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Research Article

Supplying Surplus Electricity for Local Use from Solar Irrigation in Bangladesh

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ABSTRACT

In the rural regions of Bangladesh, diesel fuel persists as a predominant resource for irrigation purposes, notwithstanding its exorbitant costs, logistical difficulties, and detrimental environmental consequences. In light of these challenges, the government of Bangladesh is actively pursuing alternative solutions. The utilization of renewable energy is on the rise, in accordance with the United Nations' Sustainable Development Goal 7. Solar irrigation systems present a sustainable and environmentally viable alternative. The Infrastructure Development Company Limited (IDCOL) has commenced solar irrigation pump initiatives in various locations, aiming to establish 10,000 systems by the year 2027. As of March 2024, IDCOL had sanctioned 1,515 solar pumps, resulting in a cumulative generation capacity of approximately 40 MWp. These initiatives possess the potential for enhanced productivity by harnessing surplus electricity during the off-peak season, during which the systems remain inactive for over half of the year. If this excess energy can be effectively integrated into the national grid or distributed locally, the previously untapped potential can be fully actualized. This study investigates effective strategies for the utilization of surplus electricity generated by solar irrigation systems to the benefit of local communities.

Keywords— *Solar Irrigation: SDG: Surplus Electricity, Solar System, Local Energy Use, Grid Integration*

1. Introduction

In Bangladesh, the agricultural sector constitutes a fundamental component of the national economy, with irrigation serving as an essential factor in facilitating optimal crop yields, particularly during arid periods. Historically, the provision of irrigation in rural regions has been predominantly dependent on diesel- or electric-powered pumping systems, both of which are characterized by high costs and significant environmental unsustainability. Upon the implementation of a solar irrigation system, it frequently produces a surplus of electricity beyond what is necessary for irrigation purposes, especially during periods of maximum solar exposure. Approximately 1.5 million units of irrigation systems were operational in Bangladesh in 2024, as illustrated in table 1 below (World Bank, 2024).

Table 1: Summary of irrigation facility used in Bangladesh (IDCOL, 2024)

Types of equipment	Operated by electricity	Operated by diesel	Total		
			Units	Irrigated area (ha)	Benefitted farmers
Deep Tube Wells	35430	2204	37634	1076141	3090358
Shallow Tube Wells	289434	1068098	1357532	2994466	12775465
Low Lift Pumps	13983	173205	187188	1248616	3495695
Manual and Artesian Well	0	0	0	8780	32452
Traditional Method	0	0	0	8065	25760
Gravity Flow	0	0	0	238871	185550
Solar Pump	0	0	2787	11960	39900
Country Total	338847	1243507	1585141	5586899	19645180

Diesel fuels approximately 1.2 million of the total irrigation units. Often, the difficulties associated with transporting diesel to the fields and maintaining a steady supply create stress for farmers, making them dependent on intermediaries. These middlemen, in turn, inflate diesel prices, leading to increased overall costs for irrigation and food production.

Figure 1.1: Diesel irrigation pump

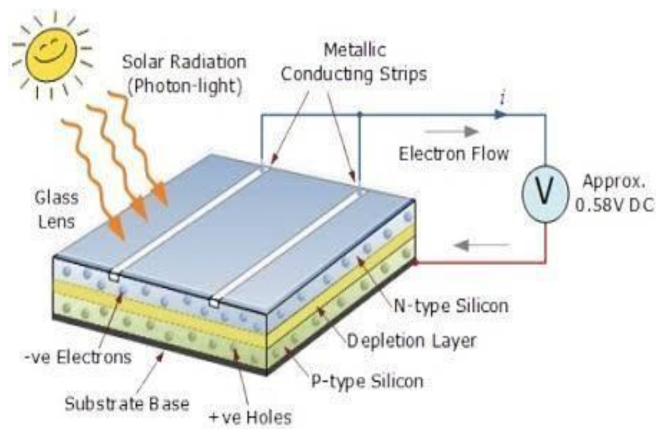

Figure 1.2: Working principle of solar cell

20% of the remaining irrigation units rely on electricity from the national grid, which places additional strain on the electricity infrastructure. The current diesel pumps play a significant role in depleting the country's fossil fuel reserves and contributing to overall greenhouse gas (GHG) emissions. The government's aim is to replace diesel pumps with solar pumps, which lower electricity usage and help reduce CO_2 emissions.

When a p-n junction is formed, electrons from the n-type material try to move into the p region, resulting in a layer with a negative charge. Similarly, holes from the p-type material seek to migrate toward the n region, creating a layer with a positive charge. Consequently, due to the electric field in the depletion zone, electrons and holes continue to move toward the n-type and p-type regions, respectively.

