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Research Paper

An Experimental Model to Manage Power Flows in Isolated Wind System for Irrigational Regime

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ABSTRACT

This paper focuses on irrigational problem in isolated systems with the participation of wind power generation. Power flows in whole system are regulated basing on analyzing the relation of ambient temperature and humidity, capacity of energy storage system (ESS). It means that the higher humidity is, the less water is; the higher temperature is, the more water must be used; the lower capacity is, the lower power consumption is. An experimental model is established to describe the irrigational problem and verify the ability to regulate power flows in a system including three water pumps, Raspberry Pi board controller, a 100-W wind generator and a battery. Python application was used to designed and programmable human-machine Interface (HMI) and control relays corresponding to different operating modes by using measurement or virtual information. Control command can be created by manual or automation basing on analyzing the relation of ambient temperature and humidity, capacity of ESS. Experimental results showed the ability to regulate power flows in whole system based on the evaluation of the irrigational demand and available energy supply. It also showed the good meaning in reality to improve life time for ESS and good capability to irrigational demand.

Keywords: Energy power flow, irrigational regime, isolated power grid, power-flow management, control power flow.

I. INTRODUCTION

Wind is a clean and inexhaustible energy in long time. Wind power generations can provide low price electricity and no environment pollution, harness everywhere in the world and decrease the human dependence on traditional energy sources that are increasingly depleted.

A simple model for locations with no electric grid such as islands or plateaus, wind power generation can be used to provide electricity directly for water pumps without controlling as represented in Fig.1 [1].

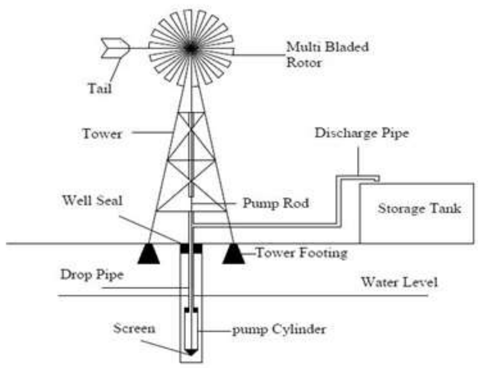


Fig. 1 A wind generator providing electricity directly for a water pump

The generator in Fig.1 supplies electricity to the water pump to fill a water storage tank up. The water from this tank can be used to irrigate at the time that we need and it is enough water. In this model, trees can provide water directly by using the difference of pressure or height water. It makes difficult to apply wind generations in agriculture field such as regulating water for indoor gardens.

Combining a wind generator type PMSG (Permanent Magnetic Synchronous Generator) with an ESS is a good solution for isolated grids in irrigational regime to overcome above disadvantage. This model can help to supply electricity directly to electric loads without having the grid. There are some researches such as determine optimal capacity of ESS [2], optimizing the operation of whole system with the participation of photovoltaic generations/diesel generator [3] or optimizing cost/benefit when considering economic factor [4]. Another approach is that manages energy and power flows considering economic factor with the participation of the power system [4-5]. Energy management and power-flow control problems in system having wind generations often have special issues corresponding to each application.

This paper will solve the irrigational regime for an indoor garden in agriculture field without having power system to replace traditional fuel generators using petrol or oil at water pumping locations. The demand of electric loads (water pumps) can be met by PMSGs and ESS. In almost systems, water pumps often controlled by workers to switch on/off. It means that these systems can't dismiss electric loads (water pumps and other devices) automatically when wind generators and ESS are not ability to provide power. However, automatic demand for irrigational regime is very high to help to reduce the number of operating labors. It must be adapted by using ambient temperature, humidity and rain sensors to regulate the optimal water quantity and irrigational time. It also helps to save cost for labors and investment. Moreover, this system can become more intelligence by forecasting the load demand and the environment conditions to ensure the backup of ESS, etc.

For above purposes, the next section of this paper will concern with structural system, wind characteristic and problem of power-flow management in system having the participation of wind generations. Section III will propose an experimental model and control strategy. This section will also present experimental results. The last section of this paper will show some achieved issues and contributions.

