Renewable Energy System Using Weather Data for Optimal Scheduling*

Duy Tan Nguyen, Duy Anh Nguyen

Abstract- ***There is no doubt that renewable energy (RE) is now playing a key role in our daily life and has become more popular thanks to many advantages such as environment friendly, unlimited sources and so on, variable of applications. Obviously, the only one obstacle we must face is the dependence upon weather conditions which have been, so far, the unpredictable variants of most RE systems. Hence, in this paper, we propose a new algorithm using weather forecast and historical weather data in order to optimize performance of RE systems. Basically, this algorithm is not only making full use of weather data base but also helping us decide whether to discharge the load or have it operates on high performance at least in the next three hours [1]. We have already embedded it into our RE system combining with Darius wind turbine and photovoltaic (PV) system, the result is showed below.***

Keywords: ***Weather database; Optimize resources; Wind power system; Photovoltaic system.***

I. INTRODUCTION

We have built an algorithm to make full use of database including historical weather data and live weather data to make decision should or not discharge loads in our renewable energy system. The live weather data we use is from Weather Underground (one of the weather forecast sources of Google) while our historical weather data is just corrected the featured months in a year.

Hence, we analyze the data from the past and compare with the other one at the present. We start with simple techniques such as finding the correlation between wind energy, solar energy and weather conditions. Then we use MATLAB plots for fine grained analysis. We try to find the relation between our renewable energy and weather attributes.

After processing data and making decision, our system can work more fluently with a higher performance. Once the algorithm is embedded in the system, the power from wind turbine and PV panel is used more efficiently and economically. More detail, our system includes wind turbine, solar panel, a battery bank as a backup source and another component to connect system. The exceed power from wind turbine and solar panel is charged into the battery. When the capacity is more 75%, the controller will get the result from the data analyzing, by collecting the wind speed, temperature from the weather forecast in the next hours at the present day. After that, the system compares with data at the same time in previous years. Therefore, if the data form the past and the present are suitable for user can discharge loads, the system shows messenger notifying the status of the system in the next hours and user can decide should or not let all the load operate 100% power. Please note that, these predictions can only be applied within a day.

II. BASIS THEORY

A. Wind turbine

In this paper, our system used a vertical wind turbine operating well in any wind direction. In addition, the output power is ratio with the input velocity wind. In fact, wind turbine cannot collect 100% kinematic energy from the wind or converts this kind of energy to electrical energy. Thus, we needed to pay more attention to the coefficient of the system, this coefficient gives full effect on the wind turbine output power. 20% - 25% is the normal average value of this coefficient. For more detail, the formula below shows us about relationship between wind speed with output power and wind energy with electrical energy [11].

$$P_{turbine} = \frac{1}{2} C\rho A v^3 \quad (1)$$

Where:

ρ – air density (kg/m^3)
C – coefficient of power
A – frontal area (m^2)
v – velocity of the wind (m/s)

Equation (1) show us how power output depends on the velocity wind.

On the one hand, although a small change of wind speed can make the wind turbine power increases significantly, the wind is not stable during a day or at least in hours. In order to overcome this drawback, we can use weather forecast or historical data to calculate the power in next hours. Then, we can have many selections that perfectly suit to the status load at the same moment.

On the other hand, wind speed is not the only factor has effect on the output power wind turbine. Moreover, air density, temperature and many other factors influence the wind turbine. However, within the scope of this paper, we just focus on the impact of wind speed to the system.

To improve the reliability of our system, we built another power source, and it was photovoltaic system.

