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RESEARCH ARTICLE

OPTIMAL ENERGY MANAGEMENT STRATEGY OF DC MICRO-GRID FOR MODERN AGRICULTURE: CASE OF MANDIANA PREFECTURE, REPUBLIC OF GUINEA

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Abstract

This study delineates a DC Micro-Grid (DCMG) system designed for the rapid distribution of electricity for residential and agricultural water utilization. The Solar Photovoltaic Panels (SPP) do not consistently gen erate uniform energy output, and the Battery Energy Storage Systems (BESS) should maintain an optimal charge level, avoiding both excessi ve depletion and overcharging. Moreover, residences must consistently maintain a power supply.We developed an Optimal Energy Manageme nt Strategy (OEMS) for our system, encompassing SPP, BESS, househ old loads, and a Pumping Water System (PWS) in rural regions. The research region, Mandiana, is situated in eastern Guinea,with approxim ate geographical coordinates of 10° 38' 0" North and 9° 18' 0" West. The system is engineered to fulfill daily energy requirements and was developed via MATLAB/Simulink. The simulation findings indicate that the suggested approach can provide water for irrigation, power for domestic use, and enable battery charging and discharging. It is applica ble to any system with a DC load.

Introduction:-

According to studies, Africa's population is anticipated to reach 2.4 billion by 2050, accounting for more than half of global population growth over this time period [1].Globally, the population is expected to reach 9 billion by 2050 and 11 billion by 2100, implying that food production must increase by 70% to fulfill demand [2], [3]. As a result, guaranteeing food security has become a top priority in agricultural research. According to the International Labour Organization (ILO), farming provides a living for at least half of the African population, with over 80% of farmers working on tiny plots of less than two hectares [4]. When agriculture declines, the impacts might extend beyond individual families. A decrease in crop production can disrupt markets and affect people across the country[4].

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Agriculture is the primary sector of activity for over 67% of the people in the Republic of Guinea (11º 00' N and 10º 00' W), employing 52% of the labor force [5], [6]. By 2022, his contribution to the country's GDP had risen to 27 percent. However, agricultural potential remains underutilized; food self-sufficiency is still uncertain, and Guinea continues to import a variety of agricultural products, including rice [6], [7]. Due to significant challenges, Guinean agriculture needs a true innovation that incorporates new concepts, methods, and technologies tailored to small-scale exploitation [8]. In this regard, using photovoltaic solar energy in conjunction with a water pumping system to provide a sustainable supply of water is an effective way to stimulate the agricultural sector [9].

This initiative falls under the broader framework of the country's energy policy, as outlined in the LettrePolitique de Developpement du SecteurEnergetique 2012 (LPDSE), which aims to reduce reliance on fossil fuels, increase electricity exports by utilizing Guinea's hydroelectric potential, promote renewable energy programs, and increase energy efficiency[10].Furthermore, in the case of Mandiana in Guinee, the predominant agricultural activity is the maize culture, which is vital to local food and the rural economy. This region has challenges such as climate change, limited access to electricity, and geographic constraints that affect food security and economic development. Mandiana is a very wet area that is part of the large basin of the Niger River. This location is a plus because the Niger and its tributaries (the Sankarani, the Fie, and the Milo) water the prefecture (figure 1). These rivers water huge, fertile plains that haven't been used yet. Using irrigation for farming could improve these plains. Therefore, the fact that these valleys of fresh water exist is a wonderful opportunity to restart indigenous agriculture with well-designed irrigation systems for food security and crop diversity in Mandiana[11].