II. IRRIGATIVE WIND SYSTEM

A. Structural system

Due to unstable characteristic of wind generations, isolated wind power systems often have ESS to improve the ability to meet load demand. ESS can be charged at redundant times and discharged at deficient times. Furthermore, wind generator in these systems are often PMSG type because rated power implement is not high. The structural system of an experimental model for irrigational regime including three water pumps and LED indicators is depicted in Fig. 2 [2], [4-6].

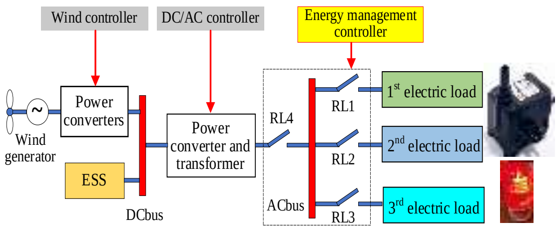


Fig. 1 Structural system

Each block in Fig.1 plays an individual task for the system, such as:

Power converters for wind generator type PMSG can be controlled AC/DC converter or a combination of non-controlled AC/DC converter and controlled DC/DC converter. The role of these converter is to harness maximum power from PMSG at any time and transfer this power to DCbus. Controllers for these converters are put in wind controller.

Power converter and transformer convert DC current to AC current with suitable frequency and magnify potential value to suitable amplitude for electric loads. It is controlled by DC/AC controller.

Power consumption of electric loads must be regulated by energy management controller. Control signal from this controller is sent from this controller to relays to change on/off states that help to change instantaneous power consumption.

B. Wind characteristic

Wind controller often designed to control PMSG that track maximum power point corresponding to each wind value based on four operating regions in Fig.3 [1]. It notes that the first and fourth regions can't generate any power; the third region generate rated power; the second region provides fluctuated power [1].

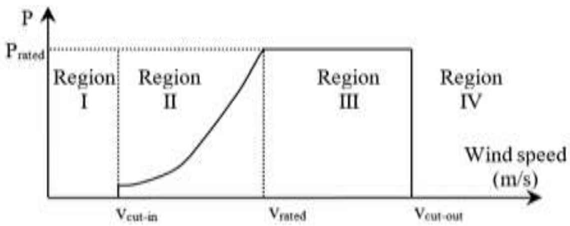


Fig. 3 Working region diagram for a typical PMSG

Power generating from a PMSG can be defined by equation (1) [1], [6]:

$$P_{PMSGins} = \begin{cases} 0 & when\ v < v_{cut-in}\ or\ v \geq v_{cut-out} \\ P_{rated}\left(\dfrac{v_{ins} - v_{cut-in}}{v_{rated} - v_{cut-in}}\right)^3 & when\ v_{cut-in} \leq v_{ins} \leq v_{rated} \\ P_{rated} & when\ v_{rated} \leq v_{ins} < v_{cut-out} \end{cases} \quad (1)$$

where: v_{cut-in} is start-up wind speed for generating power;

v_{rated} is rated wind speed for generating rated power;

$v_{cut-out}$ is cut-out wind speed to protect wind turbine;

P_{rated} is designed maximum power of wind generator;

v_{ins} is instantaneous wind speed (measured by anemometer).

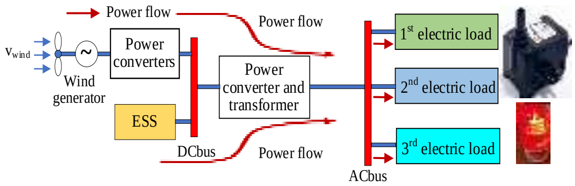
Wind controller in Fig.1 does tasks to harness maximum power by using a maximum power point tracker in case of the second wind speed region.

