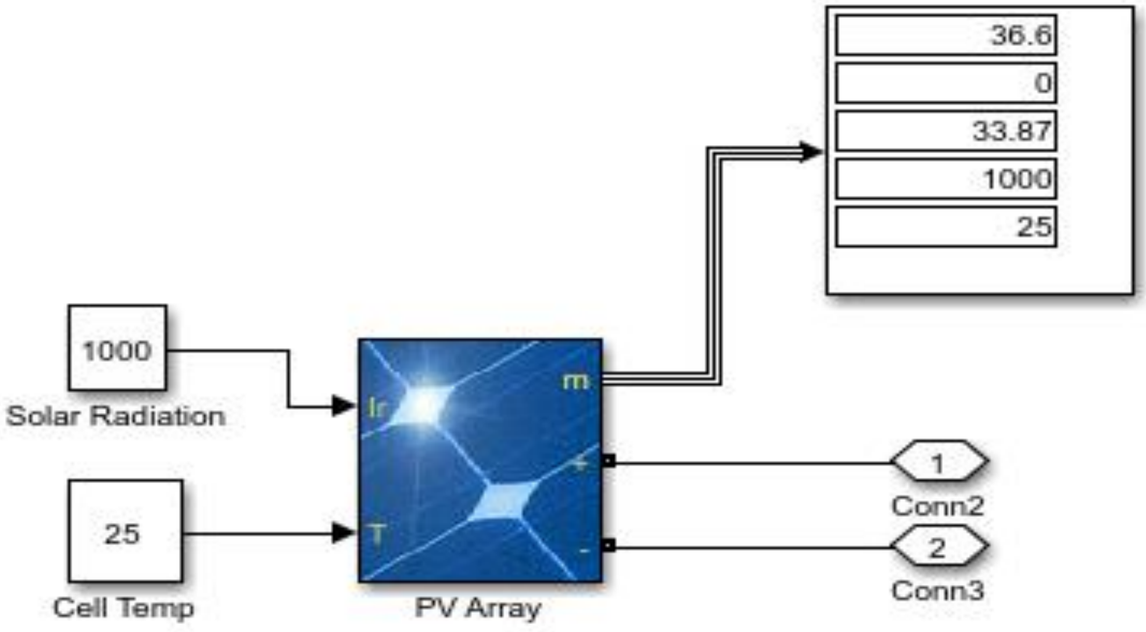

Figure 6: Solar Panel/PV array

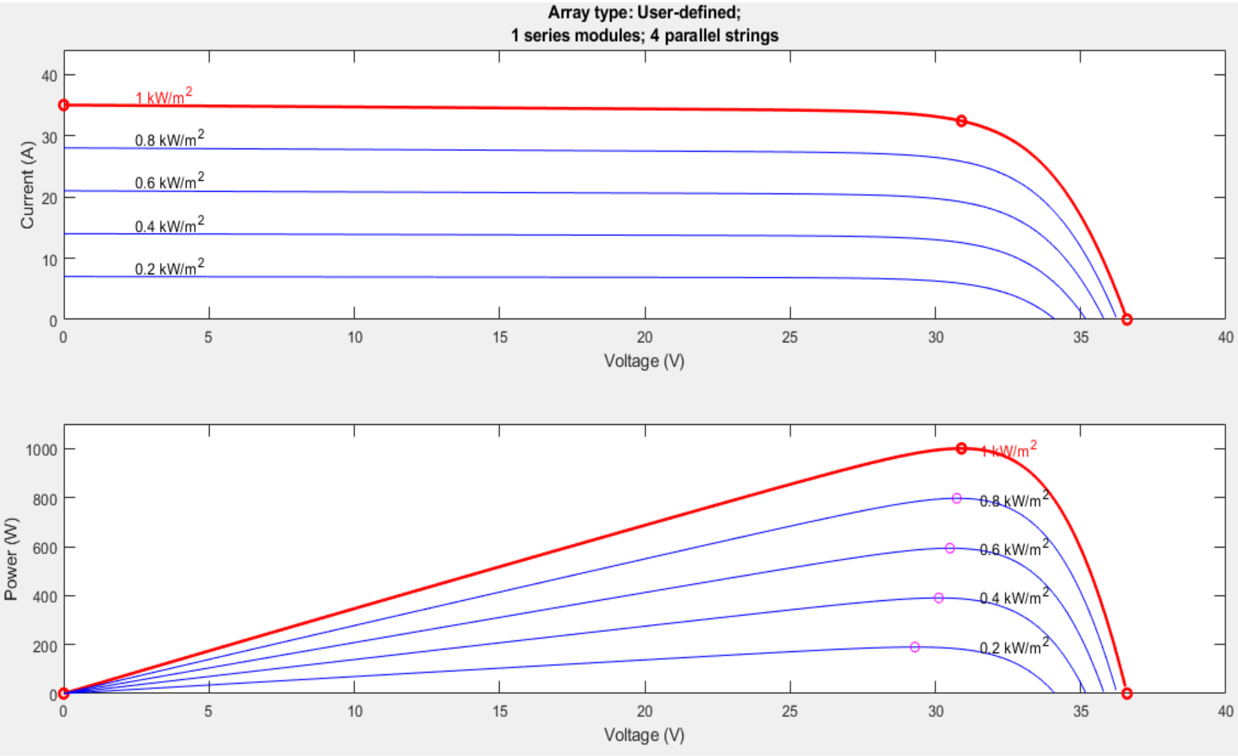

Figure 7: PV array IV and PV Curve

D. PV Array DC-DC Buck Converter

When the required input voltage is different than the available source voltage, DC-DC Buck converter is often used to convert the voltage. These converters are nonlinear, dynamic systems that change over time, and their power levels range dramatically from low to high (18). A converter needs to provide a suitable voltage for each electronic device since different electronic