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Design and Implementation of Adaptive Hybrid Controller for the Load and Power Management of Renewable Energy-based Systems

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ABSTRACT:
The development of renewable energy-based applications is nowadays a forced demand of society, for chasing the target set by the governments and the concerned organizations, to reduce or limit the carbon penetration in the environment. Researchers and scholars putting their sincere efforts toward the development of efficient and reliable renewable energy-based applications. The scope of this paper is to present a Renewable Energy based Irrigation System capable of maintaining the application-based power demand. The REBIS consists of a photovoltaic generator as the main power source supported by an energy storage system (battery). For this hybrid system, the development of a utility-based Adaptive Hybrid Control is proposed to regulate the charge/discharge cycle of the battery energy while maintaining the load demand simultaneously. A case study, supporting the time-bound irrigation, is considered to verify the viability and performance of the proposed system. This proposed system and controller are first simulated in MATLAB, and then implemented at the hardware level in the LabVIEW environment.

KEYWORDS: Battery Supported Photovoltaic System, Renewable Energy Based Irrigation System, Load Current Regulation, Adaptive Hybrid Control, Power Management.

1. INTRODUCTION

Continuous energy is desired to develop and propagate any modern human development sector, and green energy supply is a forced demand of this present era. The energy consumption rate has increased drastically in the last decade. This consumption is being mitigated, largely, by coal-linked power plants.

In the annual report issued by the Paris-based autonomous intergovernmental organization, The International Energy Agency (IEA) said that in 2021 CO_2 emissions from coal-fired power plants rose to a record 9.7 Gt, representing an increase of nearly 6.6% from the previous year (2020). In the Indian scenario, the coal-fired generation shows an increment of 13% above the previous year's levels [1]. To get on track with the Net Zero by 2050 Scenario, an annual average reduction of emissions from coal-fired power plants of around 8% is needed through to 2030 [1].

The primary sector, essentially the agriculture field reported a 5 % annual hike in the power demand, this is due to the optimum use of the agriculture machinery, mainly for irrigation purposes. The agriculture field needs 4 to 8 percent of the total energy demand [2].

In connection with the Indian farming scenario, the electricity consumption during 2020-21 by the agriculture sector was 17.67% with a 6.92%-year growth (the base year 2019) [1]. Apart from the electricity consumption (228172 GWh), it also includes 628 metric tonnes (738823.53 ltr.) of diesel used during the year 2021-22 mainly for irrigation support, out of which 84% diesel was used by the marginal farmers [1,3].

The purpose of this study is to design and control the Renewable Energy based Power Application (REbPA), capable of replacing the diesel pump commonly used for time-bound irrigation in the rice field.

Photovoltaic (PV) energy, wind energy systems (WES), hydrogen-based fuel cell (FC), and storage systems such as batteries and/or supercapacitors are some of the matured technology applications that are being used largely for decarbonized power generation. Compared to PV power generation, the performance of WES is highly intermittent, while FC power generation is not very economical, especially where low-cost energy is required, such as in agriculture.

However, the power generated by a PV system is dependent on the availability of sunny hours. For reliable operation, a PV system must be integrated with

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other alternate power sources such as Fuel Cell (FC) systems, ultra-capacitor banks, or Battery Energy Storage Systems (BESS), to ensure continuous generation during cloudy days or at night.

Integrating the PV generator with a battery storage system is economical and reliable in operation for low-cost power applications [4].

The proposed system consists of a photovoltaic generator as the main power source supported by a battery energy storage system. For this hybrid system, the development of a utility-based modified Proportional and integral (PI) controller (MoPIC) is considered to regulate the charge/discharge cycle of the battery energy while maintaining the load demand simultaneously.

2. LITERATURE REVIEW

The replacement of carbon-based power demand with renewable one is not always encouraged by the users, even if it is an economical initiative. The requirement-based approach is a good solution.

A rich of literature work and research have been reported related to renewable energy integration, control technique, and their applications in the irrigation &/or farm machinery fields.

In [5], authors proposed a bidirectional power flow control of a grid-interactive solar photovoltaic (PV)-fed water pumping system. In this technique, a brushless DC (BLDC) motor drive is used to run a water pump. However, in this inverter-based system, variation in system voltage is uncontrolled.

In, [6], authors reported various control strategies carried out in solar PV and wind energy-based water pumping systems. The systems are linked with the energy management strategies applied for renewable energy-fed water pumping systems assisted with third energy systems (battery bank, fuel cell, etc). This paper presents an application-based mechanism to ensure reliable operation but lacks the utmost utilization of an added third energy system.

A fuzzy pre-compensated hybrid proportional-integral (PI) controller-based permanent magnet synchronous motor (PMSM)-driven standalone solar water pumping system has been reported in [7]. This topology uses a solar photovoltaic (PV) array to convert solar power into electrical power. In this topology, maintaining the DC-link voltage is a major issue, simultaneously this system is not connected to alternate power backup to work without constraint during the cloudy season and/or at night.

In [8], a low-cost automated solar water pumping system has been proposed for irrigation in developing countries. This microcontroller-based system works on the initial feedback provided by the system. This system, however, fails to explain the monitoring of the voltage and current level during the load change.

For the efficient functioning of the renewable energy-based irrigation supporting system suitable controller design is of utmost importance.

In [9], the author presented a hybrid whale optimization–P&O (WOPO) algorithm to extract the maximum possible power from PV during both PSC and normal conditions. The author compares this result with genetic algorithm (GA), particle swarm optimization (PSO), and gray wolf optimization (GWO) for maximum power point tracking (MPPT) under PSC. Nevertheless, WOA only works when the entire system is working in the stable zone, i.e. variation in the irradiance is very slow.

A good amount of location-based crop-irrigation solutions has also been reported in the literature. For example, in [10], a site in the San Joaquin Valley, CA, USA has been selected to validate the water required for the reference crop. In this research article, a detailed study concerning the different development stages, and the requirement of different amounts of water for each stage is carried out carefully. However, this study is not concerned about the “time-bound irrigation” support.

The load matching to the renewable energy-based irrigation supporting system is a serious issue for the efficient functioning of the system, and it must be concerned for reliable operation.

The novelty of this research paper is that,

I. A Renewable Energy based Irrigation System (REBIS) is proposed, capable of maintaining the application-based power demand.
II. Suggested a modified Proportional & Integral (PI) controller (MoPIC), designed to work for the proposed REBIS, to regulate the charge/discharge cycle of the battery energy while maintaining the load demand simultaneously.
III. Bring forward a case study, regarding the time-bound irrigation support, to verify the viability and performance of the proposed system.
IV. The system is proposed to implement at the hardware level and to ensure that, the operation of the system is efficient and user-friendly, the controlling of the system in the LabVIEW environment is planned.

