DESIGN AND ANALYSIS OF A ROOFTOP HYBRID SOLAR PV SYSTEM USING HOMER PRO AND MATLAB SIMULINK

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***Abstract*—**In this research work, the primary target was to design a hybrid solar PV system through numerical modeling here. Here a hybrid system was proposed with a load capacity of around 1 kW. MATLAB Simulink was used to design and simulate the proposed scheme. Aspects, like the availability of physical space, electrical system scale, and on-site electrical system experts mark the areas attractive sites for rooftop solar PV implementation. Moreover, rooftop hybrid solar viability is contingent upon numerous capricious factors and the success in one site may not be reproducible at another site due to some exterior aspects, like national policy, native natural gas resources, energy fares, and availability of solar irradiance. As such, this research also investigated the feasibility of diverse kinds of rooftop systems for solar power generation and distribution in residential households, which can operate in parallel with the on-grid or in an island mode to deliver a tailored state of high reliability and flexibility to grid instabilities. This cutting-edge, integrated distribution system addressed the necessity of applying them in the sites without electric supply and/or transportation limitations in inaccessible places, and to protect the loads at a critical juncture and parsimoniously thoughtful growth.

***Keywords*—**Rooftop Hybrid Solar Home System, Design, Simulation, MATLAB.

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I. INTRODUCTION

PREVIOUSLY, the major source (~75%) of electrical energy production was the fossil fuels, such as oil, natural gas, coal, etc. However, these sources emit lots of carbons [1]. But, now due to the arrival of various renewable energy sources, especially, the current solar-based photovoltaic or PV system, a low-carbon discharging technological solution, is suitable for most of the South Asian regions due to the huge areas with plentiful solar irradiation [2], because this data at the site is necessary to assess the electrical output power generated per day by the solar PV panels [3]. It has already been revealed that electrical energy can be generated from the sun radiation on a very large scale on this earth, approximately 1.8×10^{11} MW [4].

Most solar PV systems are any one of the two types, such as Utility-Scale Solar Energy (USSE) installations [5] and distributed generation [6], which may be installed either on the ground or the rooftops. The power produced during the daytime, when sunlight is available, is used locally and then feeding the surplus power back into the power grid. In a residential system, a small system usually up to 20 kW is sufficient while in communal houses, commercial buildings, and industrial structures with a size of near about 1 MW. Due to the much-reduced size of the power plant-type fixings, the rooftop solar system possesses countless returns to make this world a better place to live in [7].

A hybrid rooftop solar system is a combination of both the on-grid [8] and off-grid-tied [9] solar systems. Hence, these systems are usually known as off-grid solar systems with the service of backup power. They are also known as grid-tied solar with extra battery storage. The solar hybrid method stocks energy in electrical form from sunlight in the day and then can deliver reserved power when the grid power goes off. This is seamless for house proprietors because most of the businesses are being operated during the day; a common grid-fed solar scheme is the most economically viable option for them. As such, a rooftop hybrid solar system is designed and analyzed using MATLAB Simulink, in this work.

II. Literature Review

Currently, many countries including Bangladesh are installing the solar home system on building rooftops [10-12]. Recently, Bangladesh has installed its largest solar rooftop with a $16 million budget and 16 MW of power generating capacity in Chittagong [13].

The world's largest solar mini-grid rooftop system has been installed in Italy, which project name is CIS (Centro Ingrosso Sviluppo Campano) in Nola, located in Nola - Naples, Italy, Nominal Power is 25 MWp, Annual Production is 33 GWh and which has completed in 2013. Now this project is in operation [14].

In Bangladesh, to find out the probable capability of the rooftop solar power generation areas for electrification through renewable sources, Geographical Information System (GIS) platform has been applied to map different geographical locations [15].

India envisions adding 100 GW of solar energy to the national grid in the next 7 years and sets a target of 40 GW for rooftop solar by 2022 [16]. In Asia, the largest rooftop solar PV plant has been installed on a rooftop prepared by an asbestos sheet with an area of 94,000 m^2, located in Punjab, India with a nominal power of 7.52 MWp in June 2014. It is, still in operation [17]. The world's largest single rooftop solar power plant of 11.5 MWp capacities was inaugurated in Amritsar, Punjab, India [18]. Besides, Arvind Limited has installed 16.2 MWp rooftop solar plants in Gujarat [19].

The world's first solar-powered cricket ground is Chinnaswamy stadium in Bengaluru, India. The Karnataka State Cricket Association (KSCA) installed a 400 kW solar power plant on its stadium gallery's roof to provide electrical power to the entire stadium excluding the floodlights due to its high power requirement [20].

Bangladesh Power Development Board (BPDB) installed its first solar mini-grid system on the building rooftop. In the fiscal year 2010-2011, BPDB installed 32.75 kWp solar roof-top PV systems at its building in Motijheel, Dhaka, Bangladesh, and in the next fiscal year of 2011-2012, BPDB installed 37.5 kWp solar roof-top power systems on Bidyut Bhaban, Segunbagicha, Dhaka, Bangladesh [21].

In 2007, the Asian Development Bank (ADB), while sanctioning their loans, set the conditions that there should be some mechanism to improve the energy efficiency by using efficient ventilation methods, and while using air conditioning, lighting, and other electrical systems or appliances, and as such the adopted technologies should facilitate to reduce the energy consumption by at least 4%. Besides, distributed roof-top solar PV systems should be installed on large buildings, even the ADB headquarters did it [22].

III. Problem Statement, Objectives, and Other Considerations of this Work

A. Problem Statements and Objectives

As per the technical literature surveys, nearly 78-80% of the commercial energy consumed on this earth comes from fossil fuels, like oil, coal, and natural gas, that emit a significant amount of carbon-di-oxide (CO_2) and other greenhouse gases and cause a hugely deleterious impact to environments, as well as on health, land, air, climate, and rain [23]. That is, this increases the carbon footprints. As a result, at present, most of the countries are shifting their focus to produce electrical energy from such sources that would emit less amount of carbon to the environment.

Renewable energy resources are available in nature in plentiful and can be transformed into another form of energy without thinking about their reserve unlike fossil fuels, which deplete with time. There are a variety of renewable energy resources, like wind, solar, biomass, ocean wave, and other tidal sources that are copious to harvest clean energy [24].