devices, such as ICs, have varying operating voltages (19). It is possible to build smaller devices and increase the battery's life by using a DC-DC buck convert to create a minor output voltage from a huge input power voltage (20). Figure 8 presents the circuit configuration and Table 4 illustrates the list of equipment.

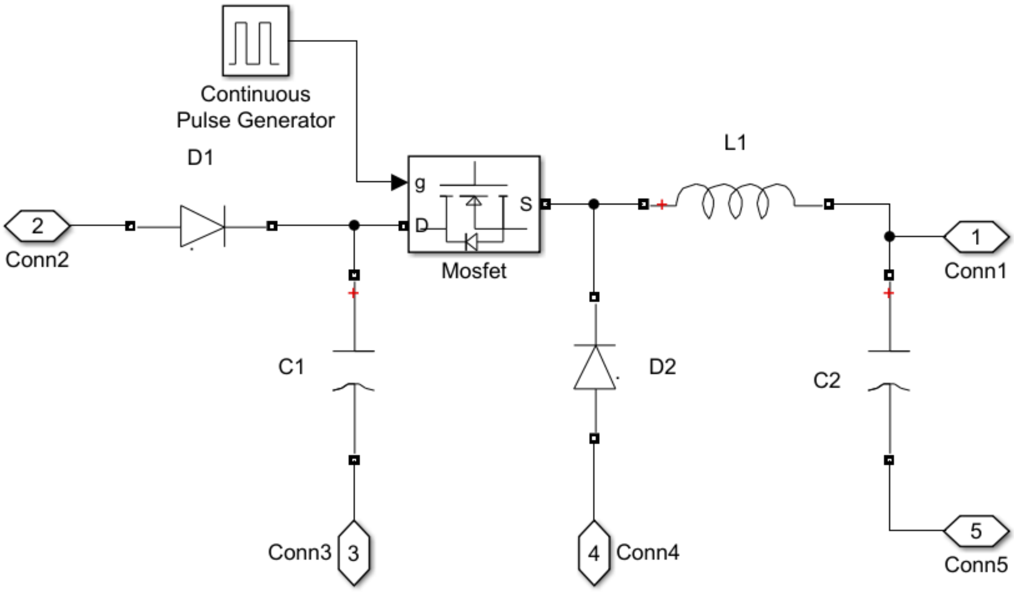

Figure 8: DC-DC Buck Converter Circuit Configuration

Table 4: Equipment List of DC-DC buck converter

No	Name	Quantity
1	Diode	2
2	Capacitor	2
3	Inductor	1
4	MOSFET	1
5	Continuous Pulse Generator	1