The paper is organized into seven sections: after a brief introduction in section one, section two covers the related field’s literature review. Section three describes the field study and the problem statement. Section four covers the system description with a short idea about the PV system, the battery energy storage system, the DC microgrid, and their controlling techniques, respectively. Section five deals with the software implementation and the hardware development followed by a discussion in section six. Section seven includes the conclusion of the project work and references.

3. CASE STUDY

A comprehensive field study was carried out with the local farmers' help in the southern area of Bihar, the state of India, where the rice crop is a major food grain, sown during the monsoon season (July to September).

Some parts of this southern zone are hilly, and according to the Köppen-Geiger climate classification, fall under the humid (Aw) & sub-humid zone (Cwg) with an annual rainfall of 90 to 120 cm with dry winter [11-12].

The following valuable information was received from the local farmers, which is as follows:

I. Rice crop needs approximately 4mm to 8mm of water per day, depending upon the temperature, and the land type (i.e. hilly or field area).

II. During the rice crop's reproductive time (i.e. July to September), it is desirable to maintain a 10cm water depth for at least 20 to 30 days in the rice field.

Accordingly, the water requirement per day depends upon the climate zone, sunshine, and temperature, which are summarized in Table 1.

Table 1 Water needs of the Rice-Crop [15].

Climate zone	**Tropical humid**		**Sub-humid**	
Sunshine	cloudy	sunny	cloudy	sunny
Mean daily temperature	15 to 25ºC	above 25ºC	15 to 25º C	above 25ºC
Water requirement per day	3 to 4 mm	5 to 6 mm	5 to 6 mm	7 to 8 mm
Total growing period	90 to 150 days		90 to 150 days	
Total water required during the entire season	450 to 600mm		600 to 700mm	

This entire area is prone to the regular electricity supply by the national grid, so apart from rainwater, farmers are dependent on other irrigation methods. A diesel pump is one of the options for dwelling the water from a deep bored well. Diesel pumps are costly and have an adverse environmental impact on the ecological system.

Thus, the only acceptable solution is, the development of a renewable energy-based irrigation system (REBIS), competent to produce an adequate amount of continuous power supply (day/night & all-weather) to overcome the diesel pump's irrigation cost and adverse environmental impact.

A renewable energy-based irrigation pumping system must be planned by the following steps: the first step is to calculate the amount of water required per day; the second step is to calculate total dynamic height; and finally, the third step is to design the suitable-capacity power system, that can fulfill the abovementioned requirement.

3.1 Water Balance Model of the Rice-crop

The water requirement of a rice crop is calculated using simple water balance models, which include different inflows and outflows of water in a rice field, as shown in Fig.2.

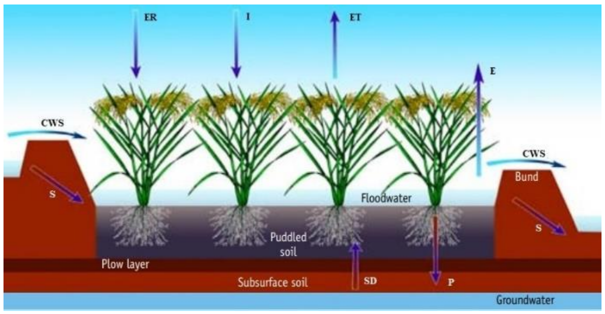


Fig. 1. Water balances (inflows and outflows) of a rice crop.

$$ER + I = ET + E + P + S + SD + CWS \qquad (1)$$

Where,
ER: Effective Rainfall,
I: Irrigation supply,
ET: Evapotranspiration loss,
E: Evaporation loss,
P: Deep percolation loss
S: Seepage loss,
SD: Surface Drainage or Run-off loss, and
CWS: Changed in Water Status.

From Equation 1, it is clear that if effective rainfall is not available, water balance solely depends on irrigation.

3.2 Calculation of the Total Dynamic Head (TDH)

The total dynamic head (TDH) can be calculated based on the mathematical model given in Equation 2. The TFL is total friction loss, that can be reduced by reducing the number of bends and the flow of the water supply [13].

$$TDH = A + B + TFL \qquad (2)$$

A and B are constants depending upon the pipe-bending and dia of the pump respectively.

Taking the value of constant A & B as unity, for a two-bend bore-well pipe, the TFL cannot exceed the value of 10. So, for open-well/pond irrigation, a TDH of up to 12m is acceptable.

3.3 Choice of the Irrigation-pump

There are different varieties of irrigation pumps available in the market. According to water pumping requirements, irrigation pumps are subdivided into three categories: submersible, surface, and floating water pumps [14].

A submersible pump draws the water from deep bore wells; a surface pump is placed outside the well and draws water from shallow wells, ponds, rivers, or tanks, while a floating pump is placed on the water plane and pumps water from the pool or tank at different heights. The most common pump is based on the centrifugal principle submersible pump, frequently used to irrigate large agricultural land [15-16].

To irrigate a one-hectare rice field, by simple calculation, one mega liter of water is required to maintain a 10 cm water depth.

Based on the water requirement calculation, and the evaluation of Equations 1 & 2, it can be suggested that the water pump with performance and technical specifications given in Table 2 will be sufficient, and economical, to fulfill the water demand within the hours. Therefore, an irrigation pump of 0.5HP capacity can be considered ideal for time-bound rice-field irrigation. Thus, the development of a renewable energy-based irrigation system (REBIS) producing a 0.37kW continuous power supply (day/night & all-weather), is needed, to overcome the diesel pump's irrigation cost and adverse environmental impact.

Table 2 Performance of a typical 0.5HP single-phase irrigation water pump [17].

Specifications	Descriptions
Performance	0.5 HP
Power rating	0.37kW
Full load current	2A
Rated voltage	210V
Rated frequency	50Hz
Rated speed	2740 rpm
Water head	12m
Discharge	1.7 Liter per sec (LPS)

4. SYSTEM DESCRIPTIONS

The proposed REBIS contains a photovoltaic generator and a battery system. The line diagram of this proposed system is shown in Fig. 2.