Already, renewable energy technologies improved a lot due to the price of electrical power generation decreased [25]. The main barrier related to generating energy from renewable resources, such as the sun, is stochastic due to the unpredictable nature of meteorological conditions [26]. The availability of sunlight depends on the location and the seasons. Therefore, depending on a single renewable energy resource is not a wise option to get the energy yield. As such, the researchers suggest using two or more renewable resources to be mixed and form a Hybrid Renewable Energy System (HRES) [27]. The main goals of this hybrid system are to develop an electrical power generation system, minimize the cost, diminish hostile effects accompanying oxidizing fossil fuels, and increase the inclusive efficiency of energy production. As a result, the Integrated Renewable Energy System (IRES) is attaining extra attention by researchers, power engineers, and policy-makers around the globe, because a hybridized system can supply reliable and highly efficient electricity to the consumers, unlike a single-renewable resource [28-29].

An HRES can be implemented in stand-alone or grid-connected modes [30]. In stand-alone mode, the system must have big-size storage to manage the load, while in grid-connected mode, the storage can be small size, and the shortages of power can be collected from the grid. It may be pointed out that a power electronic controller must be used to share the load as well as to control the voltage, harmonic, and frequency in grid-connected mode [31]. Thus, the operating model of the HRES is categorized as the island mode and grid-connected mode. In the first case, the produced electrical power is consumed locally whereas in the latter case; the renewable energy resource is coupled to the grid [32].

A photovoltaic (PV) cell is a kind of semiconductor device that can convert sunlight to a direct current (DC). A general Si-based PV cell can harvest around 0.5-0.7 V at open-circuit conditions independent of its size. The current produced from the cell is directly related to the sunlight intensity on its surface, the cell's efficiency, and size. The PV cells are usually tied in series and parallel to yield the anticipated amount of voltage and current and hence the power. This PV module is the central construction block for a PV system. Series of such PV panels are called PV arrays [33]. The performance of PV modules and array are rated as per their maximum output power (P_{max}) tested under the Standard Test Conditions (STC), which is defined at the cell operating temperature of 25°C and incident electromagnetic irradiance level of 1 kW/m^2 [34].

In Bangladesh, energy consumption is one of the major challenges. Still, there are some areas where electricity couldn't be reached and even the people who have access to grid connection power have to face power disruptions, especially in summer due to the system faults. The industries require an uninterrupted power supply to continue their production and maintain the deadline, especially for the export-oriented industries. Most of the power stations of Bangladesh are run by natural gas as it is the most important indigenous source of energy. At present, the reservation of gas has fallen to such an alarming level that if no new gas fields are discovered then this reserve may last for a maximum of a decade. So, to reduce the dependency on natural gas, alternative energy resources must be explored. As such, Bangladesh has taken a plan to generate 5% of total power generation from renewable sources by 2015 and 10% by 2020 [21]. The renewable energy systems in Bangladesh start with Solar Home System (SHS) in the rural areas where no grid line is available [22]. Now it can be expanded by the solar mini-grid system with the application areas of irrigation system, residential, and official purposes. But the solar mini-grid system needs a large land area for its installation. So, the solar mini-grid is not a feasible solution in urban areas. Therefore, the objective of this work was to explore and evaluate the potential of solar hybrid systems at the rooftop. The other objectives of this work are set as follows:

i. To study on rooftop hybrid solar PV system
ii. To propose a rooftop hybrid solar PV system
iii. To design the proposed system using MATLAB Simulink simulation software.
iv. To analyze the effectiveness of the system.

B. Scopes

Being a developing nation, Bangladesh has seen decent growth in its economy over the past few years. Its economy is ranked as the 30th largest in the world in terms of Purchasing Power Parity (PPP) [35] and has achieved estimated GDP growth of 6% over. The industrial sector alone contributes 27.9% to this accomplishment. There are a total of 4621 garment factories operating in the country now [36].

Bangladesh aims to become a high-income country by the year 2041, and as such, it needs to raise its GDP growth rate by 7.5-8% every year. However, the important part of its GDP growth depends on ready-made garment exports and increasing remittance flow. So, the government of Bangladesh prepared a Power Supply Master Plan (PSMP) of generating electricity over 20 GW by 2020 to ensure reliable and quality electricity supply at an affordable cost to all citizens because there is a strong correlation between the GDP growth and per capita electricity consumption.

Bangladesh Power Development Board (BPDB) statistics indicate that the demand is increased 100% from 2007 to 2015. As a result, the expansion of the renewable energy sector is one of the vital approaches recognized as part of the fuel divergence program. According to the Renewable Energy Policy (REP) 2009, the government of Bangladesh is steadfast to expedite both public and private sector investments in renewable energy schemes to replace aboriginal non-renewable energy sources and increase the contributions towards the current renewable energy-based electricity generations. To achieve the target of producing 10% of electricity from renewable sources by 2020, the government of Bangladesh formed the Sustainable and Renewable Energy Development Authority (SREDA) to promote renewable energy options and energy efficiency improvement. However, this target has not been achieved till now. But the global target of solar energy coverage is expected to be approximately 30% of global energy demand by 2050 and approximately 70% by 2100.

On the globe, the latitude and longitudinal position of Bangladesh is between 20.30^0 and 26.38^0 north 88.04^0 and 92.44^0 east. It is an ideal position to harness solar energy. Bangladesh receives an average daily solar radiation of 4-6.5 kWh/m². The Power Division of Bangladesh took the initiative to generate 500 MW of solar-based electrical power. The long-term power generation policy of Bangladesh is to become a low-carbon emission country by introducing a high-efficient power supply and using such technologies to generate power that would release low greenhouse gas [22].

There is a strong relationship between electricity consumption and quality of life, because, with its ever-increasing usage, the health, education, industry, social sectors are heightened. In rural areas, electrification can bring socio-economic growth by increasing literacy rates, improving health care facilities, creating employment opportunities, generating income activities, and advancing productivity. According to the United Nations Development Program (UNDP), if per capita electricity consumption can be increased then the Human Development Index (HDI) would rise [37]. They identified that the mid-level energy initiatives, such as solar micro-grid have a greater impact on raising the social status because through the small-scale solar mini-grids access to electrification can be ensured in a community very easily and thus can be created a positive feedback loop that facilitates the growth and stepping up the social life.

In this paper, the possibility of implementing a solar mini-grid system on the rooftop of buildings is discussed in detail. Then a hybrid solar PV rooftop system is designed in MATLAB Simulink for a load of around 1000 W. This research also conducted into the advantages, design, and analysis of a DC microgrid in residential applications. The DC micro-grid system is preferred when compared to replacing the entire conventional AC system with DC. The focus of this research is that a new idea of DC microgrid will be introduced and this DC micro-grid can be implemented in new households, or modified in the prevailing, with the marginal influence on the other consumers relying on the AC power. There may be verities of impacts that may be derived from such types of initiatives.