Level-1 Heading: *Equipment Value Calculation for Buck Converter*

Solar Panel data:

Supply Voltage V_s = 36.6 Volt

Frequency = 200 mHz

On Time= 2.5 sec

Off Time= 7.5 sec

Switching Period T = $\frac{1}{f}$

= $\frac{1}{200\times10-3}$ = 5 sec

Average Output Voltage V_a = V× $\frac{t1}{T}$

= 36.6 × $\frac{2.5}{5}$ = 18.3 Volt

Then,

Duty Cycle K = $\frac{Va}{Vs}$

= $\frac{18.3}{36.6}$ = 0.5

∴ Inductance L = $\frac{(1-k)R}{2f}$

= $\frac{(1-0.5)0.01}{2\times200\times10-3}$

= 0.0125 H

∴ Capacitance C = $\frac{(1-k)}{16Lf2}$

= $\frac{(1-0.5)}{15\times0.0125\times(200\times10-3)2}$

= 62.5 F

E. Battery Charge Controller

The rate at which current charges; or discharges, the battery is controlled by a charge controller, charger regulator, or battery regulator (21). Charge controller regulates voltage spikes that shorten battery life or efficiency and present a safety risk. It also prevents overcharging. Depending on the battery's technological advances, it may also carry out a controlled discharge or stop the battery from entirely draining ("deep discharge") in order to prolong the battery's life (22,23). The terms "charge controller" and "charge regulator" can refer to either an independent device or a control circuit included inside a battery package, a battery-powered device, or a battery charger (24).

Figure 9 is the Simulink schematic of battery charge controller, while table 5 illustrates its components.