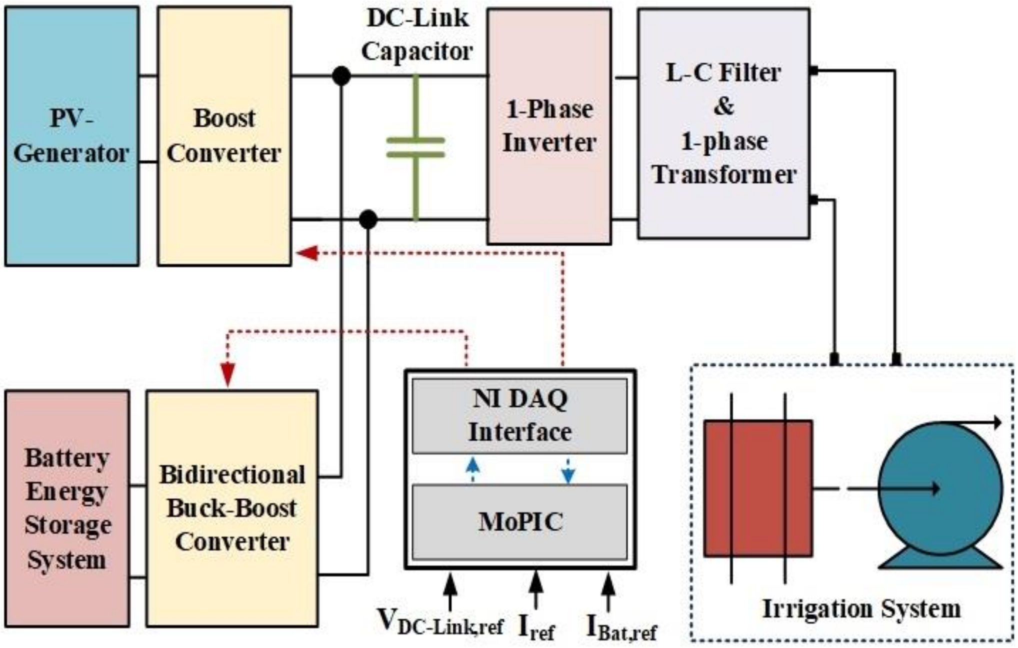


Fig. 2. Line Diagram of the Proposed REBIS.

As shown in Fig. 2, the converters associated with the PV generator and battery storage system are coupled at the DC link. The DC-link capacitor helps to stabilize the voltage fluctuation during the mode change.

In Fig. 2, the gain of MoPIC, i.e. $V_{DC\text{-}Link,ref}$, I_{ref}, and $I_{Bat,ref}$ are the reference values of the DC-link voltage, load current, and battery current respectively. LabVIEW-based National Instrument Data Acquisition System (NI DAQ Interface) communicates with MoPIC.

4.1 Modeling of the PV System

The electrical characteristics of a PV- system can be well illustrated with single and two-diode models. The single-diode model is popular and close to the PV-cell's actual behavior.

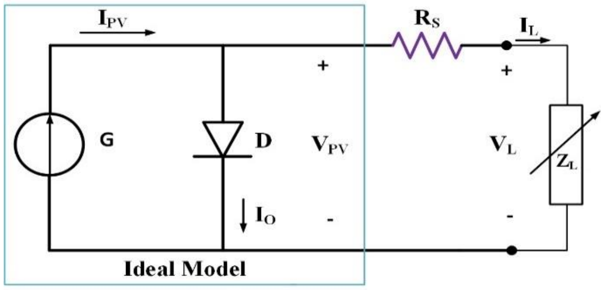


Fig. 3. Single Diode Model of the PV System.

Based on the single-diode model, as shown in Fig. 3, mathematical modeling of the PV system output voltage may be expressed as [18];

$$V_{PV} = \frac{N_S nkT}{q} \ln\left[\frac{I_{SC} - I_{PV} + N_P}{N_P I_0}\right] - \frac{N_S}{N_P} R_S I_{PV} \quad (3)$$

Where,
N_S: the number of series cells per string
n: ideality factor
k: Boltzmann's constant [J/deg.K]
T: PV cell temperature [deg.K]
q: electronic charge [C]
I_{SC}: short-circuit cell current [A]
I_{PV}: PV cell output current [A]
N_P: the number of parallel strings
I_0: PV cell reverse saturation current [A], and
R_S: series resistance of the PV cell [Ω].

4.2 Modeling of the Battery Energy Storage System

The working phenomena of a typical Li-ion battery can be represented with the help of a second-order RC model [19]. In the second-order order RC-model, an R-C network is added to the Thevenin model to represent the concentration polarization inside the battery, as shown in Fig. 4, where R_C & C_C is the concentration impedance and concentration capacitance, and R_P & C_P represents the polarization impedance and polarization capacitance respectively.

The second-order RC model better describes the internal ohmic polarization, electrochemical polarization, and concentration polarization, and the simulation results are closer to the actual operating characteristics of the battery.

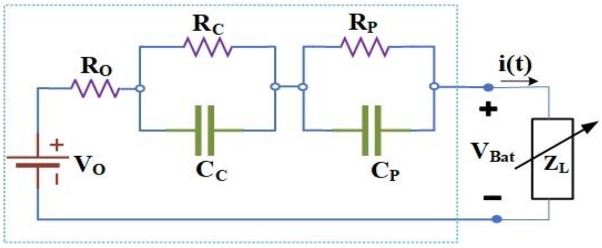


Fig. 4. R-C Model of a typical Li-ion Battery.

The battery voltage, V_{Batt}, is calculated by the two different equations for charging and discharging modes separately. The mathematical modeling of the battery characteristics has been accomplished based on Equations 3, 4 & 5 [20]

$$V_{Batt(charge)} = V_O - \frac{KQ_{max}}{0.1Q_{max} - q} i^* - \frac{KQ_{max}}{Q_{max} - q} it + A\exp(-Bq) \quad (4)$$

And,

$$V_{Batt(discharge)} = V_O - \frac{KQ_{max}}{Q_{max} - 1} i^* - \frac{KQ_{max}}{Q_{max}} t + A\exp(-Bq) \quad (5)$$

Where,
V_O: constant output voltage of the battery [V]
K: the polarization constant [$(Ah)^{-1}$].
Q_{max}: maximum capacity of the battery [Ah]
i^*: reference current [A]
i: measured (actual) current [A]
q: available capacity of the battery [Ah]
A: exponential voltage [V], and
B: exponential capacity [$(Ah)^{-1}$]

The state of the charge of the battery (SOC_{Batt}) is calculated as:

$$SOC_{Batt} = 100\left(1 - \frac{\int i(t)dt}{Q}\right) \quad (6)$$

Where,
i: instantaneous current [A], and
Q: charge stored [C].

4.3 DC Micro-grid

Solar PV systems and Battery systems act as DC sources and are connected to the DC-link capacitor through their respective converters. Voltage Source Converter (VSC) plays a vital role between the DC-link voltage and the AC loads. The capacitor's voltage is regulated using a DC-link voltage control loop that balances the capacitor's input and output powers.

In REBIS, the load frequency is maintained with the help of the PWM mechanism.

4.4 Power Converters (IGBT-based)

In this proposed system, the boost converter is connected to the PV generator, and the bidirectional buck/boost converter is associated with the battery stack for charging/discharging phenomena respectively. The converters' voltage and current are regulated with the help of the MoPIC controller.