IV. CONTROLLER CIRCUIT AND HYBRID SOLAR SYSTEM DESIGN

An AC voltage controller is an electronic circuit that uses various types of semiconductor devices like thyristors, TRIACs, SCRs, MOSFETs, BJTs, or IGBTs, to convert a fixed frequency AC voltage from one level to another level at the output or load side. This variable AC voltage is used for dimming street lights, varying temperatures, controlling the speed of motors, and other numerous applications. This kind of power electronic circuit has the advantages of low-maintenance cost and very high efficiency. Such a control circuit is a phase-controlled device, that is the phase angle between the load current and the supply voltage can be controlled by changing the firing angle of the semiconductor devices used in the circuit. As such, it is a kind of natural or line commutated circuit, and hence no forced commutation circuitry is essential. Since solar power is of DC type, therefore, we need power electronic circuits, such as AC-DC, DC-AC converters to have quality AC power for our AC power-driven appliances [38-40].

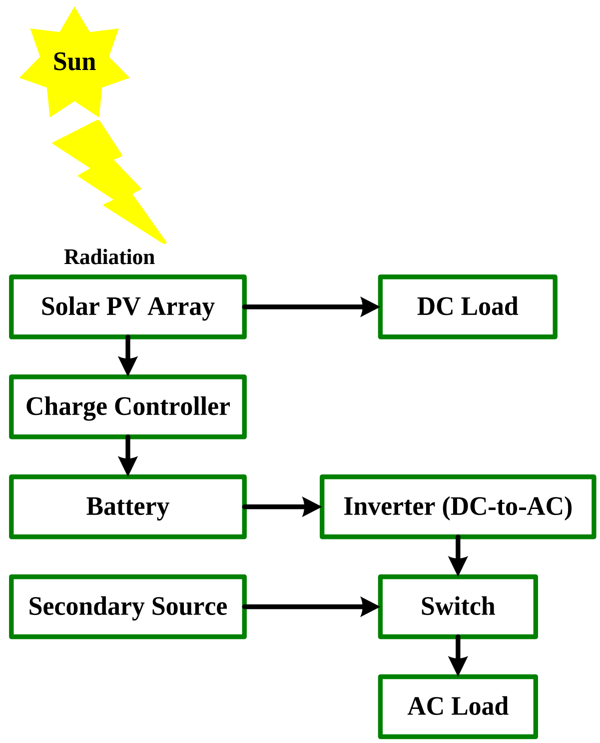

Fig. 1. Block diagram of a rooftop solar home PV system

The block diagram of the solar PV rooftop system is shown in Fig. 1. The solar PV array receives the solar radiation in the form of light during daytime and then transforms it in the form of DC electrical energy. The DC power is stored in the battery as soon as it is generated by the PV array via a charge controller circuit. When an AC appliance is to be powered from this stored DC energy, we need an inverter circuit that transforms the stored DC energy of the battery into an AC signal with appropriate voltage amplitude and frequency. However, the AC load can be driven by the power taken from any secondary source like a power grid. In that case, the AC load is connected to the power grid via an AC distribution board. AC power from the inverter circuit is supplied to the switchboard from where it is directed to the various loads connected to that particular building where this rooftop solar system has been installed. Depending on the type of system, excess solar energy can either be fed into the electricity grid for credits, or stored in different storage systems.

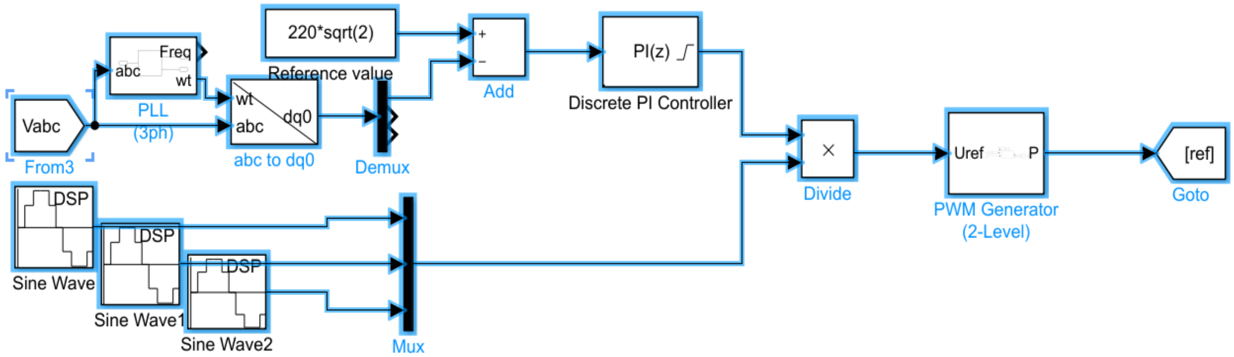

Fig. 2. Voltage controller's MATLAB Simulink diagram

On-grid or grid-tied solar energy systems are being widely used at homes and offices without any battery and are directly connected to the national grid to export the surplus of the solar energy there and thus the customer can be benefitted by lowering their utility bill. However, these types of systems cannot generate electricity during a grid failure because at that time if the power is fed to the grid then it might be dangerous for the people working there to repair the damage that occurred in the grid. But the hybrid solar systems have storage facilities that can isolate the system from the grid (also called islanding) automatically and remain to deliver power during a national grid failure.

Figure 2 shows the voltage controller's circuit diagram and Fig. 3 shows the on-grid model drawn in the MATLAB Simulink as per the block diagram of Fig. 1. This system works in two different means, such as the electrical power is supplied to the consumer's load from the utility grid when the solar power is not available, and if the solar power is available then the electrical power is supplied to the consumer's load from the solar PV system. However, in this case, the rooftop solar system is connected to the grid. As such, the on-grid solar system is much more affordable and convenient to the user.

The PV panels produce electricity when there is sunshine and it is then fed to the distribution panel to be used by the consumer. If additional power is generated then it is delivered to the grid. Thus the consumer's utility meter billing is curtailed. The utility company charges the consumer only when they consume any power from the grid.

The working procedures of this system have been described in the following steps:

Step # 1: The solar PV arrays have irradiation and temperature parameters to be set to produce electrical energy from the sunlight.

Step # 2: The grid-tied inverter module converts the DC output power of the PV array to a 3-phase AC power. The three-phase loads are also shown using the resistance and inductance. The inverter can regulate the amount of power supplied to the load.