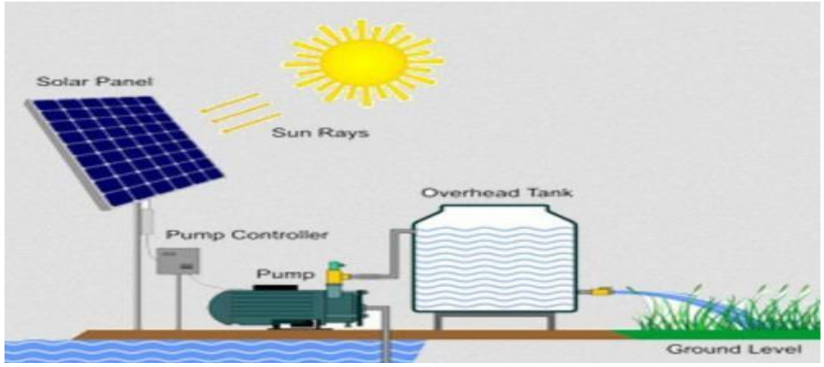

Figure1.3: Principle of solar irrigation system

Solar irrigation pumps utilize photovoltaic technology to transform sunlight into electricity, allowing the pump to move water from the source to the irrigation area. The motor converts the electrical energy produced by the photovoltaic array into mechanical energy, which is then transformed into hydraulic energy by the pump. The electric current generated by the solar panels from sunlight charges the batteries, which subsequently provide power to the pump whenever water is needed. The inclusion of batteries prolongs the pumping duration by offering a stable operating voltage to the pump's DC motor (Hahn, A, *et al.* 2020).

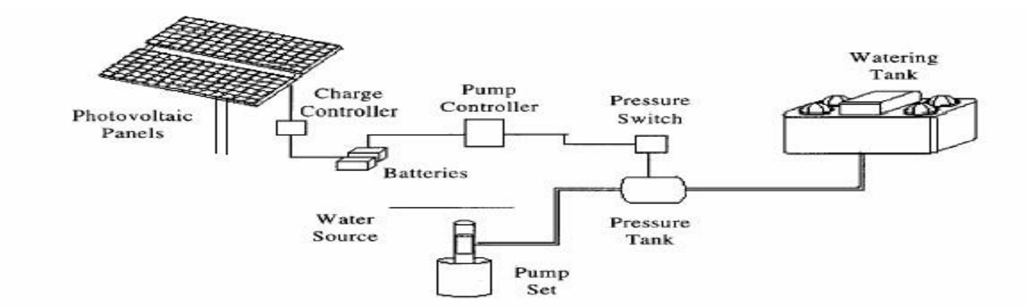

Figure1.4: Battery-coupled solar water pumping system

In a directly coupled pumping system, the electricity produced by the photovoltaic modules is directed straight to the pump, allowing it to convey water through a pipe to the intended location (Figure 1.5, Wenham *et al.* 2013). The amount of water pumped depends entirely on the sunlight that the photovoltaic panels receive and the type of pump utilized.

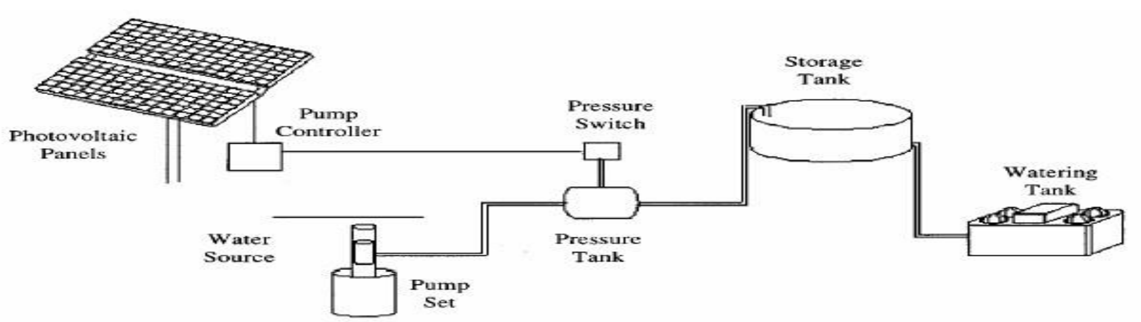

Figure 1.5: Direct-coupled solar water pumping system

An AC solar pump represents a modification of existing electric pumps through the retrofitting of specific components. Typically, electric pumps operate on AC power, while solar panel output is DC, requiring an additional inverter connection. Figure 1.6 shows the basic diagram of an AC solar pump.