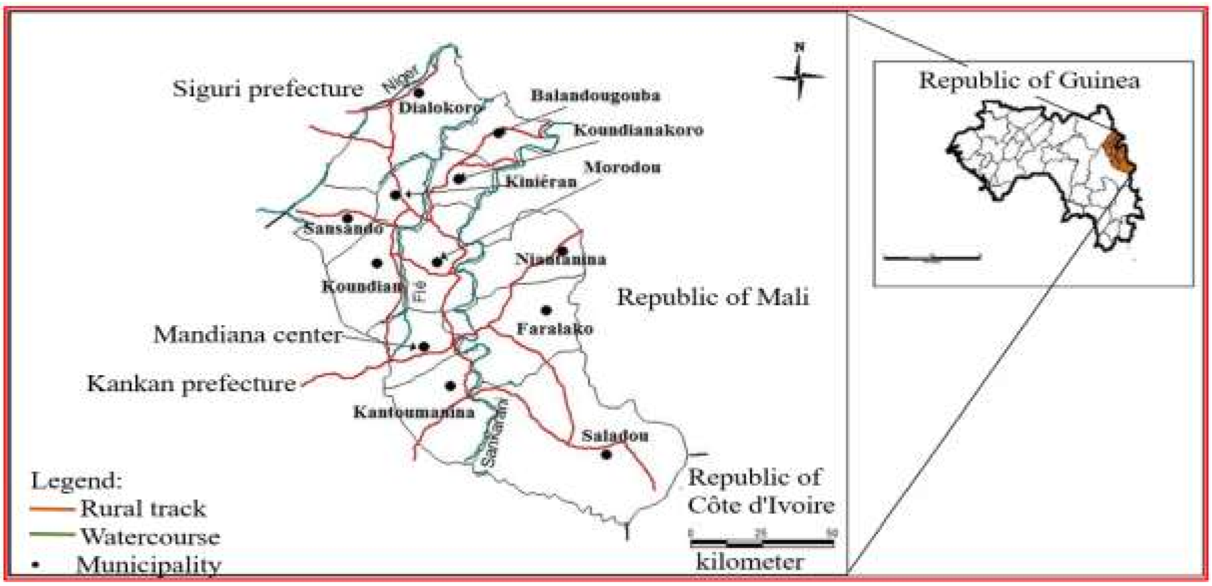


Figure 1 :Location of the study area

These benefits and inconveniences are what motivate us to keep working. In this context, we propose in this study the installation of an autonomous solar photovoltaic microgrid with storage that might help modernize irrigation, improve food security, and electrify rural areas. In fact, sustainable and productive agriculture requires a system-wide concept optimization for optimal water and energy usage, enabling more environmentally friendly and profitable production methods.Numerous methodologies for energy dispatching have been established in the literature. A Distributed System Operator (DSO) oversees energy management, as seen in[12]. The proposed method makes it possible to manage energy in the coordinated microgrid. A stochastic methodology for the dispatch of the battery energy storage system is proposed [13]. The simulation results show that the suggested method improves the dispatch policy and works better than the other techniques.

A lot of different management techniques are used and compared[14]. Because of this, the ANFIS is easier to read. To control the energy of a microgrid, an adaptive controller is used [15]. The authors assert that this technique effectively mitigates the issues of both overutilization and underutilization of an energy storage device (ESD). A new way to manage is created [16]. The goals of this strategy are to cut down on CO_2 emissions, employ more renewable energy sources, and lower the overall cost of the microgrid. An energy management model is used for a microgrid that has PV panels, a diesel generator, and a battery bank [17]. The system's performance is shown to be good after being simulated in MATLAB. Adefarati et al. [18] decreased the energy and operational costs of the diesel generator and battery storage system while maximizing the benefit/cost ratio. The methodology employed, as stated by the authors of [18], is applicable to both residential and commercial structures. W.C Clarke et al propose a two-layer economic model that reduces operational expenses and CO_2 emissions [19]. A multilayer supervisory system has been devised [20]. This technic accounts for the power requirement of the load.