The PV current, I_{PV}, is unregulated and responsible for governing the battery charge/discharge cycle. voltage, while the inner loop regulates the battery current. The system voltage (load voltage) is maintained, by maintaining the DC-Link voltage.

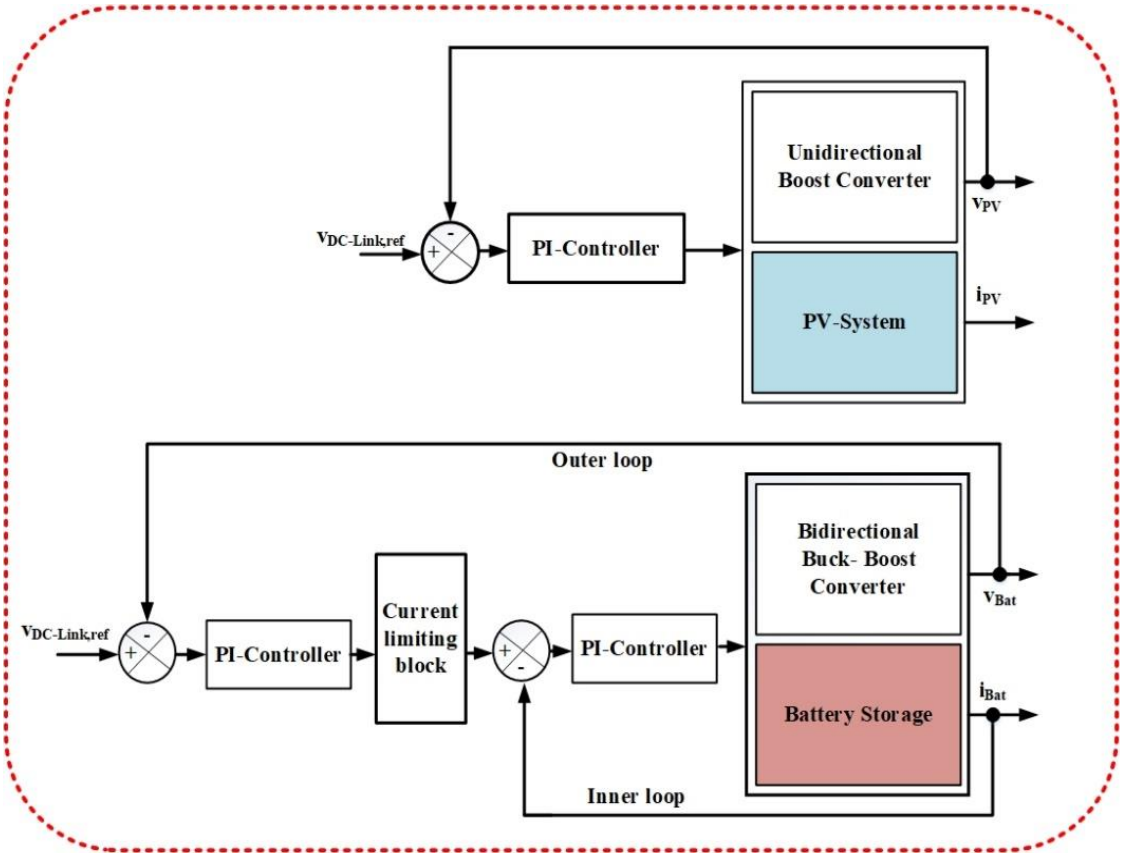


Fig. 5. MoPIC Controller.

4.5 Controller Design for PV-BESS Power Management.

A MoPIC controller is inherently a PI controller with utility-based modification. This controller is proposed for the power management of the system. This hybrid control approach regulates the load current by maintaining the load voltage at the desired level and ensuring the battery charging/discharging cycle is proper. The working of the proposed controller is shown in Fig. 5.

As shown in Fig. 5, the bidirectional buck-boost converter, associated with the battery storage system, has two loops. The outer loop maintains the battery by maintaining the DC-Link voltage. The unidirectional boost converter, associated with the PV system has a single loop linked to maintaining the PV voltage.

The working principle of the MoPIC controller, for power management and current regulation of REBIS governing the charge/discharge cycle of the battery system, is as;

I. When $I_{PV} \geq I_{Threshold}$

In this case, the battery system goes to charging mode. $I_{Threshold}$ is the threshold (reference) level of the current, to distinguish the system load current between low and high values.

II. When $I_{PV} < I_{Threshold}$

In this situation, the battery storage injects power into the system.

As shown in Fig. 5, the control actions of the MoPIC controller for regulating the PV voltage and current associated with a unidirectional boost converter can be presented mathematically as;

$$u_1 = Kp_1(I_{PV,ref} - I_{PV}) + Ki_1 \int (I_{PV,ref} - I_{PV})dt \qquad (7)$$

$$u_2 = Kp_2\left(V_{DC-Link,ref} - V_{DC-Link}\right) + Ki_2 \int \left(V_{DC-Link,ref} - D_{DC-Link}\right)dt \qquad (8)$$

$$u_3 = Kp_4(u_3^* - I_{PV}) + Ki_4 \int (u_3^* - I_{PV})dt \qquad (9)$$

Where,

$$u_3^* = Kp_3\left(V_{DC-Link,ref} - V_{PV}\right) + Ki_3 \int \left(V_{DC-Link,ref} - V_{PV}\right)dt$$

Similarly, for regulating the battery system voltage associated with the bidirectional buck boost;

$$u_7 = Kp_7\left(V_{Bat,ref} - V_{Bat}\right) + Ki_7 \int \left(V_{Bat,ref} - V_{Bat}\right)dt \qquad (10)$$

Where u_1 to u_7 are the controlled duty outputs.

5. IMPLEMENTATION

The local Solar irradiance data is given in Fig. 6. From Fig. 6 it can be observed that during the monsoon season (July to September) an average intensity of 560W/m^2 is available for utilization.

The proposed system is first simulated on MATLAB and then implemented on the hardware available in APS Lab, in the LabVIEW environment.