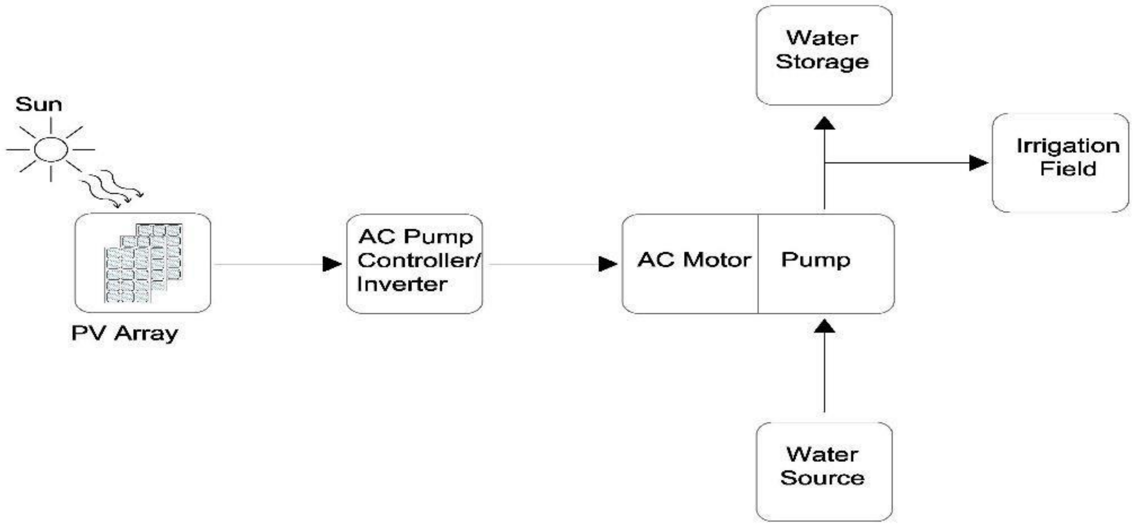

Figure1.6: Block diagram of AC solar water pump

Currently, DC solar pumps are commonly utilized globally. They operate on a straightforward mechanism. Illustration 1.7 displays the key connection diagram for a DC solar pump.

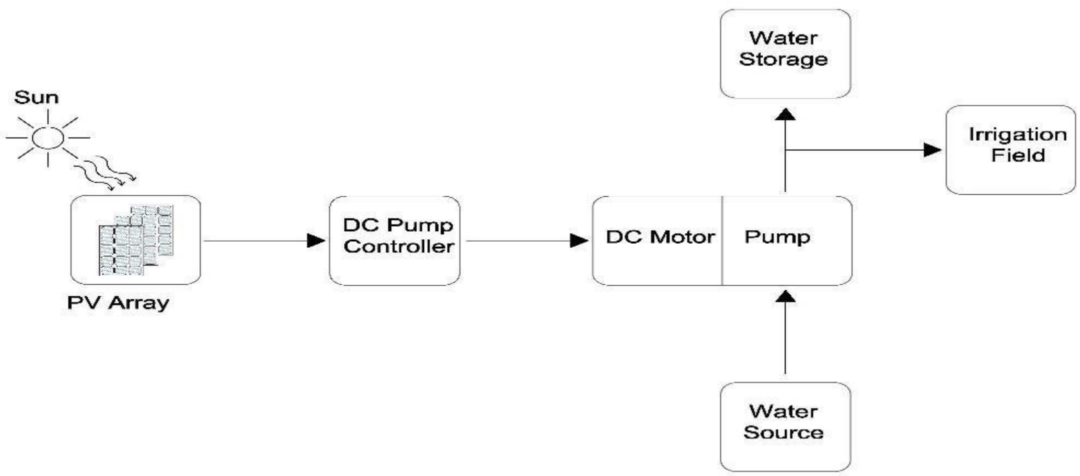

Figure1.7: Block diagram of DC solar water pump

2.0 Literature review

In previous years, important researches had been created by the researchers regarding solar irrigation system. Design of an efficient photovoltaic pump for irrigation is represented by Md. Mizanur Rahman Sarkar in March, 2011 (Sarker, 2011). Dr. Esther T. Ososanya, Dr. Sasan Haghani, Dr. Wagdy H. Mahmoud, and Dr. Samuel Lakeou presented a conference paper on the design and implementation of a solar-powered smart irrigation system in June 2015 (Haghani et al., 2015). S. Harishankar, R. Sathish Kumar, Sudharsan K.P., U. Vighnesh, and T. Viveknath made a solar-powered smart irrigation system in September 2015 (S.Harishankar *et al,* 2015).

An investigation of a grid connected solar powered water pumping system is done by Mohammed shadman Salam in February, 2016 (Mohammed shadman Salam, 2016). In August, 2017, optimization of a solar powered water pump for crop irrigation is done by Nahin Shafiq, Nafisa Navall, Sanjida Shoshi, Afnan Rudabe Rahman (Nahid Shafiq *et al*. 2017).

A report on grid integration of solar irrigation pumps is prepared by Shahriar Ahmed Chowdhury in November, 2018 (Shahriar Ahmed Chowdhury, 2018). From the previous exploration studies, there are various articles that study about solar pumps and grid integration of those. In this paper, we have discussed about the chance of grid integration of solar irrigation system in respect of Bangladesh. It will open a path of clean energy and reduction of carbon dioxide emission.