Step # 3: There is also provision for the voltage and current measurement and monitoring through the scopes from different points.

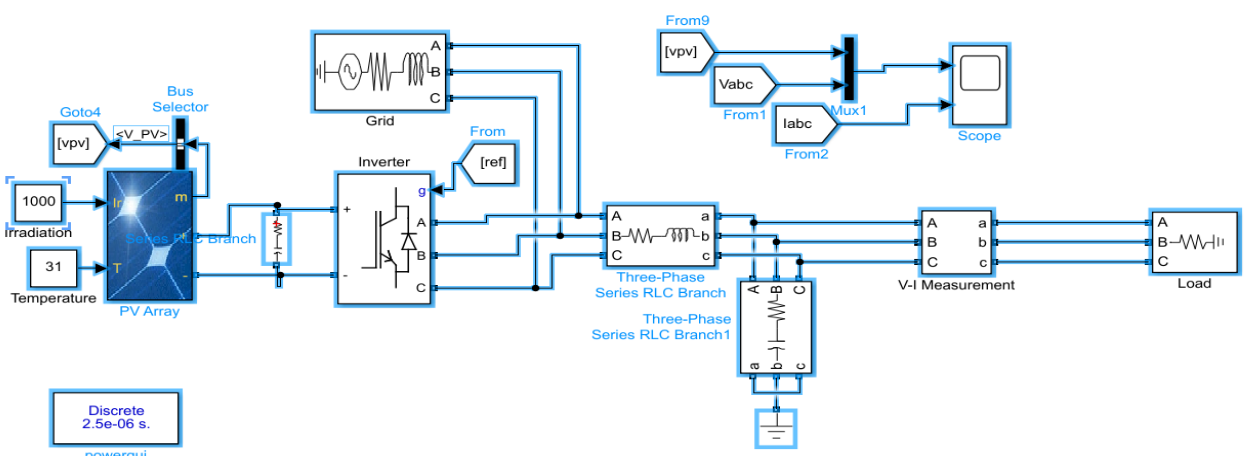

Fig. 3. On-grid system's model drawn using MATLAB Simulink

On the other hand, an off-grid solar energy system is not connected to the national grid, that is, this type of system is not able to deliver power to the grid in any case. This is tempting because the customer is 100% self-sustaining of electricity use.

Figure 4 shows the off-grid model drawn in MATLAB Simulink. As the name suggests, the off-grid solar PV system is not linked to the utility grid. As such, the surplus electrical energy produced during the daytime is stored in storage devices, like batteries. Such PV systems can be installed in localities where grid power is not accessible. Therefore, it is a completely independent power-producing system. The stored power is expended at night and some other times when the sunlight is not available due to rain, storm, fog, cloud, etc. The working procedures of this system have been described in the following steps:

Step # 1: The main power hub is solar PV. The solar PV arrays have irradiation and temperature parameters to be set to produce electrical energy from the sunlight.

Step # 2: The batteries are an indispensable part of this system to store additional electrical energy.

Step # 3: However, a standby power generator may be added to recharge the batteries in case there is no sunshine for a longer period.

Step # 4: The inverter module converts the DC output power of the PV array to a 3-phase AC power. The three-phase loads are also shown using the resistance and inductance. The inverter can regulate the amount of power supplied to the load.

Step # 5: There is also provision for the voltage and current measurement and monitoring through the scopes from different points.

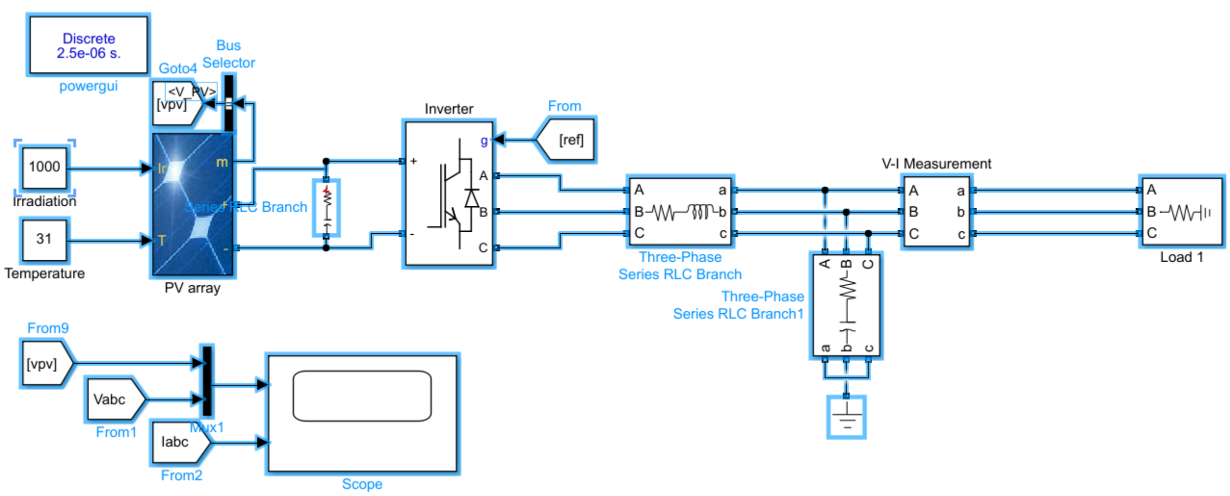

Fig. 4. Off-grid system's model drawn using MATLAB Simulink

Conversely, the hybrid solar system generates power like a grid-tied solar system but uses a special kind of hybrid inverter with batteries so that the surplus energy can be stored in the batteries and can be used later. The stored energy serves as a standby power supply when the national grid fails as it is observed in the Uninterrupted Power Supply (UPS).

Figure 5 shows the hybrid solar model drawn in the MATLAB Simulink. It is a combination of both off-grid and on-grid systems. The major differentiating option between the hybrid and other solar PV systems is that the former has an energy storage device as well as utility grid connectivity. As such, this type of system is highly reliable in terms of continuity of electricity supply to the consumer all the time. Since this system can store electricity for a longer period in batteries, electrical energy can be used from here in the future at the time of need without drawing it from the utility grid, it significantly decreases the tariff and also increases the reliability as well. The working procedures of this system are described in the following steps:

Step # 1: Here stored energy from the solar PV system is shown as a DC voltage source in the diagram. It is assumed that the DC source gets the power from the photoelectric effect when the sun shines in the day. A universal bridge inverter circuit is used to convert the DC voltage to AC voltage. The batteries are being continuously charged during the daytime to store DC power obtained from the sunlight via the PV arrays.