C. Power-flow management in irrigational system having the participation of wind generations

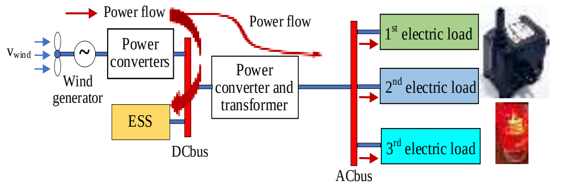
Irrigational systems operated in isolated structure grid often have some main characteristics as follows:

- Power from PMSG varied very strongly in real time due to the variation of wind speed and the response of controllers.
- Capacity of ESS always varies due to the load consumption and the work of PMSG. It must be limited in a range (from C_{min} to C_{max}=100%). Where, C_{min} is the minimum value for ESS to remain operating process at next working cycles that help to maintain life cycle time for ESS.
- The variation of environment conditions such as ambient temperature and humidity of soil.

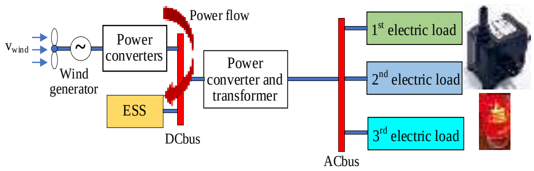
Power flows in whole system can be regulated by energy management controller, Raspberry Pi control center and relays. The distribution of power flows is represented in Fig. 4.



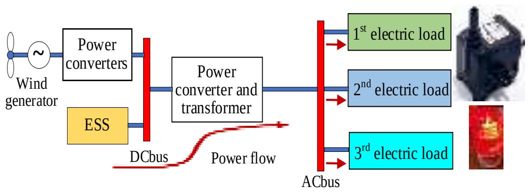
a. Both wind generator and ESS supply power for loads



b. Wind generator charges to ESS and supplies power for load at the same time



c. Wind generator only charges to ESS



d. Wind generator doesn't generate power, only ESS supplies power for load

Fig. 4 The distribution of power flows in whole system

The operation of water pumps in Fig.4 can be often executed by workers. It means that workers can switch on or off by themselves when they need. This research focuses on the ability to have intelligent operation for whole system using measured or virtual parameters. Control program can be operated by manual or automatic modes to have flexible ability in working process.

III. EXPERIMENTAL MODEL AND RESULTS

A. Experimental model

The model is designed to describe the structure of isolated grid that can supply enough power for loads in essential times. The main controller hardware is Raspberry Pi board that collects measured information from sensors, control information from workers to determine control signals for relays. The Raspberry Pi board has GPIOs (General Purpose Input Output) which can be used as control terminals. Corresponding to principal diagram in Fig.2, the complete connected wire diagram for whole system is depicted in Fig.5.

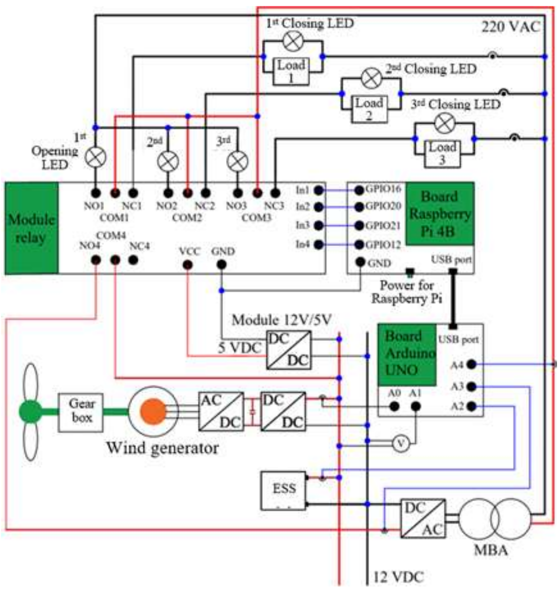


Fig. 5 Complete connected wire diagram for whole system

Main devices in the experimental model are depicted in Fig. 6.