B. Photovoltaic System

As we all know that the solar energy mainly formed by PV panels is generally more stable than wind power but they

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still depend much on the weather characteristics such as temperature, shadow status, sun direct radiation, etc. In

depends on their technical characteristics. In our system, we chose the PV panels from inductors, it is made from Silicate. Basing on follow equations, we can find out the output power and how temperature effect on our results. Notifying that the equivalent circuit and the basic equations of the PV cell/panel in Standard Test Conditions (STC) are shown, as well as the parameters extraction from data-sheet values [2].

$$V_{OC}(T) = V_{OC} + k_v(T - T_{STC}) \quad (1)$$

$$I_{SC}(T) = I_{SC}\left[1 + \frac{k_i}{100}(T - T_{STC})\right] \quad (2)$$

Where:

V_{OC} – open-circuit voltage in STC
I_{SC} – short-circuit current in STC
k_v – temperature coefficient of the open-circuit voltage
k_i – temperature coefficient of the open-circuit voltage
T – temperature at real time
T_{STC} – temperature in Standard Test Conditions

Both of these parameters V_{OC} and I_{SC} change with ambient temperature. As a result, the output power is not constant and we must consider other parameters like V_{MPP} and I_{MPP}. These are the voltage and current at the maximum power points in Standard Test Condition, all these technical characteristics have impact on the maximum power, the following equations will illustrate:

$$P_{max} = V_{OC}\, I_{SC}\, FF \quad (3)$$

$$\eta = \frac{V_{OC}\, I_{SC}\, FF}{P_{in}} = \frac{P_{max}}{P_{in}} \quad (4)$$

$$FF = \frac{V_{MP}\, I_{MP}}{V_{OC}\, I_{SC}} \quad (5)$$

Where:

FF – fill factor
η – efficiency
V_{MP} – voltage at the maximum power point in STC
I_{SC} – current at the maximum power point in STC

The fill factor, more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{OC} and I_{SC} determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to product of V_{OC} and I_{SC}.

In another way equation (5) can rewrite as below:

$$\eta_C = \frac{P_{max}}{P_{in}} = \frac{V_{max} I_{max}}{I(t) A_C} \quad (6)$$

Where:

addition, the maximum performance power of a PV panel

V_{max}, I_{max} – voltage and current at maximum power point
I(t) – solar intensity
A_C – area of solar cell

Now we pay attention to this figure, because it illustrates the correlations expressing the PV cell temperature as a function of weather variables. The impact of temperature on the electrical efficiency of a PV cell/modules can be obtained by using the fundamental equations.

$$\eta_C = \eta_{Tref}\left[1 - \beta_{ref}(T_C - T_{ref}) + \gamma \log_{10} I(t)\right] \quad (7)$$

Where:

η_{Tref} – module's electrical efficiency at the reference temperature
T_{ref} – reference temperature at solar radiation of 1000W/m^2
β_{ref} – temperature coefficient
γ – radiation coefficient

The quantities η_{Tref} and β_{ref} are normally given by the PV manufacturer. The actual value of the temperature coefficient, in particular, depends not only the PV material but on T_{ref} as well. It is given by the ratio:

$$\beta_{ref} = \frac{1}{T_0 - T_{ref}} \quad (8)$$

In which T_0 is the temperature at which the PV module's electrical efficiency drops to zero (Garg and Agarwal., 1995). For crystalline silicon solar cells this temperature is 270 °C (Evans and Florschuetz., 1978). Besides, another information that we should pay attention too is the Nominal Operating Cell Temperature (NOCT), which is defined as the cell temperature is measured under open-circuit when the ambient temperature is 20°C, irradiation is 0.8 kW/m^2 and wind speed is 1 m/s. T_{NOCT} usually values around 45 °C.

For variations in ambient temperature and irradiance the cell temperature ca be estimated quite accurately with the linear approximation (Luque and Hegedus., 2003):

$$T_c = T_a + \frac{T_{NOCT} - 20}{0.8\text{kW/m}^2} I(t) \quad (9)$$

If substitute equation (9) in equation (10) we obtain important equation (11) [2].

$$\eta_c = \eta_{ref}\left[1 - \beta_{ref}\left[T_a - T_{ref} + (T_{NOCT} - 20)\frac{I(t)}{I(t)_{NOCT}}\right] + \gamma \log_{10} I(t)\right] 100 \quad (10)$$

In this work, authors consider $T_{ref} = 25℃$, average $\eta_{ref} = 12\%$ and average $\beta_{ref} = 0.0045K$.