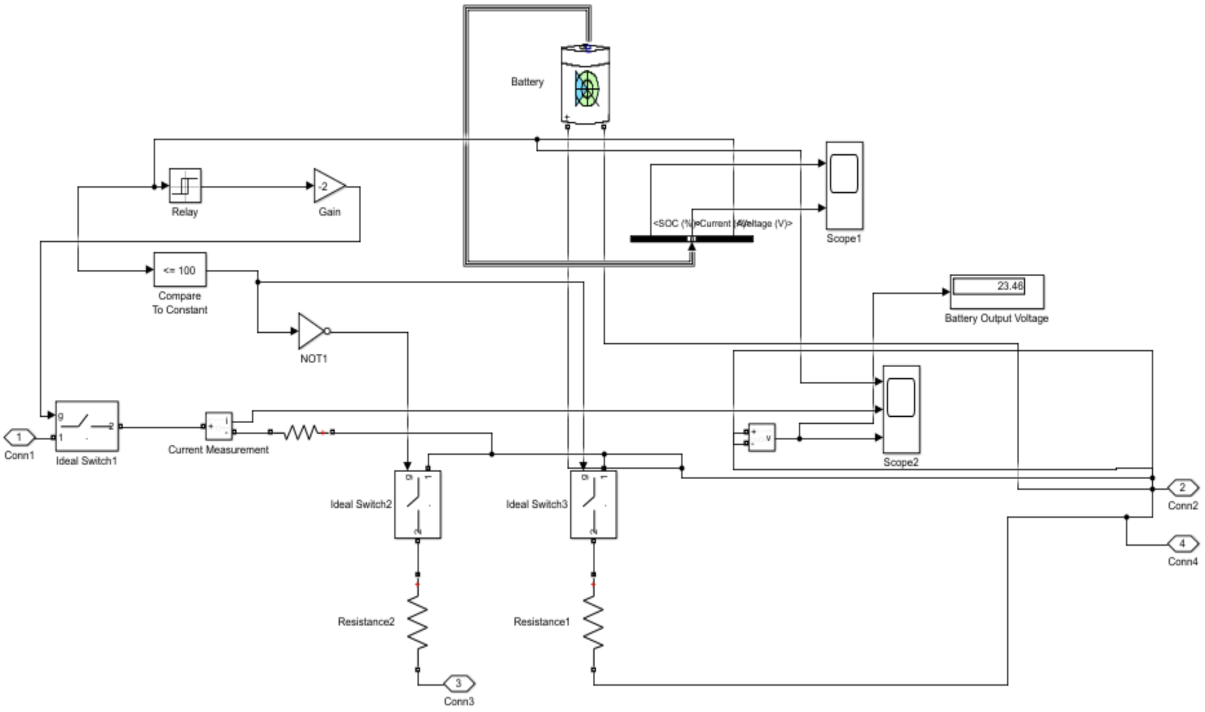

Figure 9: Simulink schematic of battery charge controller

Table 5: Components of battery charge controller

No	Name Of Equipment
1	Ideal Switch
2	Relay
3	NOT Gate
4	Resistance
5	Battery

F. Inverter

A sine wave transformer is a power inverter that creates a multistage sine wave AC waveform. Suppliers frequently refer to inverters with significantly lower distortion output as sine-wave inverters rather than enhanced sine-wave (three-stage) inverter designs. sin alone. Nearly all consumer-grade inverters marketed as "pure sine wave inverters" actually produce output that is jerkier than that of a square wave (two-step) and a variable sine wave (three-stage) inverter (25) instead of a smooth sine wave. For the majority of electronic gadgets, nevertheless, this is unimportant as they manage the output rather efficiently.

Figure 10 is the Simulink schematic of inverter circuit, while table 6 illustrates its components.

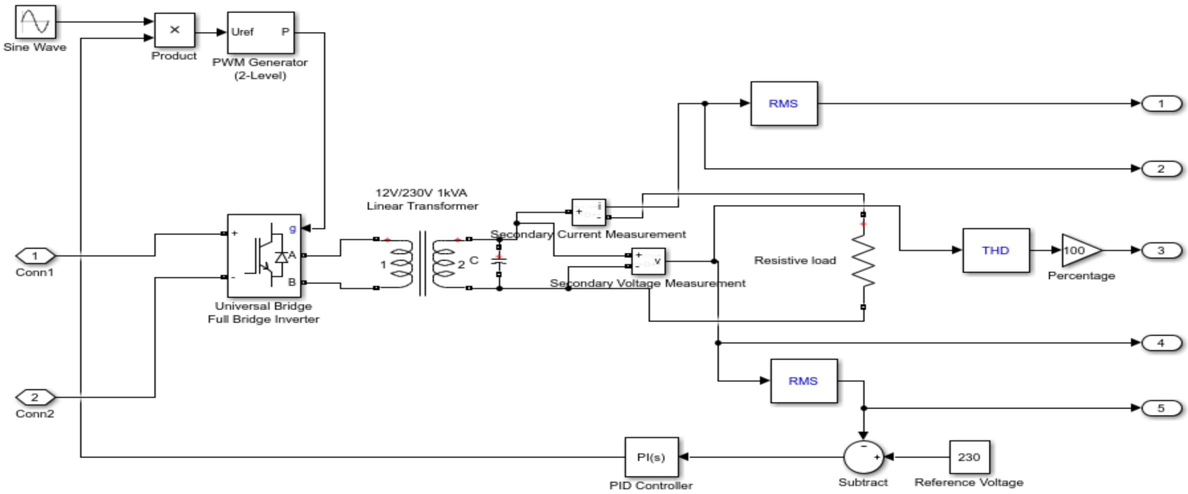

Figure 10: Simulink of Inverter Circuit

Table 6: Components of Inverter Circuit

No	Name Of Equipment
1	Sine Wave
2	A Universal Bridge Full Bridge Inverter
3	Transformer
4	PID Controller
5	PWM Generator (2-Level)

III. RESULT AND DISCUSSION

A. PV output for different Solar Radiation

Simulating the performance of the PV inverter for different values of solar radiation, at 25 ^{0}C the results are illustrated in Table 7.