3.0 MATERIALS AND METHODS

This study seeks to evaluate the possibility of using the surplus electricity generated by solar irrigation systems for local consumption in rural Bangladesh. It will investigate how the excess energy produced by solar-powered irrigation can enhance energy accessibility, stimulate economic activities, and improve the overall quality of life in rural areas.

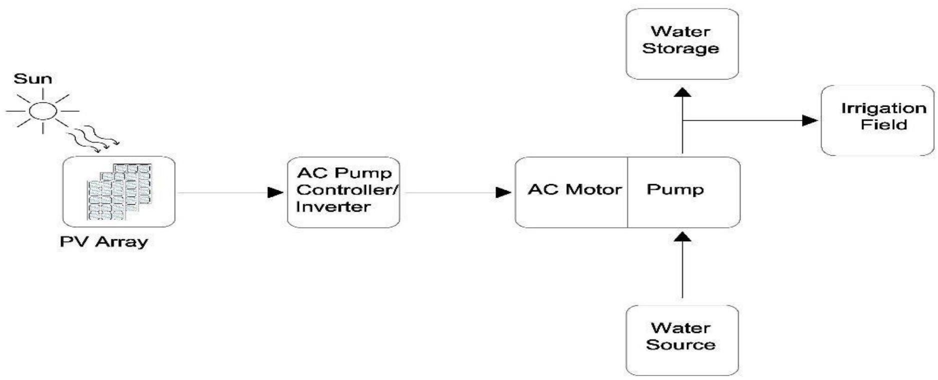

Figure 3.1: Block diagram of AC solar water pump

The research will utilize a mixed-methods strategy to gather both quantitative and qualitative information regarding the technical feasibility, economic practicality, and socio-environmental effects of these systems. This study aims to provide insights to policymakers, energy suppliers, and development organizations about the potential advantages of incorporating solar irrigation systems into local energy infrastructures, promoting increased energy access and rural advancement in Bangladesh.

Proposed Model:

The output voltage of this model is 230 volts (single phase) from the solar irrigation system using inverter. These 230 volts can be used for local use. Only simulation is shown here.

Table 3 (a): Model specification

Parameter	Value
No. of DC source	5
No. of MOSFET switch	20
Resistance	100 Ohm
Fundamental frequency	50 Hz
Switching frequency	2000 Hz
Output voltage	230 Volt

To simulate an inverter (11-level H-bridge) in MATLAB, it is essential to understand the operation of multilevel inverters, particularly in terms of handling different voltage levels across several H-bridge cells. This basic simulation framework demonstrates how to model and control an 11-level H-bridge inverter using MATLAB. Generally, an H-bridge inverter is employed to convert DC to AC, with each H-bridge capable of producing two voltage levels (positive and negative) alongside other H-bridges. A configuration for an 11-level inverter consists of 5 H-bridges. The construction of an 11-level inverter requires multiple H-bridge cells; specifically, 5 are necessary. This is because each additional H-bridge contributes two extra levels (both positive and negative), and the overall number of levels is defined by the formula 2n+1, where n represents the count of H-bridges. Carrier-based PWM is utilized to manage the H-bridge inverter switches to produce the desired output waveform. The frequency of the inverter output is denoted as f, while fs indicates the sampling frequency, which is vital for ensuring accuracy in waveform generation. In a multilevel inverter, the switching angles determine when the voltage levels transition. The inverter's output voltage is influenced by the phase angle and the corresponding level (ranging from 0 to 10), with each level linked to a specific DC voltage value that the inverter will toggle. The switching sequence of H-bridges can be optimized using PWM or SVM techniques to reduce harmonic distortion and improve inverter efficiency. The DC-link voltage for the inverter should be carefully chosen based on the desired output voltage. Sophisticated control strategies like Model Predictive Control (MPC) or PI controllers can be applied for a more precise inverter simulation.

The following MATLAB circuit diagram depicts a proposed model to implement the generated concept. An 11-level H-bridge inverter represents a type of multilevel inverter that generates various output voltage levels, helping to reduce harmonic distortion and improving the quality of the output waveform. This inverter consists of multiple H-bridge circuits, each capable of producing a specific voltage level, and when combined, they yield a range of voltage levels with enhanced control, resulting in a smoother and more efficient AC waveform compared to conventional 2-level inverters. To simulate the operation of an 11-level H-bridge inverter in MATLAB, you can make use of the Simulink environment, which supports the modeling of complex power electronics circuits (Ratterman W et al, 2007).

Key Aspects of the 11-Level H-Bridge Inverter from Simulation:

1. Multilevel Inverter Framework: An 11-level inverter can be constructed using five H-bridge cells. Each H-bridge produces three voltage levels: +V, 0, and -V.