A supervisory system is meant to optimize power output from the photovoltaic source, safeguard the battery against overcharging and deep discharging, and meet energy requirements. In [21], a novel long-term supervisory prediction system is developed to enhance the practicality and accuracy of SOAP (State Of Available Power) predictions for lithium-ion batteries in electric vehicles. A. Ndiaye et al. in [22] employed Adaptive Neuro-Fuzzy control for battery charging and discharging. A distinct supervision technic has been devised by M. Traore et al. in [23] utilizing an Arduino board to regulate the battery's charge and discharge processes and ensure its protection. This research formulates and executes an optimal energy management strategy for a Solar Photovoltaic Pumping (SPVP) system with storage, utilizing MATLAB. This approach seeks to concurrently secure the electricity supply for a residence and the irrigation system for a village in the Mandiana's prefecture. The innovation chiefly resides in the configuration of the examined direct current system and the specific aims: rural household electrification and irrigation water pumping in Mandiana prefecture.

Methodology:-

Modeling of the Studied System:-

The analyzed system (refer to figure 2) comprises a photovoltaic array, an energy storage battery system, a residence with a cumulative electrical load of 260.8 W, and an electric motor. The latter is utilized to irrigate one hectare of maize cultivation. Furthermore, two DC/DC converters are employed to enhance the output power and to increase or decrease the voltage of the photovoltaic system and the battery.

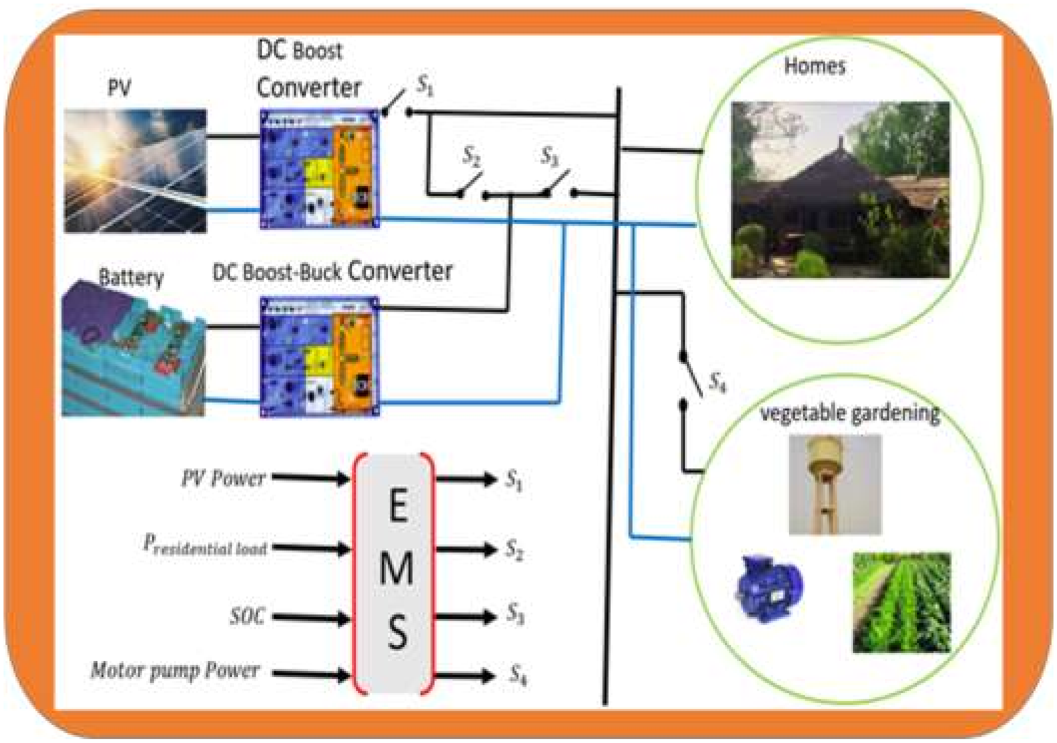


Figure 2: Studied system.