Table 7: Change of solar radiation for PV array when temperature 25 degrees Celsius

Solar radiation W/m^2	PV Array output voltage	Inverter		
		Irms	Vrms	THDv(%)
500	1.697	0.4351	229.9	0.2597
1000	4.777	0.4351	229.9	0.2595
1500	6.846	0.4351	229.9	0.2589
2000	8.951	0.4351	229.9	0.2592
2500	10.98	0.4351	229.9	0.2596

From the above table (Table 7), it can be seen that the change of solar radiation as of 500 to 2500 W/m^2 PV Array output voltage increases from 1.697 to 10.98 volt and the total harmonic distortion changes from 0.2589 to 0.2595 while the Irms and Vrms values are constant so the loads can run normally.

B. Change of Solar Temperature for PV Array

To study the effect of temperature on the PV, the system is simulated for solar radiation of 1000W/m2. The simulation results are shown in Table 8.

Table 8: Change of solar temperature for PV array when solar radiation is 1000 W/m2

Solar temperature (Degree Celsius)	PV Array output voltage	Inverter		
		Irms	Vrms	THDv(%)
20	4.759	0.4351	229.9	0.2597
25	4.777	0.4351	229.9	0.2596
30	4.795	0.4351	229.9	0.2597
35	4.812	0.4351	229.9	0.2594
40	4.831	0.4351	229.9	0.2592

It could be seen from Table 8 that for the change of solar temperature from 20 to 40 degrees Celsius, for solar radiation 1000 W/m2, the PV Array output voltage increases from 4.759 to 4.821 volt and the total harmonic distortion slightly decreases from 0.2597 to 0.2592 while the Irms and Vrms values are constant. Hence, the loads run normally.

C. Change of Reference Voltage

The inverter performance is simulated changing the reference voltage. Table 9 exhibits the values of Irms, Vrms and THDv for reference voltage range from 180 to 250 volts and solar radiation 1000 W/m2.

Table 9: Change of Reference Voltage 180-230

Reference voltage	Inverter		
	Irms	Vrms	THDv(%)
180	0.3405	180	0.204
190	0.3594	190	0.2102
200	0. 3784	200	0.224
220	0.4162	219.9	0.2472
230	0.4351	229.9	0.2597
250	0.4729	249.9	0.2999

As it is shown in Table 9, as reference voltage changes from 180 to 230 volts (at solar radiation 1000 W/m^2 and cell temperature 25 degrees Celsius), Irms value ranges from 0.3405 to 0.4729 with the Total Harmonic Distortion changing from 0.204 to 0.2999. The root mean square volt (Vrms) values remains constant so loads run normally.

D. Change of Resistive Load

In case of resistive load and for constant reference voltage (230 volts) the change in active power causes increase in Irms and decrease in THDv while Vrms remains constant.

Table 10: Change of resistive load when reference voltage 230 volt

Active power P (w)	Inverter		
	Irms	Vrms	THDv(%)
10	0.04347	229.9	0.3435
50	0. 2174	229.9	0.3321
100	0. 4347	229.9	0.3206
200	0.8693	229.9	0.2895
300	0.3043	229.9	0.2536
400	1.7391	229.9	0.2351
500	2.173	229.9	0.2272
1000	4.347	229.9	0.1845
1500	6.52	229.9	0.2008

It is noticed that for the change of active power from 10 to 1500 watts (for constant solar radiation and cell temperature (1000 W/m^2 & 25°C), Irms increases from 0.04347 to 6.52, THDv decreases from 0.3435 to 0.2008. While the Vrms values remains constant.

E. Change of Inductive Load

Considering inductive load case; for inductive reactive power of the same range as in resistive load case and constant solar radiation and reference voltage, simulation results are exhibited in Table 11.