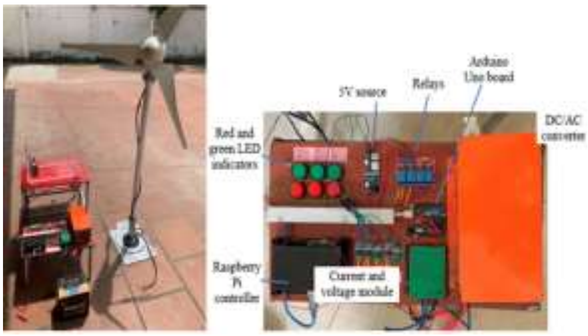


Fig. 6 Main devices in the experimental model

Control software is designed by Python application. The control program can supervise measured information from sensors to calculate the relations defined by control strategy to give control signal out. The programable factor in this problem can increase the ability to have irrigational automation in different operating conditions with the highest power supply capability. The control program switch loads on or off automatically corresponding to the relation of instantaneous values about capacity of ESS, ambient temperature, humidity.

B. Control strategy

To create control strategy for whole system, it must be noted some quantities as following:

C_{ins} is instantaneous capacity of ESS;

C_{avg} is average capacity of ESS;

H_{ins} is instantaneous ambient humidity;

T_{ins} is instantaneous ambient temperature;

T_{thres} is the threshold temperature that distinguish high and low temperature regions;

H_1, H_2 and H_3 are low, medium and high levels of ambient humidity.

Based on Fig. 4, we can define some operating states as following:

Case 1: Supply power for all loads.

Case 2: Supply power for two loads.

Case 3: Supply power for one load.

Case 4: No load is supplied power.

If wind power is redundant, power from PMSG can be charged to ESS automatically because output terminals of wind converters are connected directly to terminals of ESS. So, it is not interested in the power flows from PMSG or ESS to supply to loads in all cases. It can make easier for control program and more flexible for the operating process.

Control strategy is proposed to apply in above irrigational problem with three water pumps. It must be noted that it has only one main water pump which must be maintained to work in case of having irrigational demand and other water pumps can be cut off. Moreover, water pumps can be cut off completely if capacity of ESS falls off below C_{min} that is chosen 20%. Detailed strategy can be described as following:

- Case study 1: Values of ambient temperature and humidity, capacity of ESS are suitable (2), it must be operated all loads.

$$\begin{cases} T_{ins} \ge T_{thres} \\ H_{ins} < H_1 \\ C_{ins} \ge C_{avg} \end{cases} \quad (2)$$

- Case study 2: Values of ambient temperature and humidity, capacity of ESS are suitable (3), it must be operated two loads.

$$\begin{cases} T_{ins} \ge T_{thres} \\ H_1 \le H_{ins} \le H_2 \\ C_{ins} \ge C_{avg} \end{cases} or \begin{cases} T_{ins} \ge T_{thres} \\ H_{ins} \le H_1 \\ C_{\min} \le C_{ins} < C_{avg} \end{cases} or \begin{cases} T_{ins} < T_{thres} \\ H_1 \le H_{ins} \le H_2 \\ C_{ins} \ge C_{avg} \end{cases} \quad (3)$$

- Case study 3: Values of ambient temperature and humidity, capacity of ESS are suitable (4) or (5), it must be operated one load.

$$\begin{cases} T_{ins} \ge T_{thres} \\ H_2 \le H_{ins} \le H_3 \\ C_{ins} \ge C_{avg} \end{cases} or \begin{cases} T_{ins} \ge T_{thres} \\ H_{ins} \ge H_1 \\ C_{\min} < C_{ins} < C_{avg} \end{cases} \quad (4)$$

$$\begin{cases} T_{ins} < T_{thres} \\ H_2 \le H_{ins} \le H_3 \\ C_{avg} < C_{ins} \end{cases} or \begin{cases} T_{ins} < T_{thres} \\ H_1 \le H_{ins} \le H_2 \\ C_{\min} \le C_{ins} < C_{avg} \end{cases} \quad (5)$$

- Case study 4: Values of ambient temperature and humidity, capacity of ESS are suitable (6) or (7), it must be cut off all water pumps.

$$\begin{cases} T_{ins} \ge T_{thres} \\ H_{ins} > H_3 \\ C_{ins} \ge C_{\min} \end{cases} or \begin{cases} T_{ins} < T_{thres} \\ H_{ins} > H_3 \\ C_{ins} \ge C_{avg} \end{cases} \quad (6)$$

$$\begin{cases} T_{ins} < T_{thres} \\ H_{ins} > H_2 \\ C_{\min} < C_{ins} < C_{avg} \end{cases} or \; C_{ins} < C_{\min} \quad (7)$$

Control strategy for whole system is proposed in Fig.7. To control whole system, a HMI is designed as depicted in Fig.8.