Modelling of PV panels:-

PV panels consist of PV cells that directly convert solar irradiance into electricity. Numerous mathematical models exist for photovoltaic cells. The five-parameter model is the most utilized (figure 2)[24],[25].

$$I = I_{ph} - I_0\left[e^{\frac{q(R_s.I+V)}{\mu.k.T}} - 1\right] - \frac{R_s.I+V}{R_{sh}} \quad (1)$$

With:

$$I_{ph} = I_{sc}\left[1+\frac{R_s}{R_{sh}}\right] + I_0\left[e^{\left(\frac{R_s.I_{sc}}{\mu V_t}\right)} - 1\right] \quad (2)$$

$$I_0 = \left[I_{sc} - \frac{V_{oc}}{R_{sh}}\right]e^{\left(-\frac{V_{oc}}{\mu V_t}\right)} \quad (3)$$

where:

I is the output current of PV cell, I_{ph} is the photo-current, I_O reverse saturation current of PN junction (A), k is Boltzmann's constant, I_{SC} is short-circuit current, $V_{CO}$is open circuit voltage, μ is ideality factor, V_t is thermal voltage, R_{sh} is shunt resistance, R_S is series resistance.

The power generated by the PV is calculated by using the equation (4) [26] and depends on the cell temperature and solar radiation.

$$P_{pv}(t) = P_{m,STC}.G.\frac{\alpha_{pv}(t)}{\alpha_{STC}}.10^{-3} \quad (4)$$

$P_{m,STC}$ and α_{STC} the peak power and the efficiency of the PV modules under standard conditions (G= 1000 W/m², air density 1.5, PV temperature = 25˚C), $\alpha_{PV}(t)$ efficiency of the PV at time t. The output power generated by the pv also depends on the static converter used [27]. In this work, we used the boost converter. So, the output power of the PV is calculated as follows:

$$P_{pv,out}(t) = P_{pv}(t).\alpha_{dc,con} \quad (5)$$

With $\alpha_{dc,con}$ is the boost converter efficiency.

-Modelling of battery:-

The battery is used to store energy to be used in case of energy shortage. In this paper, the lithium battery is used. The equivalent circuit of a battery is on figure 2.

The equations (6 & 7) give the charge and discharge voltages [28]:

Charging:

$$V_{bat} = E_0 - R.i - \gamma\left[\frac{Q.i^*}{it-0.1Q}\right] - \gamma\left[\frac{Q.i}{Q-it}\right] + \beta e^{-\mathbf{B}it} \quad (6)$$

Discharge:

$$V_{bat} = E_0 - R.i - \gamma\left[\frac{Q(it+i^*)}{Q-it}\right] + \beta e^{-\mathbf{B}it} \quad (7)$$

where:

E_O is battery constant voltage (V), R is battery internal resistance, i is battery current (A), i is negative during the charge and positive during the discharge of the battery, γ is polarisation constant (V =Ah), Q is battery capacitance (Ah), i^* is battery-filtered current (A), β is exponential zone amplitude (V), B is exponential zone time-constant inverse (Ah).

The state of charge of the battery is given equation (8).

$$SOC\ (\%) = 100.\left(1-\frac{Q}{C_{bat}}\right) \quad (8)$$

With: C_{bat} : battery capacity.

To protect the battery, the following contraintsare given to the SOC (see equation 9).

$$SOC_{min} < SOC(t) < SOC_{max} \quad (9)$$

Where:

SOC_{min} and SOC_{max} are spectively the minimum and maximum values of the SOC.

-Modelling of DC motor pump:-

Two categories of motors exist: AC and DC. These are typically utilized in low-power systems due to photovoltaic technology generating direct current. Moreover, for photovoltaic installations under 5 kW, direct current motors are typically employed [29]. The power required by the motor ($P_{motor,req}$) is determined using equation (10). The equivalent circuit is depicted in Figure 3.

$$P_{motor,req} = \frac{P_{HYD,req}}{\alpha_{motor}} \quad (10)$$

where:
α_{motor} isefficecny of pump,
$P_{HYD,req}$ is hydraulic power required by pump (seeequation11) :

$$P_{HYD,req} = \frac{H.g.\rho.Q_v}{36.10^5} \quad (11)$$

H : head size (m), which is sum of static head (m) and friction losses (m), g: acceleration due to gravity (9.81 m/s^2), ρ : water density in kg/m^3 Q_v : volume of water required (m^3/day).