C. Data analyze

The main point of this work was how could we combine the historical weather data and live data from the weather forecast. Hence, in this experiment, we built a block diagram to show how these kind data connected. After that, we had chosen which months were the best for wind turbine operating well and which months were suitable for PV panels working with the highest performance [3].

Ho Chi Minh city is affected by two main wind direction and mainly monsoon winds in the west – southwest and north – northeast. Southwest wind from the Indian Ocean blew in the rainy seasons, from June to October with an average speed 3.6 m/s and the strongest winds in August, averaging 4.5 m/s. The Northeast wind blew from East Sea in every dry season, from November to February with an average speed of 2.4 m/s. In addition, there is another wind direction, south – southeast, from March to May, average speed of 3.7 m/s. Basically, Ho Chi Minh city is in the area without wind storms. From above information, we chose August is the month wind operates well in Ho Chi Minh City.

These figures bellows are the graph illustrating average temperature months in three years 2015, 2016 and 2017. From this point we can see the different temperature between months in a year is small and almost there is not change much between months. So, we can choose August for the month PV panels working well [4].

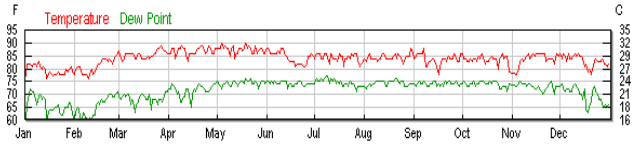


Figure 1. *Average temperature in 2015*

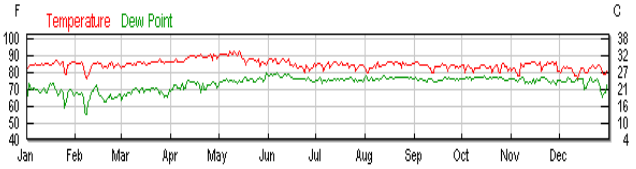


Figure 2. *Average temperature in 2016*

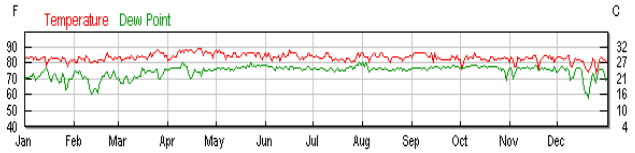


Figure 3. *Average temperature in 2017*

The historical data we collect from the Weather Underground web, and the location for this working is Ho Chi Minh city, Vietnam. The historical weather data is collected and synthesized in an MS excel. Due to confidentiality information and commercialization of weather data, we cannot collect all wind speed and temperature data of all months in three years 2015, 2016 and 2017. So, we just chose one featured month which is the best condition for wind turbine working and PV panels operating well to do database weather for our algorithm.

III. METHODOLOGY

Block diagram in the fourth picture illustrates all components in our system. In this figure, wind turbine and solar panel are the main sources of our system. A back up source is battery bank, after connecting with some converters to meet electrical characteristics of all system. Then there are four switches connect these components to the main DC bus. The output is DC loads or energy can go through a converter to supply the AC loads [5].