2. Calculation of Output Voltage: The output voltage can be manipulated by toggling various combinations of H-bridge cells to achieve the desired voltage levels.

3. Control Strategy: For multilevel inverters, frequently utilized modulation methods comprise Carrier-based PWM (Pulse Width Modulation) or Space Vector Modulation (SVM).

Stand-alone systems function independently and are not linked to the utility grid. The most basic form of a stand-alone system is a direct-coupled system, where the PV array is directly connected to the load. This configuration is employed to power ventilation fans and water pumps. Many stand-alone systems incorporate batteries for energy storage, allowing operation during cloudy days or at night (Chris Callahan *et al*. 2013).

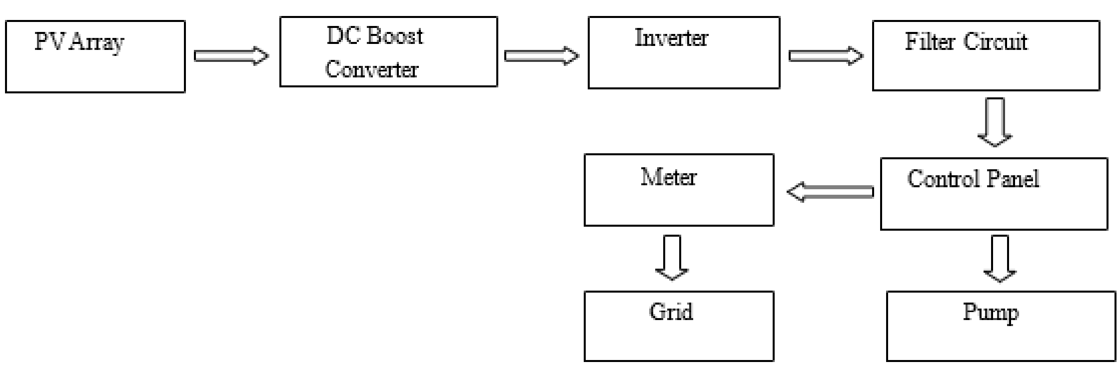

Figure 3.2: Grid connected system model

Grid-Connected Systems: These systems are linked to the grid and are designed to run in parallel with it. Since the PV array generates DC output, an inverter is necessary to transform the DC output into AC to conform to grid specifications (voltage, power, and frequency). When grid-connected systems are linked to the grid, they also cease operation when the grid fails. In times of power shortage, the system draws from the grid to function, and during excess power generation, it feeds the surplus back into the grid (Wenham et al., 2013). A grid-connected PV system is an electricity-generating solar energy system connected to the utility grid. The PV array produces DC electricity that passes through the boost converter, where it is amplified by a factor of m, and then goes through the inverter, which converts the DC into AC that must be compatible with the grid. If the generated electricity falls short of what is needed to power the load, the additional electricity is sourced from the grid.

The under-frequency and over-frequency thresholds and the associated inverter trip time are as follows:

a) When the utility frequency deviates from the nominal 50 Hz by ±2%;

b) Trip time must be within 0.20 s; and

c) This applies to both LV and MV interconnections.

Table 3 (b): Frequency disturbance (SEDRA, 2024)

Frequency at interconnection	Minimum Performance/ Action
f > 52 Hz	System will decide that whether it will be connected or disconnected
51.5 Hz < f ≤ 52 Hz	5 min
48 Hz ≤ f ≤ 51.5 Hz	Continuous operation
47.5 Hz ≤ f < 48 Hz	30 min
f < 47.5 Hz	sec

Voltage Disturbance:

a) The inverter must detect abnormal voltage conditions and respond according to the parameters outlined in table 4, as well as execute the recommended actions in table 4 (SEDRA, 2024).

b) Inverters are required to operate continuously during voltage fluctuations in the distribution network within ±10% of their nominal value.

c) Loss of mains is signified by a voltage drop of less than 50%.

d) Over-voltage and under-voltage detection must be implemented for all three phases.

Table 3(c): Voltage disturbance (SEDRA, 2024)

Voltage at interconnection	Maximum trip time (s)
V < 50%	0.10
50% ≤ V < 85%	2.00
85% ≤ V ≤ 110%	Continuous operation
110% < V < 135%	2.00
V ≥ 135%	0.05

Utility Interface Disconnect Switch:

The SIP system interconnection must include a utility interface disconnect switch that allows for the safe disconnection of the system output from the utility. This switch should be manual and capable of being locked. The load break disconnect switch must: - clearly indicate the position of the switch; - be easy to see and reach for maintenance and operational staff; and - offer visual confirmation of the switch contact position when it is in the open state. The integration of any remaining SIP systems with the grid or the installation of future grid-connected SIP systems must adhere to applicable national and international safety standards.