Control modes can be chosen by Auto button. When worker presses this button, the button will be highlight and system will be operated in automatic mode. In automatic mode, relays will be controlled by measured or virtual information about temperature and humidity. When a load is operated (relay closes), text title corresponding to the operated load will be also highlight with red color.

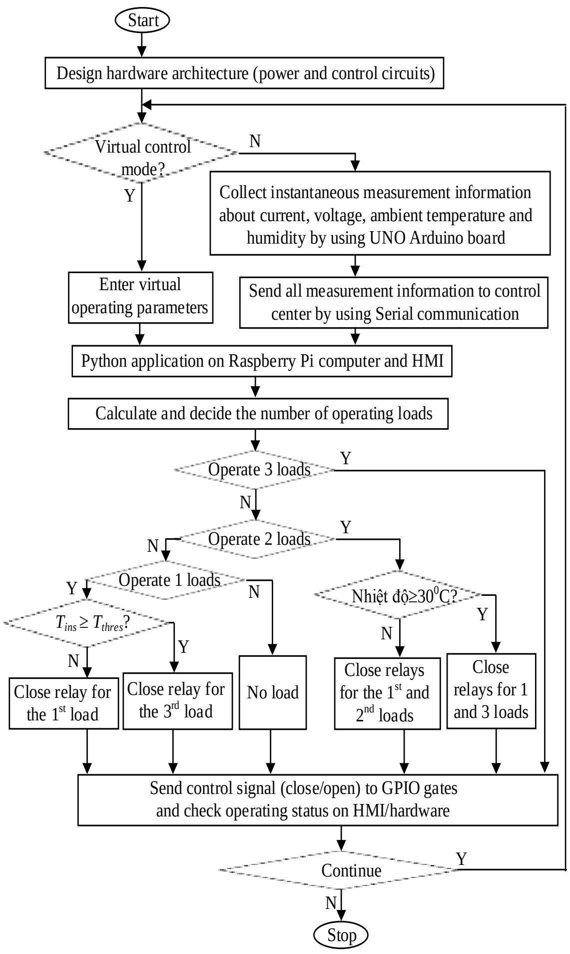


Fig. 7 Proposed control strategy

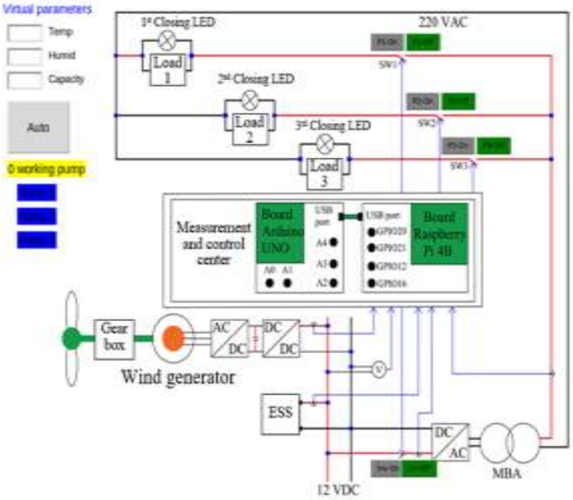


Fig. 8 HMI for control program

To have manual mode, the worker will press On/Off buttons for each relay. They will turn on or off power circuits of inverter (DC/AC converter and transformer in Fig.2) and water pumps after sending a control signal to a GPIO at low or high state.