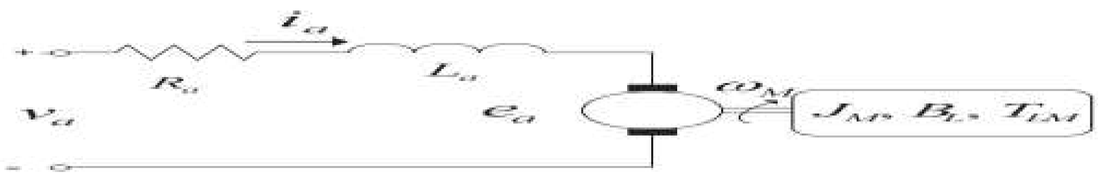


Figure 3: CC motor equivalent circuit

-Energy management Algorithm:-
This study employs an approach that initially involves the development of an algorithm (Figure 4) designed to consider energy distribution and function as a charge controller. This algorithm has four input parameters: photovoltaic (PV) power, residential load, pump power and the state of charge (SOC) of the battery. The outputs are linkedto switches S1, S2, S3 and S4 (refer to Figure 2). The switches S1, S2, S3 and S4 (see Figure 2) facilitate the energy transfer according to their state, open (0) or closed (1). When S1, S2, S3 or S4 is activated, it respectively allows for the exploitation of the photovoltaic field, the charging of the batteries via photovoltaics, the discharging of the batteries, and the operation of the pump. When a switch deactivated, the associated device is immediately disconnected from the system.

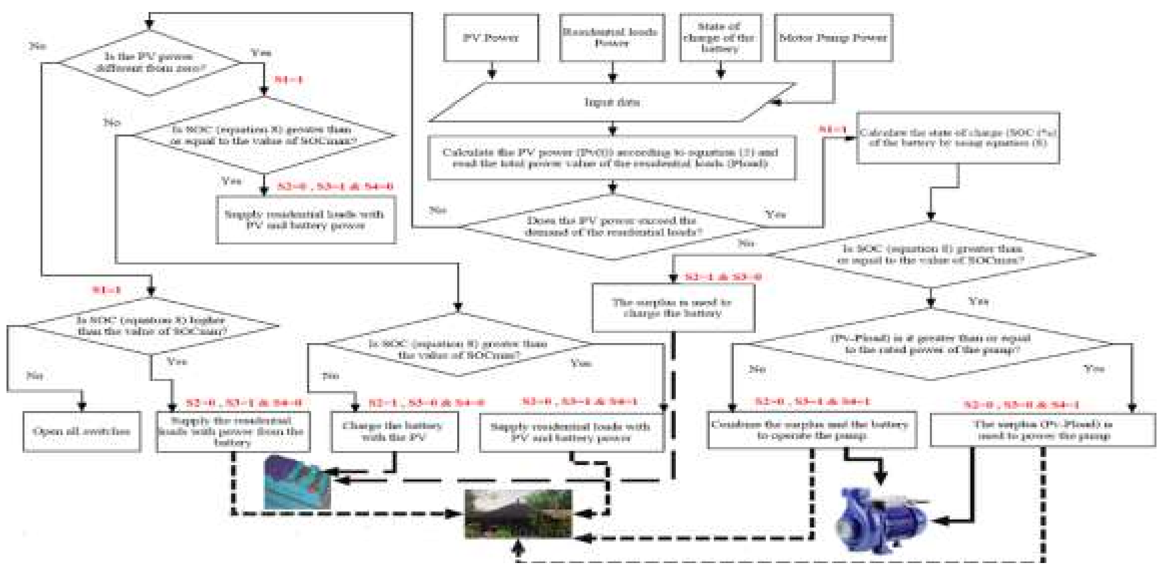


Figure 4: Flowchart of the system power management strategy.

The organizational diagram presented details the functioning of an energy management system intended for a photovoltaic (PV) installation with battery storage and for powering domestic loads, as well as a motor-pump. Photovoltaic energy is the main source, while batteries serve as the auxiliary source. The energy supply for domestic loads is a priority. The operation of the pump is contingent on an energy surplus coinciding with the full charge of the batteries.Here are the main steps of the operation:-If the PV power is greater than the energy demand of the residential loads, we verify the state of charge of the batteries.