Operation: It is crucial for the safety of both operational personnel and the public that the utility and the SIP owner collaborate to establish and uphold the necessary isolation and grounding during any work or testing activities. Both the utility and the SIP owner are responsible for meeting the requirements set forth by statutory acts, regulations, sub-regulations, specific license conditions, standardized safety protocols, and the utility's dissemination code as well as that of the national grid operator. An Interconnection Operational Manual (IOM) must be developed by the SIP owner in partnership with the utility for systems exceeding 500 kW.

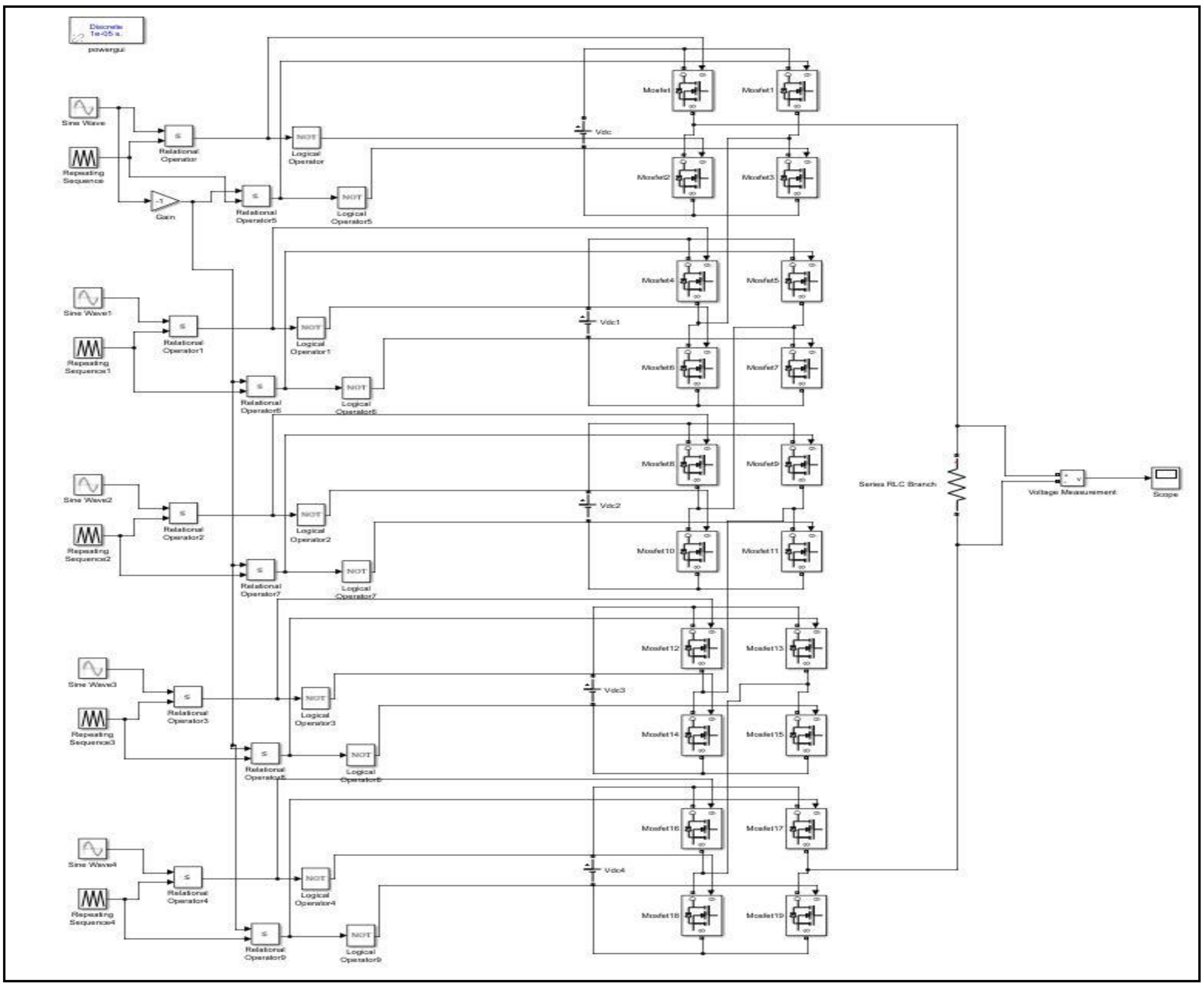

Figure3.3: Simulation model of 11 level H-bridge inverter using MATLAB

4.0 RESULT AND DISCUSSION

For resistive loads, each of the five H-bridge cells produces a voltage level of either +Vdc, 0, or -Vdc. The overall output voltage of the inverter is the cumulative voltage of all cells. A modulating signal (sine wave) is compared to a carrier signal (triangular wave) to generate the switching signals for each H-bridge cell. These switching signals dictate the state (positive, zero, or negative) of the H-bridge at any moment. The five H-bridges produce 11 unique voltage levels, which will fluctuate over time as the switching states of the H-bridges adjust according to PWM control.