C. Operating results on HMI

Experimental results were executed by following sample parameters: $T_{thres}=30^0C$; $H_1=40\%$; $H_2=60\%$; $H_3=80\%$; $C_{min}=20\%$; $C_{avg}=50\%$.

- Results in automatic mode on HMI for case 1 (operating all loads corresponding to $T_{ins} \geq T_{thres}; H \leq H_1; C_{ins} \geq C_{avg}$ as shown in Fig. 9.

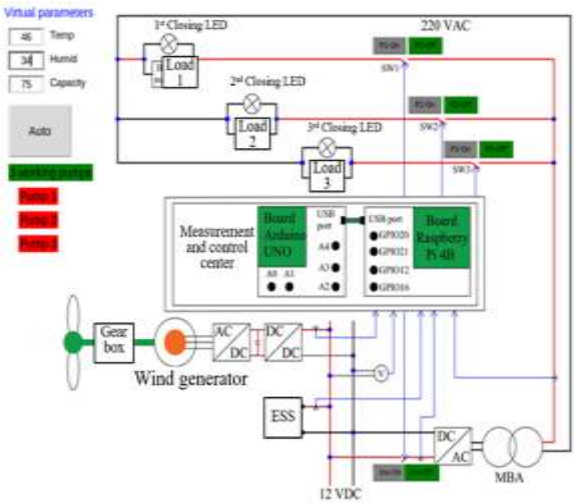


Fig. 9 Automatic mode on HMI for closing all loads

- Results in automatic mode on HMI for case 2 (operating two loads corresponding to $T_{ins} \geq T_{thres}; H_1 \leq H \leq H_2; C_{ins} \geq C_{avg}$ as shown in Fig. 10.

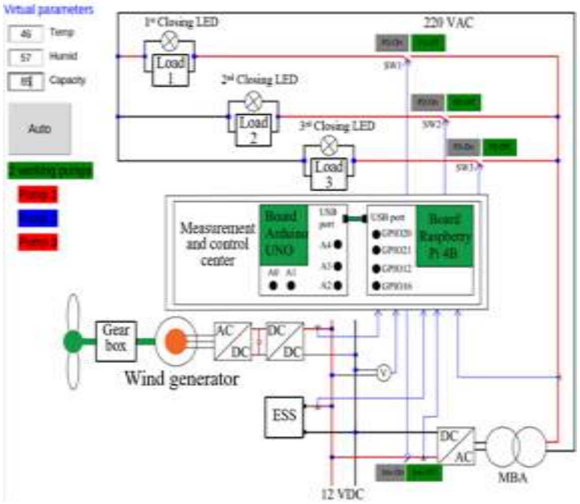


Fig. 10 Automatic mode on HMI for closing two loads

- Results in automatic mode on HMI for case 3 (operating one load corresponding to $T_{ins} \geq T_{thres}; H_2 \leq H \leq H_3; C_{ins} \geq C_{avg}$ as shown in Fig. 11.

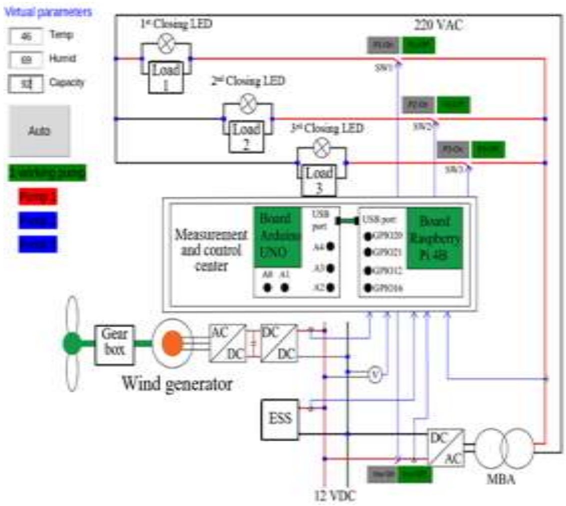


Fig. 11 Automatic mode on HMI for closing one load

- Results in automatic mode on HMI for case 4 (without loads corresponding to $T_{ins} \geq T_{thres}; H > H_3; C_{min} \leq C_{ins} \leq C_{avg}$ as shown in Fig. 12.