Step # 2: In the absence of sunlight, the consumer draws DC power from the battery, and conversion of it to AC power is performed by the inverter circuit. If the battery power goes low due to the use of a longer period then the battery power can be restored by charging it using the grid power and in that case, the consumer also draws their required power from the utility grid by paying a tariff to the utility company. This ensures an uninterrupted power supply to the users.

Step # 3: The inverter module converts the DC output power of the PV array to a 3-phase AC power. The three-phase loads are also shown using the resistance and inductance. The inverter can regulate the amount of power supplied to the load.

Step # 4: There is also provision for the voltage and current measurement and monitoring through the scopes from different points.

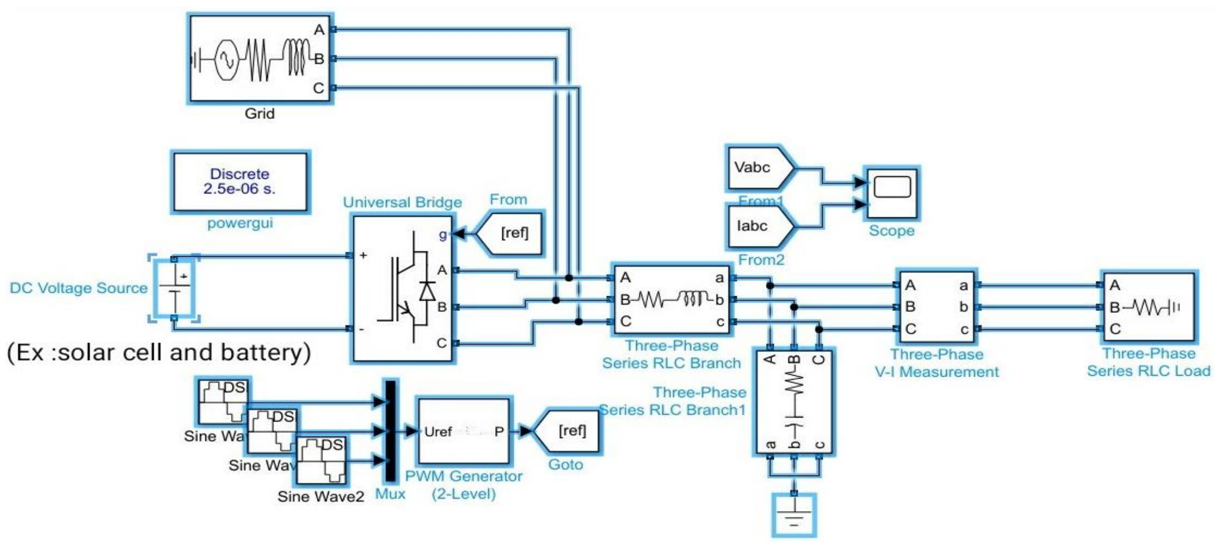

Fig. 5. Hybrid solar system's model drawn using MATLAB Simulink

V. Results and Discussions

A. Performance evaluation with on-grid system

Each panel type and architecture has a slightly different type of curve. That means the voltage and current characteristics are different due to the panel's variety. These characteristics change with temperature, irradiance, and many other factors as we have discussed. Since we are dealing with grid-tied systems, we need to address the role of the *I-V* curve in the inverter design using a sine-wave inverter with maximum power point tracking. Our goal is to get the most out of the inverter and the rest of the system.

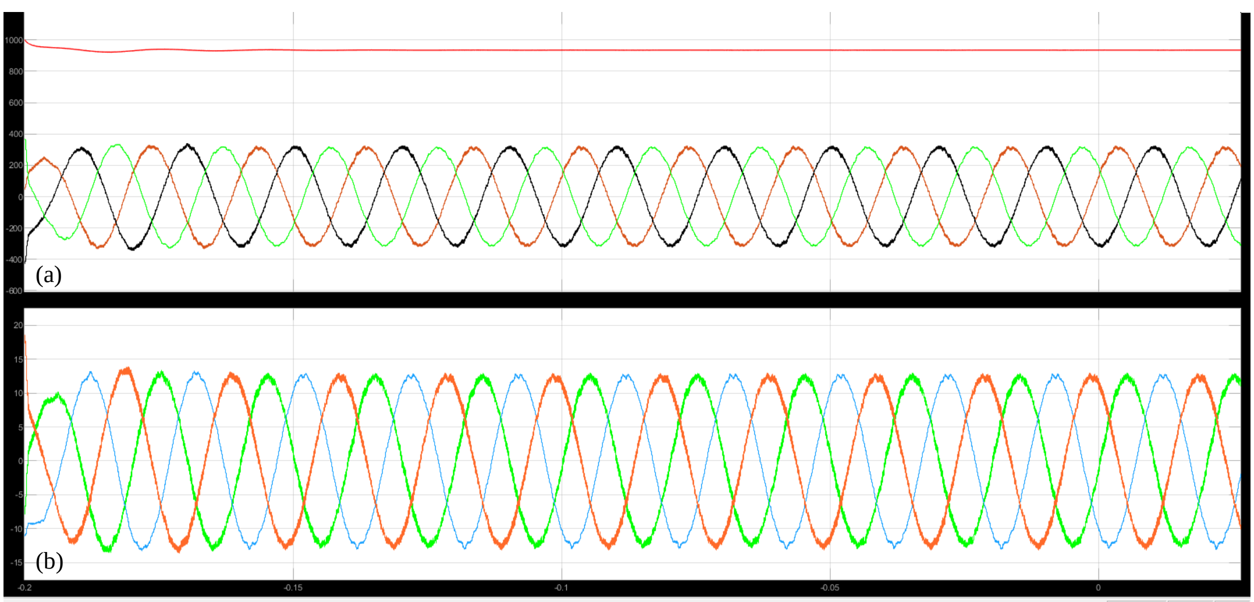

Fig. 6. Output (a) voltage and (b) current wave shapes for the three phases obtained from the simulation of the Simulink diagram of an on-grid system