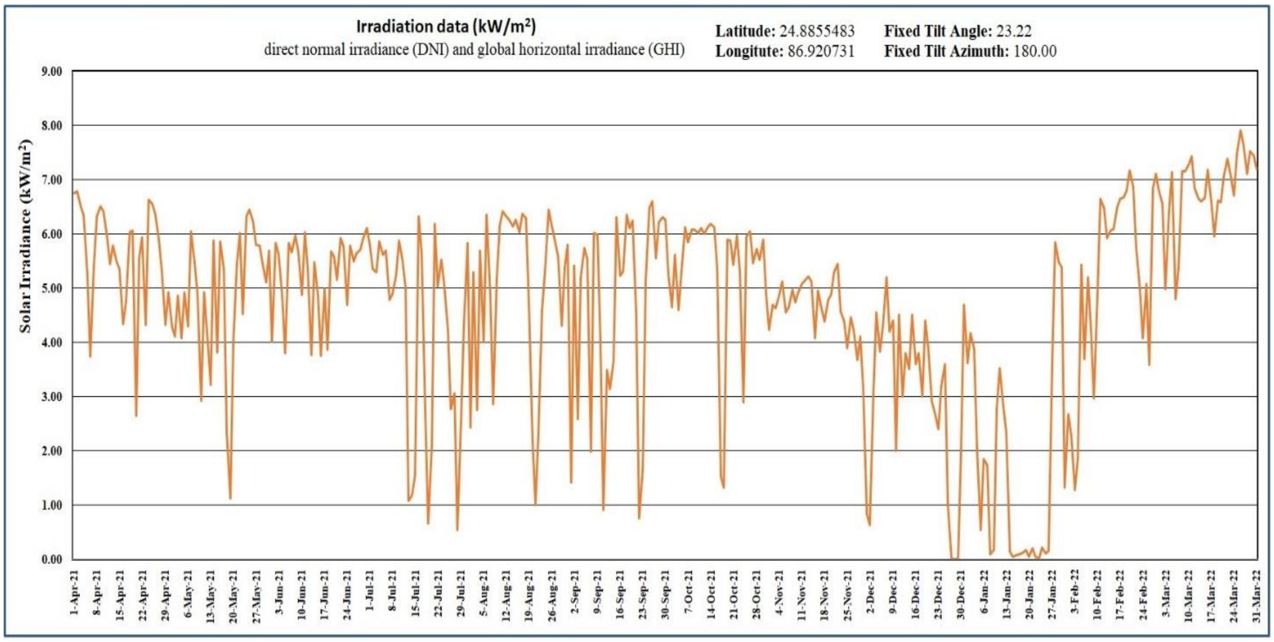


Fig. 6. Local Solar irradiance data [21].

Considering all the conditions, the performance of REBIS, designed as per the ratings of the components given in Table 3, will be sufficient i.e. it can deliver an adequate amount of power, day/night and in all weather, to ensure time-bound irrigation.

Along with this, most economic power dispatch will also be achieved to support low-cost irrigation.

5.1 MATLAB Implementation

MATLAB model, as shown in Fig. 7, is developed based on the mathematical modeling as given in equations 1 to 10, and the line diagram of the system (Fig. 2). Rating of the components in MATLAB is taken precisely, like that of the hardware setup (Table 3).

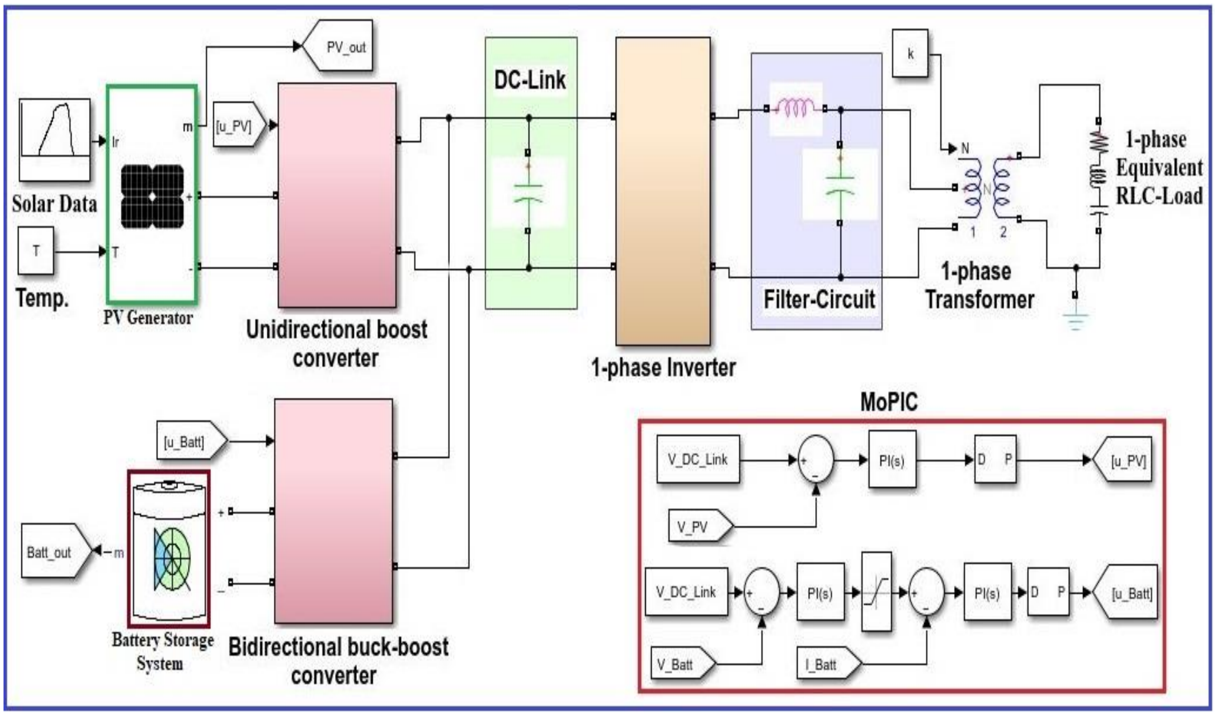


Fig. 7. MATLAB simulation block-set of the proposed system.

5.2 Hardware Implementation

Based on the MATLAB model, hardware implementation is carried out in the laboratory, as shown in Fig. 8.

The system is tested with real local solar irradiance data, at varying ambient temperatures. Controlling of the hardware components is carried out in the LabVIEW environment, as shown in Figs. 9 & 10.