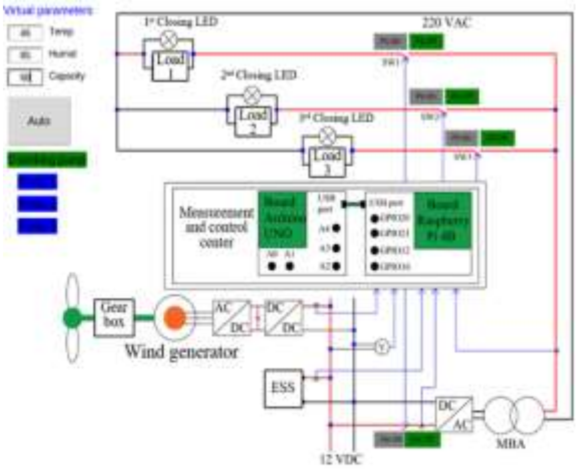


Fig. 12 Automatic mode on HMI without load

D. Results on experimental devices

• Manual mode

At manual mode, we can close any load (water pump) without being interested in its order. This control mode can help workers change the operating state for loads if they see that it must be change to be suitable for tree in the garden or avoid failures.

Received result in manual mode without closing load is shown in Fig.13. Received result in manual mode in case of closing one load is shown in Fig.14. Received result in manual mode in case of closing two loads is shown in Fig.15. Received result in manual mode in case of closing all loads is shown in Fig.16.

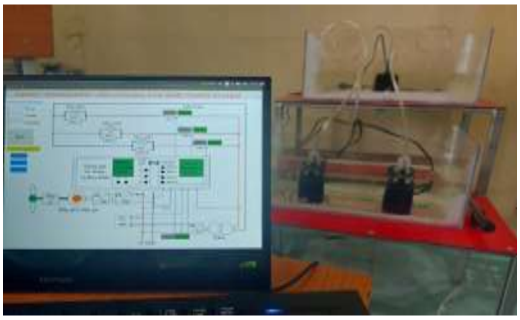


Fig. 13 Manual mode without closing load

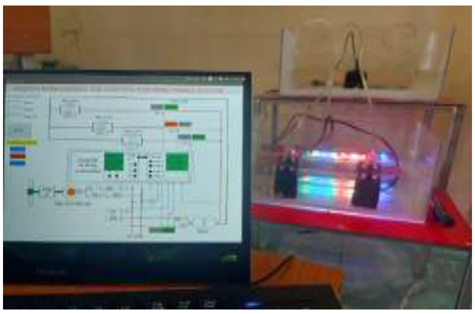


Fig. 14 Manual mode in case of closing one load

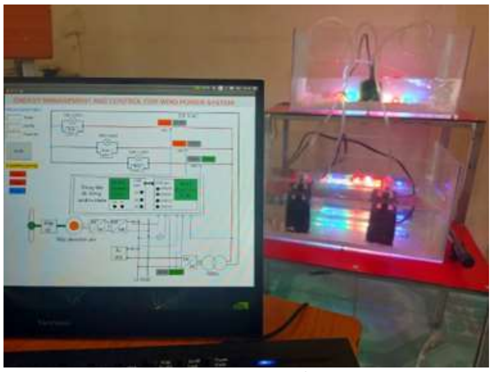


Fig. 15 Manual mode in case of closing two loads

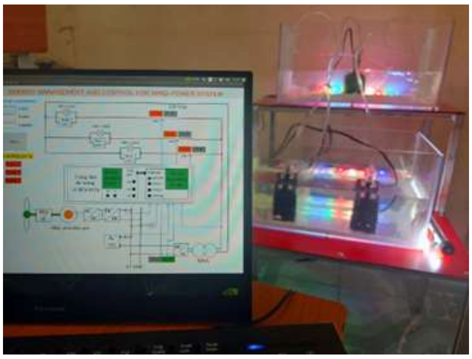


Fig. 13 Manual mode in case of closing all loads

• Automatic mode

This mode is designed to close loads automatically based on measured or virtual instantaneous information about ambient temperature and humidity, capacity of ESS.