If this parameter is greater than or equal to its maximum value, SOC_{max} , we supply the pump either with the excess production alone (S1 and S4 closed, S2 and S3 open) or by combining the PV and the battery (only S2 is open). If the state of charge of the batteries is not at its maximum, we charge them with the remaining production.-If the energy demand of the residential loads is higher than the PV power, we control the power and state of charge of the batteries. And if the latter are non-zero and greater than or equal to their maximum value (SOC_{max}), respectively, we power the residential loads with PV and batteries (S1 and S3 closed, S2 and S4 open). And if the batteries are not full, but SOC_{min} <SOC<SOC_{max} , we continue to power the residential loads. Otherwise, we recharge the batteries.-When the photovoltaic system is not generating electricity, whether it is during the night or on a particularly cloudy day, the batteries ensure the energy supply for the house. If the batteries are completely discharged, the house will be without electricity.

Results and Discussions:-

We recompiled the residential loads of the house to assess the energy demand. The pumping system necessitates a water supply of 3.39 m³/day, with a flow rate of 1.13 liters per hour and a total dynamic head (H) of 27.5 meters. So, equation 12 gives the hydraulic power:

$$P_{HYD\,,req} = \frac{27.5 * 9.8 * 100 * 1.13}{36.\,10^5} = 85\ \text{W} \quad (12)$$

This value leads us to choose the Aquatec SWP-4000 pump whose characteristics are shown in table 1.

Table 1: Pump characteristics

Type of pump	Voltage	Weight	Maximum head pressure (Ft)	Power rating	Maximum ampere	Maximum dynamic head	Efficiency
Permanent magnetDC	12-30 Vdc	4.5 kg	230	110 W	3.7 A	70 m	90 %

The power demand of the pump is known as follows (equation 13):

$$P_{motor\,,req} = \frac{85}{0.9} = 94\ \text{W} \quad (13)$$

In certain scientific studies, simulation software is necessary prior to experimentation. So, in this work, we used MATLAB/Simulink software to implement the system we studied (Figure 5). The simulation uses a total of 400 W for the PV array, 260.8 W for the house's electrical loads, and 110 W for the pump motor. The battery can hold 100Ah.