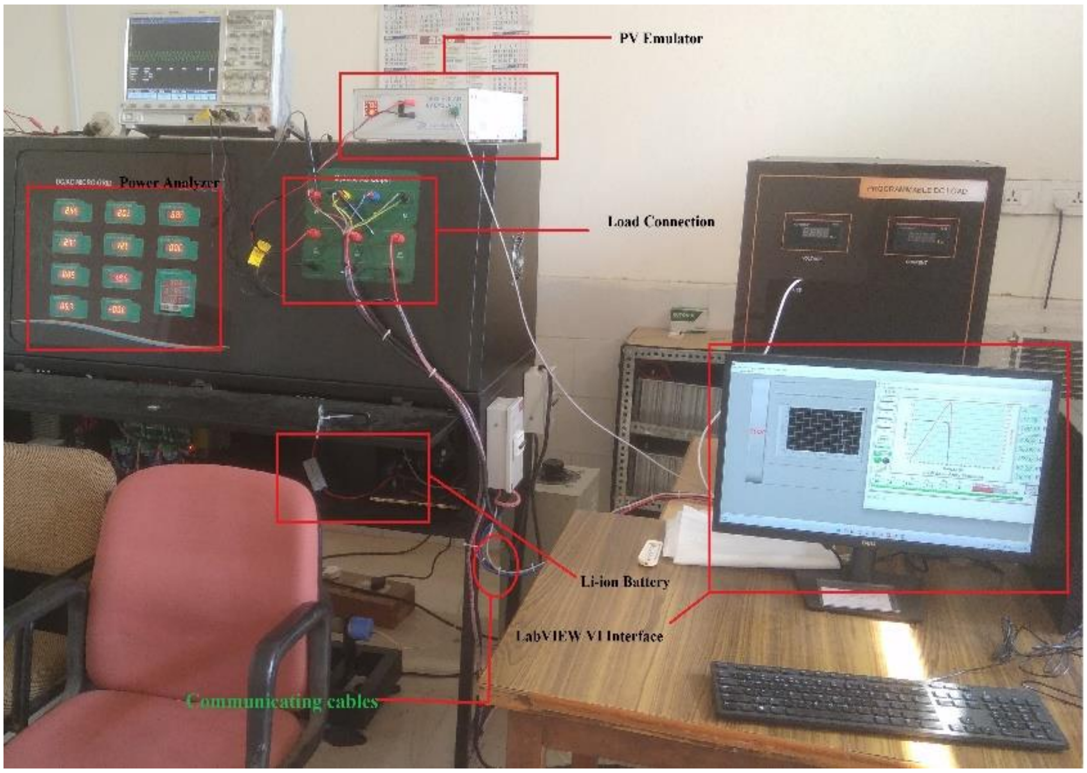


Fig. 8. Hardware setup, APS-Lab, NIT Kurukshetra, India.

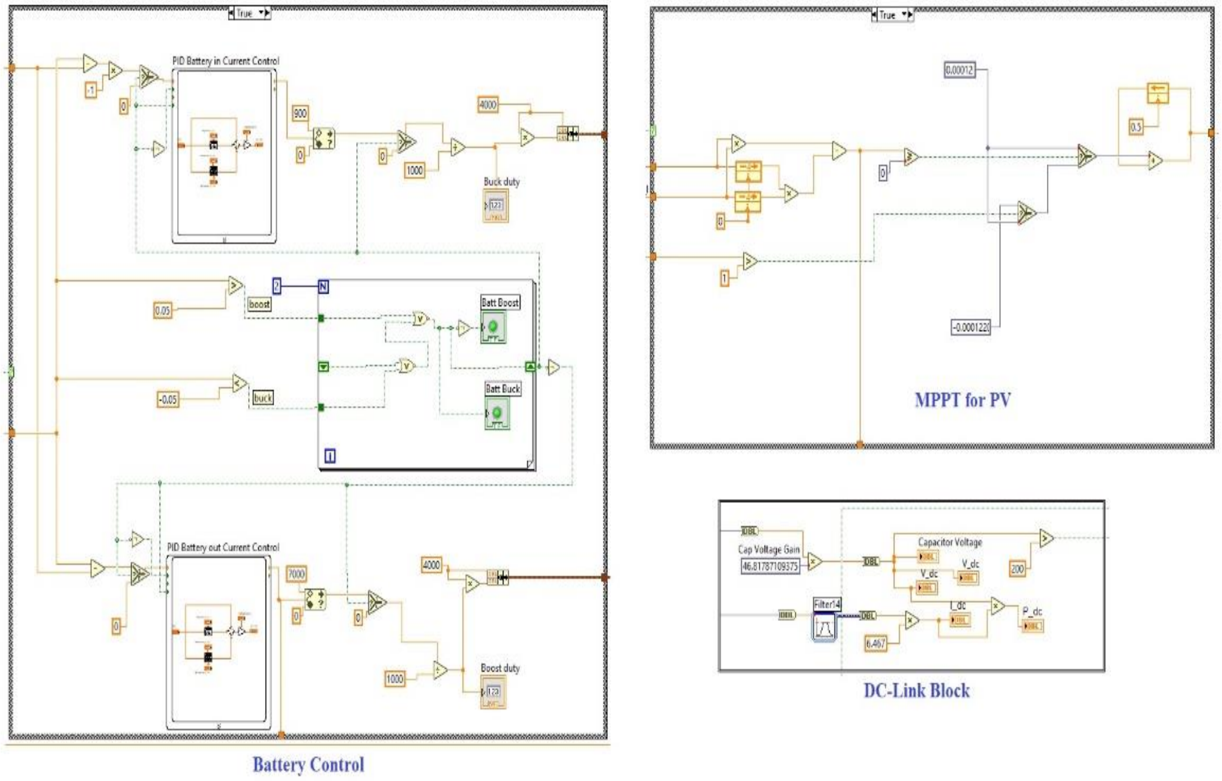
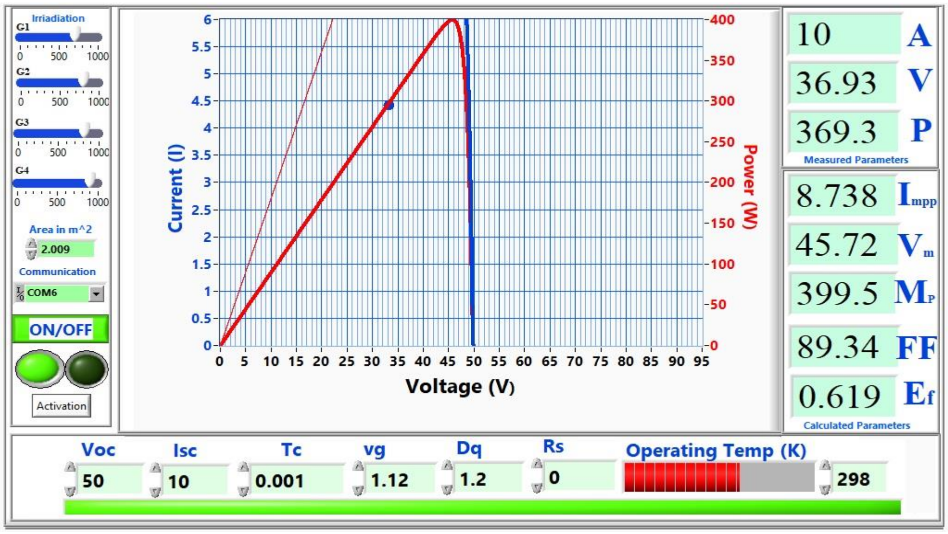


Fig. 9. Virtual Interface (VI) of the Hardware Setup in LabVIEW Platform.