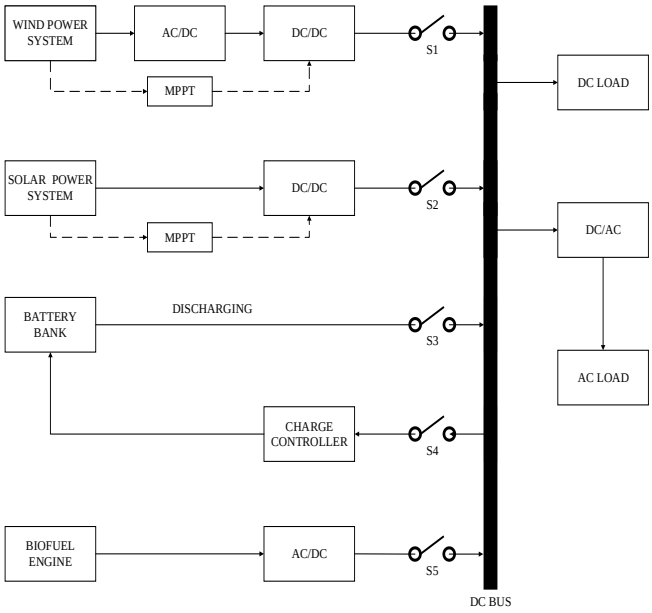


Figure 4. *Block diagram of system*

Wind power system: the core system is vertical wind turbine. This type turbine can operate in any wind direction but its power still depends on wind velocity. Equation (1) shows how big dependent is. Wind speed and power are third-order proportional, when the wind speed increase or decrease, the output power increase (decrease) in proportion to the cube. To solve this drawback, an algorithm MPPT is added into system. The algorithm helps turbines can operates at maximum output power as long as possible, even the wind speed changes or not. The output power is converted into DC current before providing all the loads.

Solar power system: temperatures and sky conditions are two main factor having strong impact on the output power of solar panel. Equation (10) expresses the effect of environment temperature on cells temperature. Then, equation (11) illustrates how cells temperature carries out output performance solar system. Moreover, this system need algorithm MPPT and some converter to convert and optimize output DC current.

Battery bank: we recommend two backup sources in our system, one of them is battery bank. This battery banks

operates with an algorithm to control its charge or discharge action. The charge controller can extend the life battery and help them work more stable.

Biofuel engine: the last back up source is biofuel engine. The reasons we add this type of source into our system is the ability supply power in the bad weather for serval days. However, we want this back up source to be used hardly, we still want turbine and solar panels to be the main sources for all loads.

In figure 4, we use serval switches to connect all components in system. These switches can open or close to connect or disconnect one or serval blocks with the main DC line. Then, all power supplies to DC loads or go through DC/AC converter to provide AC current to AC loads.