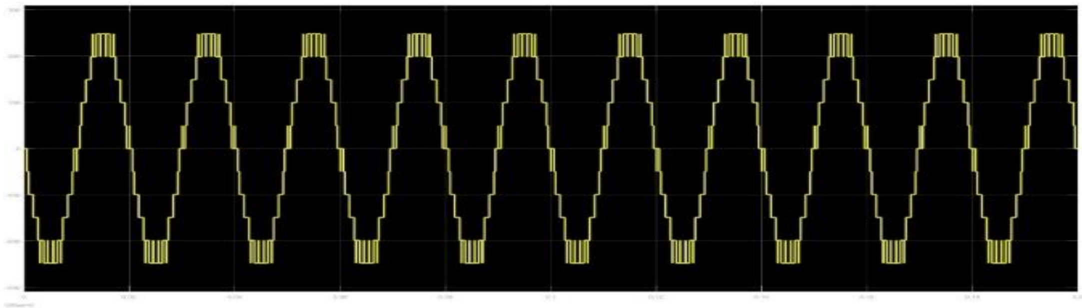

Figure 4.1: shows the output voltage waveforms. 11 level for the voltage is clearly shown. And the voltage is 230V.

The FFT function in MATLAB conducts the Fast Fourier Transform on the time-domain signal (V_out), converting it into the frequency domain. We analyze the frequency components of the output voltage by taking the magnitude of the FFT. The first harmonic represents the fundamental frequency (usually aligning with the desired 50 Hz or 60 Hz depending on your system's frequency), while harmonics (higher-order) correspond to multiples of the fundamental. The total harmonic distortion (THD) is calculated as the ratio of the square root of the sum of the squares of all harmonic components to the amplitude of the fundamental frequency.

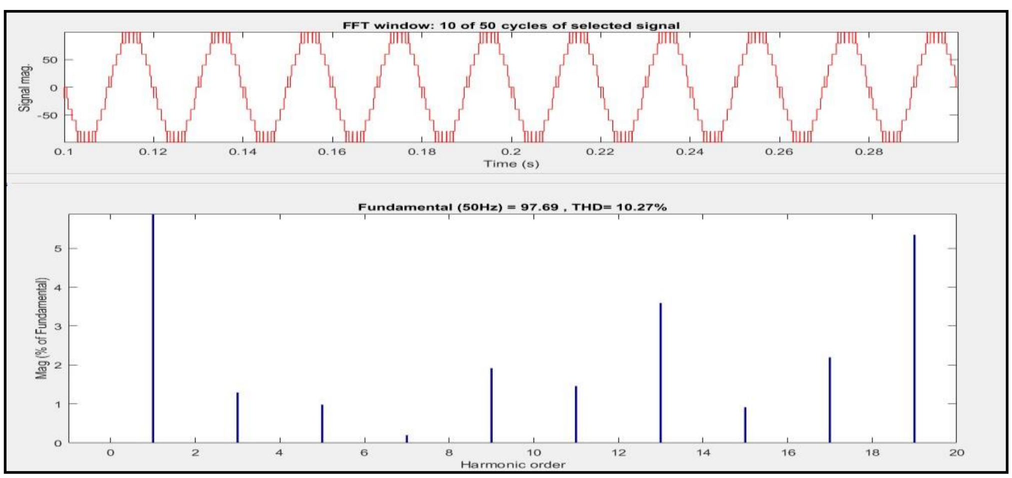

Figure 4.2: THD level of 11 level H-bridge inverter

To model an 11-level H-bridge inverter with an R-L load (a combination of resistance and inductance), adjustments to the simulation are necessary to consider the inductive aspect of the load. The presence of the inductive load creates a phase difference between voltage and current, which means that the current does not directly mirror the voltage as it would in a purely resistive scenario. We will simulate an 11-level H-bridge inverter that produces a multilevel voltage waveform while driving an R-L load, incorporating the essential voltage-current relationship pertinent to inductive loads. This inverter consists of five H-bridge cells. Each H-bridge can generate voltage levels of +V, 0, and -V. The load consists of a resistor RRR and an inductor LLL, forming a first-order RL circuit. Consequently, there will be a phase shift in the current flowing through the load relative to the applied voltage.