Table 11: Change of inductive load when reference voltage 230 volt

Inductive reactive power QL (positive var)	Inverter		
	Irms	Vrms	THDv(%)
10	0.04347	229.9	0.3382
50	0. 2174	229.9	0.3124
100	0. 4351	229.9	0.2597
200	0.8702	229.9	0.1884
300	1.304	229.9	0.2545
400	1.7391	229.9	0.2154
500	2.176	229.9	0.05195
1000	4.348	229.9	0.2063
1500	6.527	229.9	0.3697

Change of inductive reactive power (from 10 to 1500) for the same solar radiation and temperature as previous cases, Irms has the same increasing values from 0.04347 to 6.527 while the total harmonic distortion in this case increased from 0.3382 to 0.3697. Vrms value remains constant.

IV. CONCLUSIONS

Electricity is a fundamental requirement for development. The increase in modernization, as well as the increase in the standard of living, are directly connected with the greater use of electricity. Home appliances are wired into solar power, saving fuel generation capacity. Therefore, the current research investigates the use of solar energy for home electricity requirements. Despite the system's complexity, the solar source is cost-free, eco-friendly, and dependable. A few variables have arisen over the last ten years to lower barriers to the wide application of PV systems and increase their contribution to the world's energy portfolios. These include expanding government rewards programs, reducing PV system costs, improving solar cell efficiency, and more. The increased economic viability could not have occurred at a more advantageous time to offer a clean power generation solution to meet the rapidly growing demand. In addition to the free resource's sporadic nature, there are difficulties incorporating it into electrical power systems when using it. As a result of doing this research, different values can be changed, and it can be seen how the output changes. Firstly, Solar radiation changes over time, increasing the PV array's output voltage and THDv. Secondly, changing the solar temperature changes the PV array output voltage and total harmonic disturbance increases. Thirdly, changing the value of the reference voltage changes Irms and THDv. Finally, when loads are added (resistive and inductive load), the Irms value increases, and the THDv value decreases. Again, if inductive load is added, the Irms value remains the same, but the value of THDv increases. The research investigated the performance of different types of inverters designed, modelled, and analyzed in the MATLAB/Simulink simulation software.

V. ACKNOWLEDGEMENTS

During this research, my honorable supervisor, Muhammad Moshiur Rahman Tarafder, Assistant Professor, Faculty of Electrical and Electronics Engineering, Stamford University Bangladesh, provided supervision, continuous care, and guidance discussions. I am very grateful to him for his continued support, unforgettable help and kind encouragement throughout the process of my research paper.

VI. CONFLICTS OF INTEREST

Authors have no conflicts of interest, as it has been clarified.

VII. RECOMMENDATIONS FOR FUTURE WORK

Further investigation is required on the following points:

a) It is possible to develop and implement a prototype in order to test the proposed operating strategies.

b) A simulation study can be used in the practical supply of home appliances as well as the security analysis of a home appliance system and some types of inverter designs.

REFERENCES

1) A. A. O. Nathan David, “Solar Power System: A Viable Renewable Energy Source for Nigeria,” Quest Journal of Electronics and Communication Engineering Research (JECER), vol. 1, no. 1, pp. 10-19, 2013.
2) S. Chakraborty, B. Kramer, and B. Kroposki, “A review of power electronics interfaces for distributed energy systems towards achieving low-cost modular design”, Renew. Sustain. Energy Rev., vol. 13, no. 9, pp. 2323–2335, Dec. 2009.
3) Y. Huang, F. Z. Peng, J. Wang, and D. W. Yoo, “Survey of the power conditioning system for PV power generation”, in Proc. IEEE PESC, Jun. 18–22, pp. 1–6, 2006
4) R. Margolis, “A review of PV inverter technology cost and performance projections,” National Renewable Energy Laboratory, NREL/SR 620- 38771, 2006.
5) S. D. Finn, A high performance inverter technology, architecture and applications, in Conf. Rec. IEEE-APEC Conf., San Diego, CA, 1993, pp.556560.
6) Green, Martin A. “The path to 25% silicon solar cell efficiency: his-tory of silicon cell evolution.” Progress in Photovoltaics: Research and Applications 17.3 (2009):183-189
7) B. K. R. Digi K Dileep, “A Brief Study of Solar Home Inverters,” 2018 International Conference on Control, Power, Communication and Computing Technologies (ICCPCCT), p. 339, 2018.