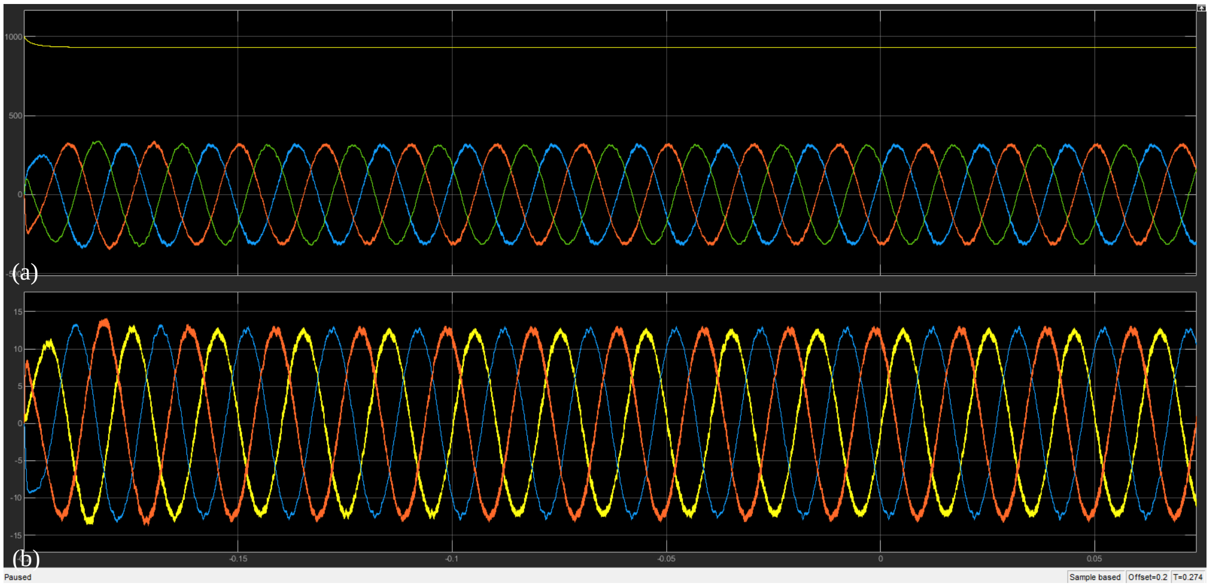

Fig. 7. Output (a) voltage and (b) current wave shapes for the three phases obtained from the simulation of the Simulink diagram of an off-grid system

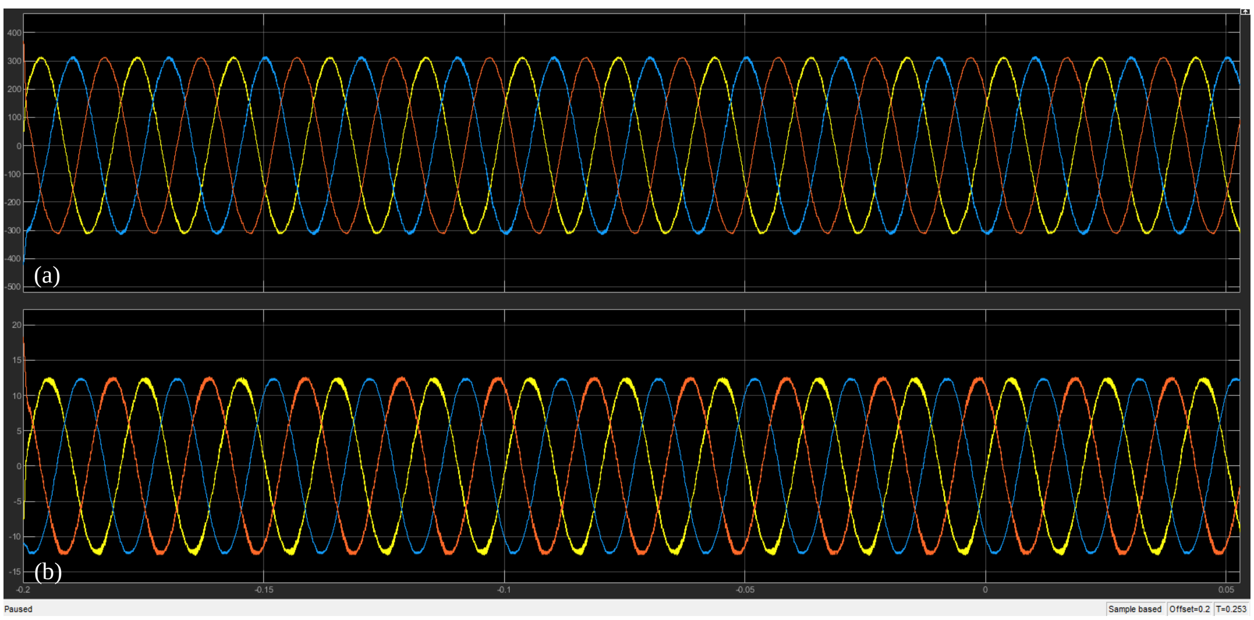

Fig. 8. Output (a) voltage and (b) current wave shapes for the three phases obtained from the simulation of the Simulink diagram of a hybrid system

The *I-V* curve of the solar panel affects the system performance. There is an *I-V* curve for Standard Test Conditions (STC), the representative form of the *I-V* curve. Figures 6 (a) and (b) show the output voltage and output current wave shapes respectively for the three phases of the inverter output side obtained from the simulation results of an on-grid system. On the *y*-axis, the current is represented in amperes and voltage is in volt. As the irradiance increases, the current increases. Therefore, in the real world, the upper portion of the curve fluctuates up and down with time represented on the *x*-axis. On the other hand, voltage is inversely affected by temperature. As temperature rises, the voltage decreases; as the temperature drops, the voltage increases. The peak voltage is over 300 V and the peak current is around 14 A. Often, the emphasis is given to the *I-V* curve at STC.

B. Performance evaluation with an off-grid system

The overall efficiency of the system must be taken into consideration while designing and sizing a solar PV system. Figures 7 (a) and (b) show the output voltage and output current wave shapes respectively for the three phases of the inverter output side obtained from the simulation results of an off-grid system. On the *y*-axis, the current is represented in amperes and voltage is in volt. As the irradiance increases, the current increases. Therefore, in the real world, the upper portion of the curve performance evaluation with an off-grid system curve fluctuates up and down with time represented on the *x*-axis. Here also, the voltage is inversely affected by temperature. As temperature rises, the voltage decreases; as the temperature drops, the voltage increases. The peak voltage is over 300 V and the peak current is around 14 A.