Received result in automatic mode in case of closing one load $(T_{ins} \geq T_{thres}; H_1 < H < H_2; C_{\min} \leq C_{ins} < C_{avg})$ is shown in Fig.17.

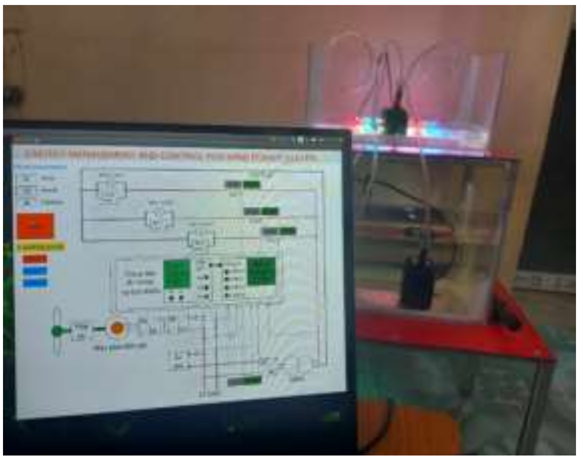


Fig. 17 Automatic mode in case of closing one load

Received result in automatic mode in case of closing two loads

$(T_{ins} \geq T_{thres}; H_1 < H < H_2; C_{ins} > C_{avg})$ is shown in Fig.18.

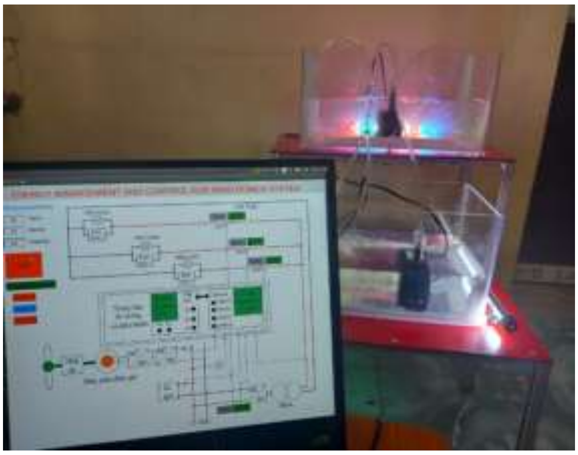


Fig. 17 Automatic mode in case of closing two loads

IV.CONCLUSION

This paper focused on an isolated power grid for irrigational regime with the participation of wind generations and ESS. Authors proposed a method to regulate power flows in whole system based on the instantaneous relation of ambient temperature and humidity and the capacity of ESS. Author used Python application to establish constrains for this model. It was also used to design an HMI and operating mode for whole system. Control signals could be sent to GPIO terminals of Raspberry Pi.

An experimental model was designed and a control strategy was proposed in this paper to adapt to special requirements of irrigational regime. Values of temperature were divided into two ranges by a threshold T_{thres} (called high and low levels). Values of humidity were divided into four ranges by three thresholds, called ($0 \div H_1$), ($H_1 \div H_2$), ($H_2 \div H_3$) and ($H_3 \div 100\%$). Values of available capacity of ESS were divided into two ranges, called ($C_{min} \div C_{avg}$) and ($C_{avg} \div 100\%$).

Received experimental results were shown the designed control program could adapt well to manual and automatic requirements for irrigational regime. The effectiveness received from the proposes showed the ability to bring optimal energy in whole system and improve life cycle time for ESS. This problem can be developed and solve in the future by using Artificial Intelligence to forecast the variation of loads, wind energy and add some constrains about growing period of trees to enhance the control and automation. Research results showed the ability to apply renewable power generation such as wind or photovoltaic generations in a system. If it has the participation of both generations, they will support for each other about implemented locations and available power at daytime and night-time. Moreover, it will help to reduce the dependence of electric power for irrigational regime to the utility.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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