8) E. Odunlade, “AC Circuit Theory (Part 3): Peak, Average and RMS Values,” Circuit Digest*,* February 14, 2018.
9) Bhuvaneswari, G., and R. Annamalai. “Development of a solar cell model in MATLAB for PV based generation system.” India Conference (INDICON),2011Annual IEEE.IEEE,2011.
10) Dey, Bijit Kumar, et al. “Mathematical modelling and characteristic analysis of Solar PV Cell.” Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2016 IEEE 7th Annual. IEEE,2016.
11) Hossain, Md Shohag, Naruttam K. Roy, and Md Osman Ali. “Modeling of solar photovoltaic system using MATLAB/Simulink.” Computer and Information Technology (ICCIT),2016 19th International Conference. IEEE,2016.
12) Carabe, J., and J. J. Gandia. “Thin-film-silicon solar cells.” OptoElectronics Review 12.1 (2004):1-6.
13) Sun, G., F. Chang, and R. A. Soref. “High efficiency thin-film crystalline Si/Getandem solar cell.” Optocs xpress 18.4 (2010):3746-3753.
14) Healy, S. A., and M. A. Green. “Efficiency enhancements in crystalline silicon solar cells by alloying with germanium.” Solar energy materials andsolarcells28.3(1992):273-284.
15) Augusto, Andr, et al. “Series connection front-to-front and back-to-back of silicon heterojunction solar cells.” Photovoltaic Specialists Conference (PVSC),2016 IEEE43rd.IEEE,2016.
16) Mochizuki, Yuki Yachi, Toshiaki. (2017). “Relationship between power generated and series/parallel solar panel configurations for 3D Fibonacci PV modules.” 126-130.10.1109/ICRERA.2017.8191253.
17) Rasheed, J. Fatima, and V. Suresh Babu. “Simulation on performance of series and parallel connected tandem solar cells A comparison study.” IEEE Region 10 Symposium (TENSYMP),2017. IEEE, 2017
18) A. P. Dancy, et al., “High-efficiency multiple-output DC-DC conversion for low-voltage systems,” IEEE Transactions on Very Large-Scale Integration (VLSI) Systems, vol. 8, pp. 252-263, 2000.
19) K. Chomsuwan, et al., “Photovoltaic grid-connected inverter using two-switch buck-boost converter,” in Conference Record IEEE Photovoltaic Specialists Conference, 2002, pp. 1527-1530.
20) K. Yao, et al., “A novel winding-coupled buck converter for high-frequency, high-step-down DC-DC conversion,” IEEE transactions on Power Electronics, vol. 20, pp. 1017-1024, 2005.
21) “Charge Controllers for Stand-Alone Systems” (Web page), part of A Consumer's Guide to Energy Efficiency and Renewable Energy, U.S. Department of Energy. Retrieved on 2007-08-20
22) Webarchive backup: Brown, David. “Technical Article: Battery Charging Options for Portable Products.” (Commercial website). Analogic Tech, 2006-07-01. Retrieved on 2007-08-21.
23) “United States Patent 5475294: Charge controller for battery charger.” (Website) Freepatentsonline.com. Retrieved on 2007-08-21.
24) Webarchive backup: “Remote Observation Station, Entry #F2040: Abstract.” Circuit Cellar Flash Innovation 2003 Design Contest, via circuitcellar.com. 2003. Retrieved on 2007-08-21
25) Taylor-Moon, Jonathan (2013). “Alabama Engineering University, Invertors, Prof. dr. Eng. Jonathan Taylor - Moon | Power Inverter | Photovoltaic System”. Scribd. 7 (Convertor and invertor technologies)