C. Performance evaluation with a hybrid system

The potency of an associate off-grid star inverter refers to the magnitude relation of its output power to its input power underneath nominal operating conditions, expressed as a share. In general, the nominal potency of an associate off-grid star inverter refers to a strictly resistive load. Because the overall value of star systems is comparatively high, the potency of off-grid star inverters ought to be maximized, system prices ought to be reduced, and also the cost-effectiveness of star systems ought to be improved. However, additionally, the affordable configuration of the system ought to be adopted to form the electrical phenomenon system load work close to the simplest potency purpose the maximum amount as doable due to the high worth of star cells, to maximize the employment of star cells and improve system potency.

Figures 8 (a) and (b) show the output voltage and output current wave shapes respectively for the three phases of the inverter output side obtained from the simulation results of an off-grid system. On the *y*-axis, the current is represented in amperes and the voltage is in volt. As the irradiance increases, the current increases. Therefore, in the real world, the upper portion of the curve fluctuates up and down with time as shown on the *x*-axis. We also observed that the voltage is inversely affected by temperature. As temperature rises, the voltage decreases; as the temperature drops, the voltage increases. The peak voltage is over 300 V and the peak current is around 14 A.

VI. CONCLUSIONS

In this research work, the primary target was to design a hybrid solar PV system. At first, theoretical studies on this topic were completed and then the system model was designed and drawn in MATLAB Simulink for a load of around 1 kW. After that, the model was simulated to observe the voltage and current wave shapes generated from this system. However, to observe and compare the performance of this system, both the on-grid and off-grid systems were modeled and simulated. A hybrid solar PV system gives impetus to the use of renewable sources of energy. Reliability is achieved due to the regionalization of electricity supply to get 24 hours of power supply due to receiving the power from multiple sources.

REFERENCES

[1] IEA Data: *https://www.iea.org/reports/key-world-energy-statistics-2021/transformation#electricity-generation*, accessed on 26 July 2021.

[2] B. Lu, A. Blakers, M. Stocks, T. N. Do, "Low-cost, low-emission 100% renewable electricity in Southeast Asia supported by pumped hydro storage," *Energy*, vol. 236, 2021, ISSN 0360-5442, *https://doi.org/10.1016/j.energy.2021.121387*.

[3] A. Aktaş and Y. Kirçiçek, "Examples of Solar Hybrid System Layouts, Design Guidelines, Energy Performance, Economic Concern, and Life Cycle Analyses," in "*Solar Hybrid Systems: Design and Application*," Chapter 13, Academic Press, 2021, pp. 331-349, ISBN: 9780323884990, Editors: A. Aktaş and Y. Kirçiçek, *https://doi.org/10.1016/B978-0-323-88499-0.00013-6*.

[4] P. K. Soori, L. Parthasarathy, M. Okano, and A. Mana, "Intelligent Off-Grid Photovoltaic Supply Systems," *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, vol. 2, no. 4, pp. 592-596, 2008, *scholar.waset.org/1999.5/5704*.

[5] R. R. Hernandez, M. K. Hoffacker, and C. B. Field, "Land-Use Efficiency of Big Solar," *Journal of Environmental Science and Technology*, December 2013, American Chemical Society Publications, doi: dx.doi.org/10.1021/es4043726.

[6] E. Rakhshani, K. Rouzbehi, A. J. Sánchez, A. C. Tobar, and E. Pouresmaei, "Integration of Large Scale PV-Based Generation into Power Systems: A Survey," *Energies*, MDPI, vol. 12, 1425, April 2019, *doi:10.3390/en12081425*.

[7] Asian Development Bank (2014). Handbook for Rooftop Solar Development in Asia. Mandaluyong City, Metro Manila, Philippines, *https://hdl.handle.net/11540/2497*, accessed on 28 December 2020.

[8] S. Moury and R. Ahshan, "A feasibility study of an on-grid solar home system in Bangladesh," *1st IEEE International Conference on the Developments in Renewable Energy Technology* (ICDRET), Dhaka, Bangladesh, 17-19 December 2009, pp. 1-4, doi: *10.1109/ICDRET.2009.5454208*.

[9] S. S. S. Ranjit, C. F. Tan and S. K. Subramaniam, "Implementation Off-Grid Solar Powered Technology to Electrify Existing Bus Stop*," 2nd IEEE International Conference on Intelligent Systems, Modelling and Simulation*, Phnom Penh, Cambodia, 25-27 January 2011, pp. 231-234, doi: *10.1109/ISMS.2011.44*.

[10] S. Ahmed, K. N. Ahshan, M. N. A. Mondal, "Rooftop Solar: A Sustainable Energy Option for Bangladesh." *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE), vol. 17, issue 3, May-June 2020, pp. 58-71.

[11] Sustainable Renewable Energy Development Authority (SREDA), National Database of Renewable Energy, *http://www.renewableenergy.gov.bd/index.php?id=1&i=3*, accessed on 16 December 2021.

[12] O. E. Olabode, T. O. Ajewole, I. K. Okakwu, A. S. Alayande, D. O. Akinyele, "Hybrid power systems for off-grid locations: A comprehensive review of design technologies, applications and future trends," Scientific African, vol. 13, 2021, e00884, ISSN 2468-2276, *https://doi.org/10.1016/j.sciaf.2021.e00884*.