Area in m^2: 2.009

Communication: COM6

Measured Parameters

10 A

36.93 V

369.3 P

Calculated Parameters

8.738 I_{mpp}

45.72 V_m

399.5 M_P

89.34 FF

0.619 E_f

Voc: 50

Isc: 10

Tc: 0.001

vg: 1.12

Dq: 1.2

Rs: 0

Operating Temp (K): 298

Fig. 10. Control panel of the PV generator in the LabVIEW environment.

The MoPIC is designed in LabVIEW with the help of GUI-supported mathematical modeling at the VI panel, as shown in Fig. 9. In the control panel, as shown in Fig. 10 the user controls the duty cycle of the converters by generating the gate pulse with the help of the FPGA-based microcontroller. The host PC communicates with the controller by LAN/Ethernet cable.

5.3 Results and Discussions

The MATLAB simulation and hardware results are shown in Figs. 11 to 14. The performance of the PV generator in MATLAB simulation, with varying insolation at different ambient temperatures, can be visualized in Fig. 11.

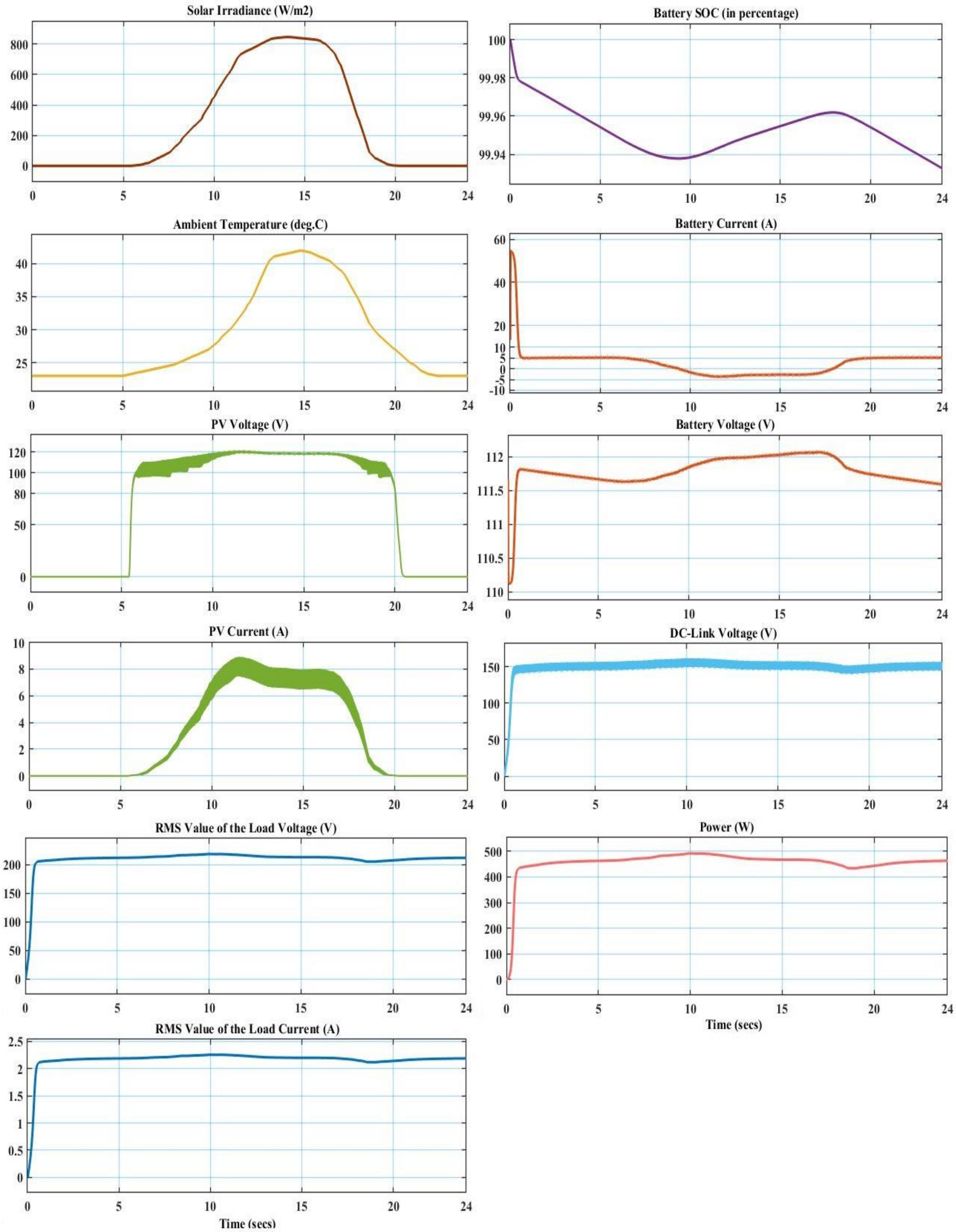
In Fig. 11, it can also be observed that, according to the performance of the PV generator, the battery storage system takes action accordingly. i.e, as per the power availability, the battery is operated in charging/discharging mode, for power storage or to mitigate the load demands as per the requirement. To verify the frequency limit, phase order, and the magnitude of the load current and the load voltage are plotted in Fig. 12.

The hardware results, as shown in Figs. 13 & 14, mimic the performance of the MATLAB simulation results.

The ratings of the components during the simulation and in hardware implementation are taken the same.

Table 3. Ratings of the components (Available in Advance Power System Lab, NIT Kurukshetra).

Field Programmable Gate Array (FPGA) Box		
1.	Control card technology	FPGA
2.	Pull-up card for inverter gate firing	8 PWM signals
Single-phase inverter		
1.	DC input voltage	150V
2.	Output voltage, & Current	112V, 5A
3.	Switching frequency	10kHz
LC filter for the single-phase inverter		
1.	Inductor	3mH, 10A
2.	Capacitor	10µF
Photovoltaic system specifications and ratings		
1.	Short-circuit current, & open-circuit voltage	20A, 50V
2.	Maximum output power	1kW
Boost converter for PV system		
1.	Input voltage, & current	50V, 20A
2.	Output voltage, & current	150V, 10A
3.	Switching frequency	20kHz
Battery Energy Storage System (BESS)		
1.	Battery type	Lead-acid
3.	Output voltage, & Capacity	96V, 26Ah
Bidirectional buck-boost converter for BESS		
1.	Voltage, & Current	105V, 10A
2.	Switching frequency	20kHz



Solar Irradiance (W/m2)

Battery SOC (in percentage)

Ambient Temperature (deg.C)

Battery Current (A)

PV Voltage (V)

Battery Voltage (V)

PV Current (A)

DC-Link Voltage (V)

RMS Value of the Load Voltage (V)

Power (W)

RMS Value of the Load Current (A)

Fig. 11. MATLAB Simulation Results: Performance of the PV and Battery System at different temperatures with varying solar irradiance.