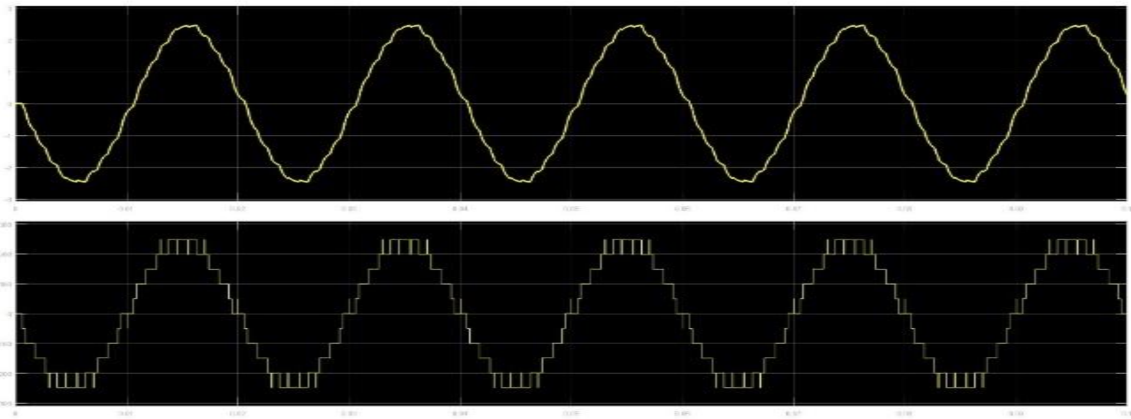

Figure 4.3: Current and voltage with R-L load

To determine the voltage total harmonic distortion (THD) in the context of an R-L load for an 11-level H-bridge inverter, we must adhere to the following steps. The key distinction when utilizing an R-L load as opposed to a resistive load is that the R-L load affects the current waveform; however, the voltage THD is still derived from the voltage waveform, not from the current. Here, we will concentrate on calculating the THD of the inverter's voltage output when it is connected to an R-L load, as well as simulating how the R-L load impacts the voltage waveform. The THD of the voltage is assessed by isolating the harmonic components of the voltage waveform using FFT (Fast Fourier Transform) and comparing them against the fundamental frequency.

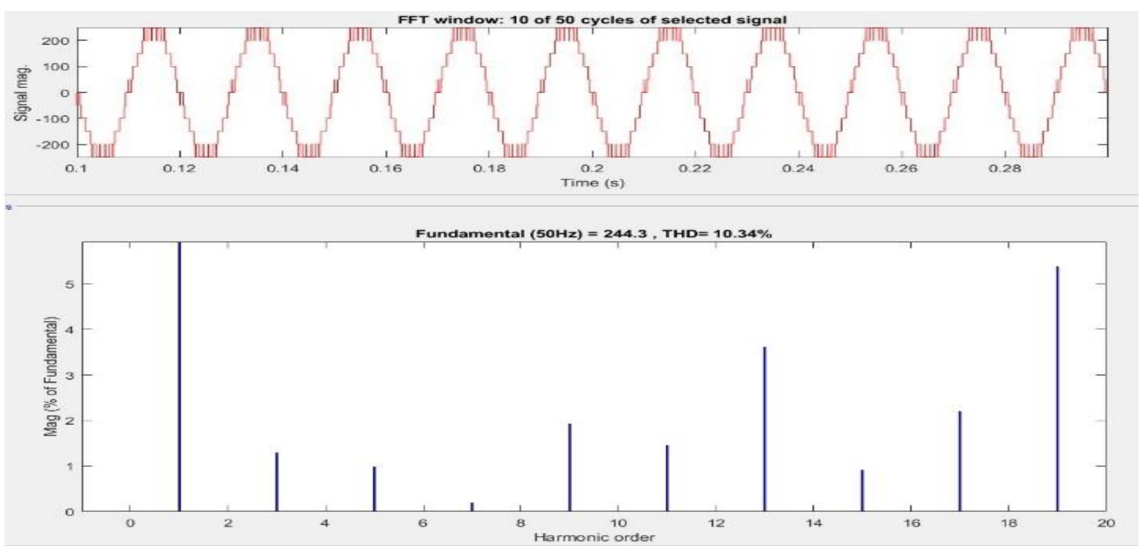

Figure 4.4: Voltage THD with R-L load

5.0 ACKNOWLEDGEMENT
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6.0 CONFLICT OF INTEREST: The authors declare no conflict of interest.

7.0 AUTHORS CONTRIBUTIONS
Research concept and Research design – Hasibur Rahman and Prapti Rani Roy, Materials and Data collection – Hasibur Rahman and Afia Ibnat Ruxy, Data analysis and Interpretation – Md. Moien Uddin and Hasibur Rahman,

Literature search and Writing article – Md. Moien Uddin, Critical review and Article editing – Hasibur Rahman, Final approval – All authors.

8.0 CONCLUSION

Utilizing surplus electricity from solar irrigation systems offers a promising approach to support rural electrification and sustainable energy access in Bangladesh. By channeling excess solar power to local communities, this model can improve energy availability, reduce dependence on fossil fuels, and promote rural economic development. However, for effective implementation, key enablers such as supportive regulatory policies, investment in grid infrastructure, and active participation from farmers and local users are essential. Coordinated efforts among government agencies, utilities, private sectors, and communities will be crucial to realizing the full benefits of surplus solar electricity and achieving national renewable energy targets.

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