[13] Bangladesh Inaugurates Largest Solar Rooftop, PV Magazine, *https://www.pv-magazine.com/2021/06/21/bangladesh-inaugurates-largest-solar-rooftop/*, accessed on 22 June 2021.
[14] Enel Green Power Half-year Report, 30 June 2010, p. 14.
[15] T. Jamal, W. Ongsakul, J. G. Singh, S. Salehin, and S. M. Ferdous, "Potential rooftop distribution mapping using Geographic Information Systems (GIS) for Solar PV Installation: A case study for Dhaka, Bangladesh," *3rd IEEE International Conference on the Developments in Renewable Energy Technology* (ICDRET), Dhaka, Bangladesh, 29-31 May 2014, pp. 1-6, doi: *10.1109/ICDRET.2014.6861648*.
[16] Going Solar On Rooftops: India targets 40GW by 2022, *https://www.engerati.com/energy-retail/going-solar-on-rooftops-india-targets-40gw-by-2022/?register=success*, accessed on 15 December 2021.
[17] M. N. Alam, R. Karim, and M. R. Islam, "A Comparative Study on Installation of Solar PV System at Garments Roof Top," *Proceedings of 11th Global Engineering, Science and Technology Conference*, 18-19 December 2015, pp. 1-17, BIAM Foundation, Dhaka, Bangladesh, ISBN: 978-1-922069-92-4.
[18] *https://www.business-standard.com/article/economy-policy/world-s-largest-rooftop-solar-power-plant-inaugurated-in-punjab-116051701113_1.html*, accessed on 15 December 2021.
[19] *https://www.constructionweekonline.in/people/arvind-unveils-indias-largest-rooftop-solar-project-at-16-2-mw*, accessed on 15 December 2021.
[20] Bengaluru's Chinnaswamy Stadium: World's First Solar-Powered Cricket Ground, *https://economictimes.indiatimes.com/news/sports/bengalurus-chinnaswamy-stadium-worlds-first-solar-powered-cricket-ground/articleshow/46672112.cms*, accessed on 16 December 2021.
[21] BPDB "Power System Master Plan Summery 2010," Bangladesh Power Development Board (BPDB), *http://www.bpdb.gov.bd/download/PSMP/PSMP2010(Summary).pdf*, accessed on 16 December 2021.
[22] BPDB "Development of Renewable Technologies by BPDB" Bangladesh Power Development Board (BPDB), 2015, *http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=26&Itemid=24*, accessed on 16 August 2021.
[23] N. Boubekri and V. Shaikh, "Machining using Minimum Quantity Lubrication: A Technology for Sustainability," International Journal of Applied Science and Technology, vol. 2, no. 1, pp. 111-115, 2012.
[24] D. K. Lal, "Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER," *International Journal on Electrical Engineering and Informatics*, vol. 3, no. 3, pp. 307-325, 2011.
[25] Fu-B. Wu, B. Yang, and Ji-L. Ye, "*Grid-scale Energy Storage Systems and Applications*," Academic Press, 2019, Ch.1, Development of Energy Storage Technology, pp. 1-15, ISBN 9780128152928, *https://doi.org/10.1016/B978-0-12-815292-8.00001-0*.
[26] J. P. Painuly and N. Wohlgemuth, Editor(s): J. Ren, "*Renewable-Energy-Driven Future*," Academic Press, Ch. 18 Renewable energy technologies: barriers and policy implications, 2021, pp. 539-562, ISBN 9780128205396, *https://doi.org/10.1016/B978-0-12-820539-6.00018-2*.
[27] W. Ma, X. Xue, and G. Liu, "*Techno-economic Evaluation for Hybrid Renewable Energy System: Application and Merits*," Energy, vol. 159, 2018, pp. 385-409, ISSN 0360-5442, *https://doi.org/10.1016/j.energy.2018.06.101*.
[28] A. M. Patel and S. K. Singal, "Optimal Component Selection of Integrated Renewable Energy System for Power Generation in Stand-Alone Applications," *Energy*, vol. 175, May 2019, pp. 481-504, ISSN 0360-5442, doi: *10.1016/j.energy.2019.03.055*.
[29] A. B. Kanase-Patil, A. P. Kaldate, S. D. Lokhande, H. Panchal, M. Sureshm and V. Priya, "A Review of Artificial Intelligence-Based Optimization Techniques for the Sizing of Integrated Renewable Energy Systems in Smart Cities," *Environmental Technology Reviews*, vol. 9, issue 1, pp. 111-136, December 2020, doi: *10.1080/21622515.2020.1836035*.
[30] R. Singh, R. C. Bansal, A. R. Singh, and R. Naidoo, "Multi-Objective Optimization of Hybrid Renewable Energy System Using Reformed Electric System Cascade Analysis for Islanding and Grid Connected Modes of Operation," *IEEE Access*, vol. 6, pp. 47332-47354, 2018, doi: *10.1109/ACCESS.2018.2867276*.
[31] D. Mazzeo, N. Matera, P. De Luca, C. Baglivo, P. M. Congedo, and G. Oliveti, "Worldwide Geographical Mapping and Optimization of Stand-Alone and Grid-Connected Hybrid Renewable System Techno-Economic Performance Across Köppen-Geiger Climates," *Applied Energy*, vol. 276, 2020, 115507, ISSN 0306-2619, doi: *10.1016/j.apenergy.2020.115507*.
[32] A. K. Behura, A. Kumar, D. Rajak, C. I. Pruncu, and L. Lamberti, "Towards Better Performances for a Novel Rooftop Solar PV System," *Solar Energy*, vol. 216, pp. 518-529, 2021.
[33] M. A. Eltawil and Z. Zhao, "Grid-connected Photovoltaic Power Systems: Technical and Potential Problems—A Review," *Renewable and Sustainable Energy Reviews*, vol. 14, issue 1, 2010, pp. 112-129, ISSN 1364-0321, doi: *10.1016/j.rser.2009.07.015*.
[34] Syafaruddin, E. Karatepe, and T. Hiyama, "Performance Enhancement of Photovoltaic Array Through String and Central Based MPPT System Under Non-Uniform Irradiance Conditions," *Energy Conversion and Management*, vol. 62, 2012, pp. 131-140, ISSN 0196-8904, doi: *10.1016/j.enconman.2012.03.028*.
[35] Gross Domestic Product 2020, PPP- World Bank Data Bank, https://databank.worldbank.org/data/GDP_PPP.pdf, accessed on 17 December 2021.
[36] M. K. Islam, "Impact of COVID-19 on Garment Sector in Bangladesh," *International Journal of Scientific and Research Publications*, vol. 10, issue 11, November 2020, pp. 147-156, ISSN 2250-3153, doi: *10.29322/IJSRP.10.11.2020.p10716*.
[37] R. Brecha, "Threshold Electricity Consumption Enables Multiple Sustainable Development Goals," *Sustainability*, MDPI, vol. 11, pp. 1-15, 2019.
[38] I. Ahmed and M. H. Bhuyan, "A Critical Review on Open Loop Analysis of Single-Phase Non-Isolated AC-DC Buck Converters," *Southeast University Journal of Electrical and Electronic Engineering* (SEUJEEE), ISSN: p-2710-2149, e-2710-2130, vol. 1, issue 1, January 2021, pp. 7-12.
[39] S. M. Faruk, M. M. Hossain, A. A. Mansur, and M. H. Bhuyan, "Improvement of Input Side Current of a Three-Phase Cúk Rectifier," *Southeast University Journal of Science and Engineering* (SEUJSE), 1999-1630, vol. 9, no. 1-2, December 2015, pp. 45-51.
[40] S. M. Faruk, M. M. Hossain, and M. H. Bhuyan, "Shaping the Input Side Current Waveform of a 3-ϕ Rectifier into a Pure Sine Wave," *International Journal of Electronics and Communication Engineering*, vol. 15, no. 9, September 2021, pp. 344-355.

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