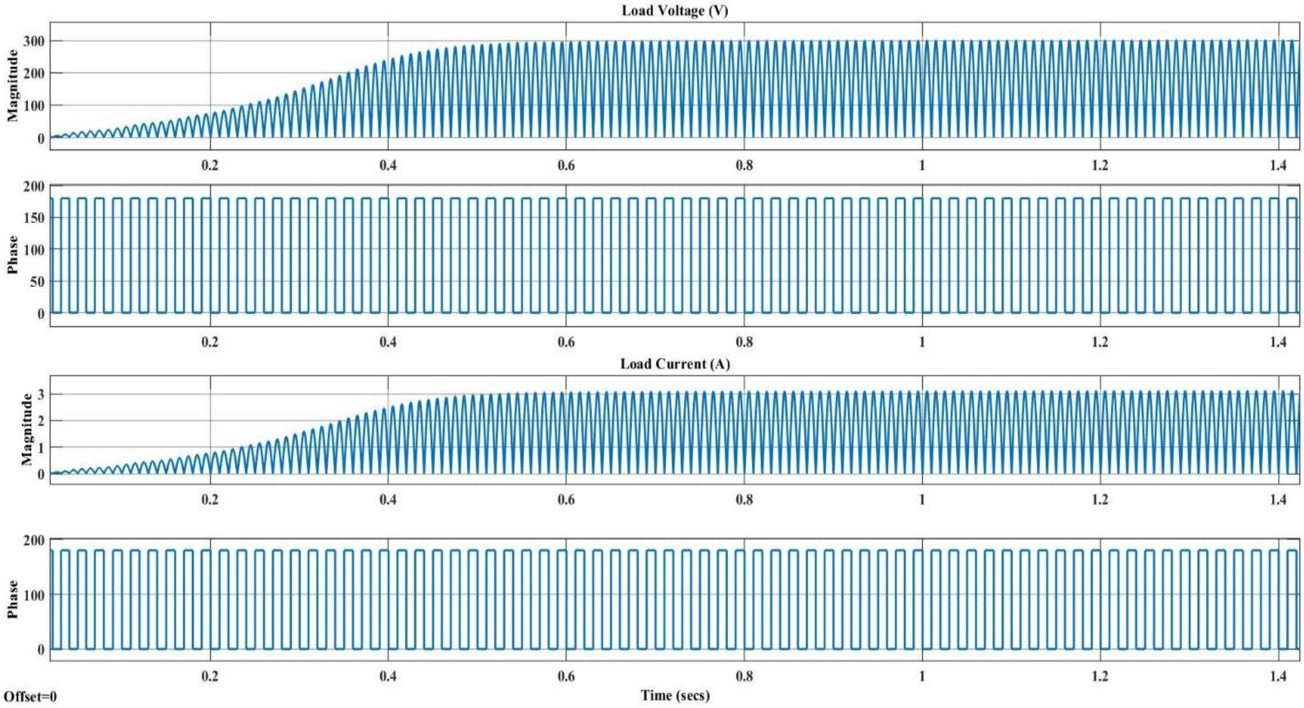


Fig. 12. MATLAB Simulation Results: Phase & Magnitude of the load voltage and current.

The simulation results, as shown in Figs. 9 & 10, reveals that the performance of the proposed system is satisfactory, and all the parameters are well regulated. Based on the performance of the MATLAB simulation the system is simulated at the hardware level, taking the rating of the components exactly as the same taken in the MATLAB.

The controlling of the REBIS is implemented in the LabVIEW environment. The MoPIC, developed for the controlling of REBIS, is designed in the LabVIEW platform. The hardware results, thus obtained, are shown in Figs. 11 & 12.

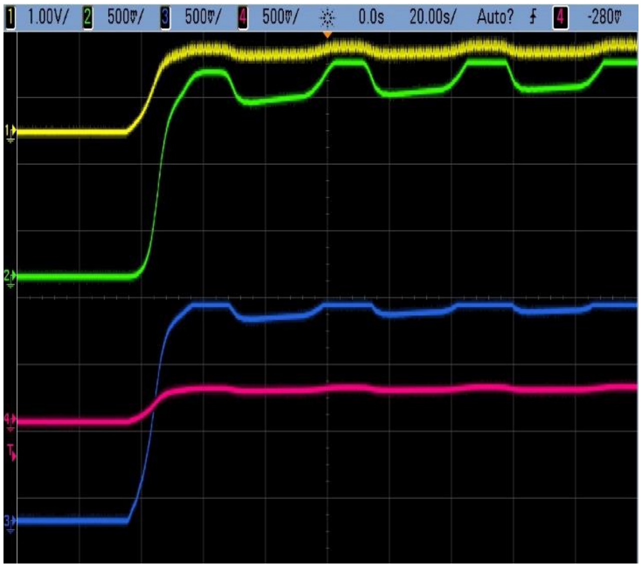


Fig. 13. Hardware Results: DC-Link Voltage, Power delivered by the system, RMS value of the voltage & Current.

Fig. 14. Hardware Results: Battery Current, Battery Voltage, PV Voltage & PV Current.

For the viability of the system performance, step response is obtained during the MATLAB simulation and hardware, as shown in Table 4.

Table 4. Step Response Characteristics..

Load-current during a bright day

	Simulation Results	Hardware Results
Rise Time	0.271	0.606
Settling Time	0.738	0.682
Overshoot	0.03	0.11
Undershoot	2.1	2.87
Peak	0.87	1

Load-current during a cloudy day

	Simulation Results	Hardware Results
Rise Time	0.181	0.263
Settling Time	0.98	1.76
Overshoot	1.935	2.233
Undershoot	0.88	1.13
Peak	1.94	2.76

Comparative analyses (quantitative and qualitative) of the MATLAB simulation and the hardware results, as shown in Fig. s 11, 12; 13 & 14, and in Table 4, provide the following important information:

i. Battery charging/discharging activity during the load change is fast and responsive and settles in within seconds.
ii. PV current and voltage are regulated and remain within the limits.
iii. The system is stable and fulfills the desired load demands.
iv. Frequency remains within the limit with ± 5% tolerance, which is acceptable.
v. MATLAB model of the system mimics the actual hardware setup's behavior, and it can be said that the desired system is capable of generating sufficient power to run the irrigation pump.

6. CONCLUSIONS

The REBIS designed and modeled for irrigation purposes is suitable not only for paddy fields but also for any crop. This hybrid system is working in standalone mode with controlling activity in the LabVIEW environment.

The dynamic behavior of the hybrid system is tested under varying solar radiation at different ambient temperatures, where the solar radiation and the temperature data are based on real-world records. The LabVIEW-based control strategy (MoPIC) for the developed system is efficient and exhibits excellent performance even for longer periods.

This system can be extended for the higher load demand by changing the rating of the components. During the off-irrigation period, this hybrid system can be used for farm and home illumination.

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