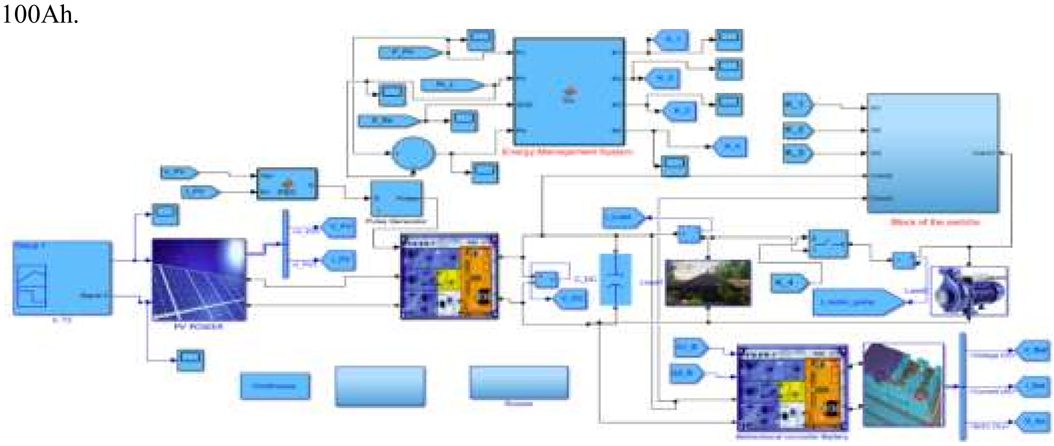


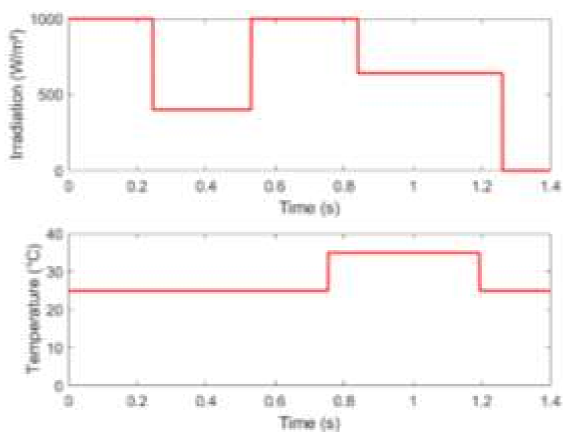
Figure 5: Studied system implemented under matlab/Simulink

Figures 6 to 12 display the simulation results. Figure 6 shows how much heat and radiation the PV system is getting. The photovoltaic system's power output is affected by these changes in the weather. Figure 7 displays the currents flowing through the motor pump and the electrical loads. When the pump motor isn't powered, the current is zero. Figure 8 displays the battery's current and voltage. This figure indicates that the charge current is negative while the discharge current is positive. The voltage remains relatively constant in comparison to the current in both stages.

Figure 9 illustrates the power consumption of the house load, the PPS generator, and the BSSE. This figure comprises five components, detailed below:

Components A and C charge the battery and transmit electricity from the photovoltaic system to the residence. The photovoltaic panels generate excess power over the required amount. Part E discusses the depletion of the battery's power and its distribution of energy to the residence. This component of the photovoltaic panels is no longer functioning. Figure 10 illustrates the battery's charge level, indicating that it depletes more rapidly than B&D components. The latter indicates the remaining charge in the battery and demonstrates that the system is both charging and draining it. The photovoltaic-battery system employs B&D components to supply electricity to the residence and recharge the battery.

The photovoltaic system is incapable of generating sufficient energy to satisfy the demand. This concept explains why the battery compensates for the deficit of energy. Figure 11 shows how strong the motor pump is and how much stronger the PV power is than the electrical loads in the house. The latter confirms that the pump is only working if the power difference exceeds 75 W, which is the pump's rated power. Figure 12 shows what the four switches are doing. The switch S1 stays closed until the panels run out of power, as shown in Figure 9, Switch S4 turns on the motor that pumps water. It only works when the PV system is down. The PV-battery system can provide enough power for the house and the motor, so S4 stays closed the rest of the time. The states of switches S2 and S3 show that you can't charge and discharge the battery at the same time. You can either charge it with S2 closed and S3 open, or you can discharge it with S3 closed and S2 open.



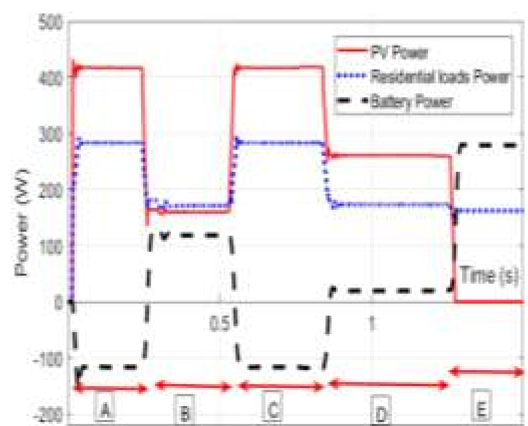


Figure 6: Temperature and Solar irradiation.Figure 9: PV generator, the battery and the house load power.

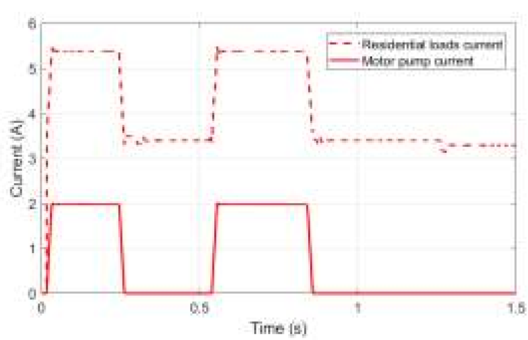
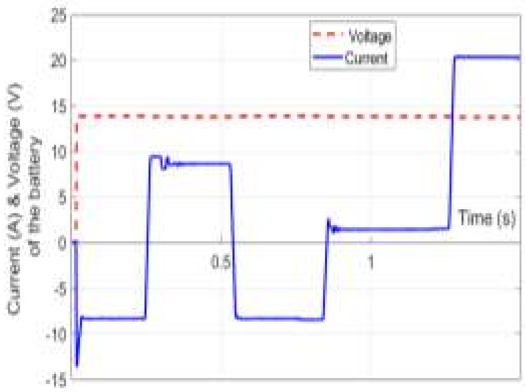


Table 4: Numerical values of the switch status

Switch	A	B	C	D	E
S1	1	1	1	1	0
S2	1	0	1	0	0
S3	0	1	0	1	1
S4	1	0	1	0	0

Figure 7: Currents of the loads and the motor pump.



8: Current and voltage of the battery.

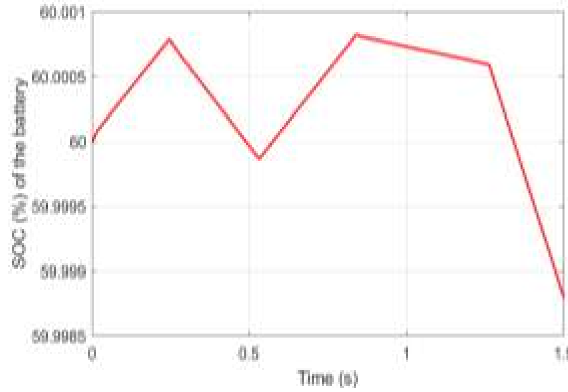
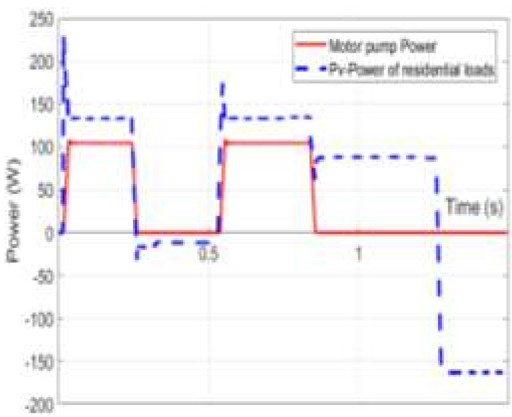


Figure 10: State of charge of the battery



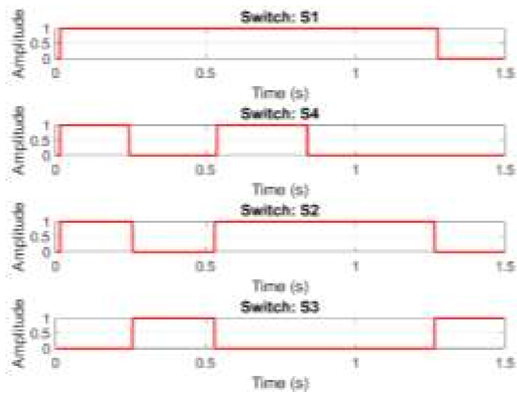


Figure 11: Motor pump difference between the

Figure 12: of the Switch's.

PV power and loads power in the house.

This system optimizes the use of photovoltaic power, battery charging, and the needs of residential loads and the motor-pump by keeping the battery within defined SOC ranges to avoid overcharging or deep discharging.

Conclusion:-

The purpose of this paper is to improve how a DC grid sends energy between a house's electrical charge, which is its residential load, and a motor pump for farming. A new algorithm for managing energy has been made and put into action in MATLAB-Simulink. The results demonstrated that the proposed technique guarantees energy distribution and irrigation. This means that all farmers can use the PV-Battery system and our proposed method to grow more crops while using less muscle energy. This will help them live a life as people in cities do.

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