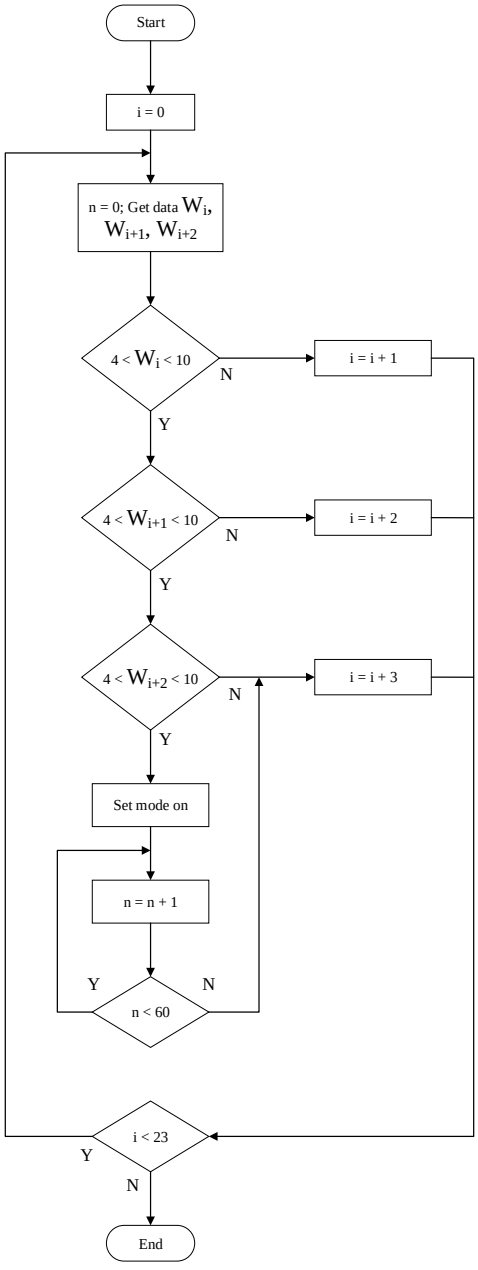


Figure 5. *Checking weather data algorithm*

Next step, we built an algorithm for our system. This algorithm used the data after analyzing and the status battery to calculate how many hours user can discharge all the loads. That means the system would announce when user could let all loads operate at 100% performance. For this purpose, we needed to know the status of all the load, we just recommend some representative loads. We present detail information about these loads in the next part, now we move to the condition to active mode which all loads work 100% performance. The figure 5 illustrates details about this algorithm.

Basically, the algorithm starts with the first hour of day, it gets information about wind speed through weather forecast data. But, when it gets data, the system compares this present data with previous year data (2015, 2016 and 2017). Absolutely, there are different between the current and the past data, so we choose a range that if three-next-house wind speed is in that range, we active the 100% working mode (wind speed is from 4 m/s to 10 m/s). Or if not, the algorithm checks the next houses and continue to the end of the day.

More specifically, the algorithm works as 6 steps follow:

- First, a variable i is set up. This variable represents for hours in a day. For example, i = 0 means it is 12:00 AM, the next variables i means the next hours. In the beginning of the day, value i is set to 0 and move on the second step.
- Second, based on the current variable i, the weather data (in this situation, this kind of data is wind speed) is got from database. From the present, system collects the 3-next-hour wind speed. For clearly understand, we name the wind speed in first hour is W_i, the second is W_{i+1}, the third is W_{i+2} and move on the next step. Another variable n is set up and illustrates for seconds in hours (i). In the beginning, value n is set to 0, when variable i is updated, value n is reset to 0.
- Third, the system sets up a range from 4 (m/s) to 10 (m/s), if the W_i value is in this range, the system moves on the fourth step. Otherwise, the variable i is added 1 unit. Then, new variable i is checked, if its value smaller than 23, the system updates new values i and return the second step. In case variable i is bigger than 23, the system stops.
- Fourth, the value W_{i+1} is has the same process with value W_i in the previous step. Instead of adding one unit, variable i is added to 2 units if W_{i+1} is not in allowed range. Then, new variable i is checked, if its value smaller than 23, the system updates new values i and return the second step. Or if not, the system stops.
- Fifth, this step almost has the same process with the fourth step. The value W_{i+2} is checked in allowed range, when its value still is in the range, the active

mode is set on. Active mode means all the loads in system can operate with 100% performance (this mode is just only actives when all 3 values W_i, W_{i+1}, W_{i+2} meet fully requirement system). Otherwise, variable i is added to 3 units if W_{i+2} is not in allowed range. Then, new variable i is checked, if its value smaller than 23, the system updates new values i and return the second step.

- Sixth, n is added 1 unit and checked it larger than 60 or not. If n is still smaller than 60, the system continues add 1 unit to n and check when it larger then 60. When value n is beyond 60, variable i is added 3 units. Then, new variable i is checked, if its value smaller than 23, the system updates new values i and return the second step. Or if not, the system stops.

About the loads, because of lacking details load information, we just recommend the general loads of our system includes 2 main loads, in addition, we put into system from 2 to 3 extra loads. These loads are reduced or cut off if the power supply is not enough that keep the main loads operate continuously. We do not suggest the algorithm which decides extra load can operate in the normal mode or can operate with how many allowed percent performance.

IV. RESULT

To show how algorithm operate, we built a GUI interface to represent principle working in our system. From the window, all the input data like, wind speed, temperature, status battery… were shown at the present time and the next hours. And the results were the status of all systems like power from wind turbine, solar panels, or capacity of battery bank and some suggestions for user to do with the system. This GUI interface let user choose the input data of wind turbine and the loads that they want to use in this system. So, they can consider which loads they can use or what power of the device they use. In general, this GUI focus on the output power off all system and show how the weather condition effect on wind turbine, solar panel to output power.

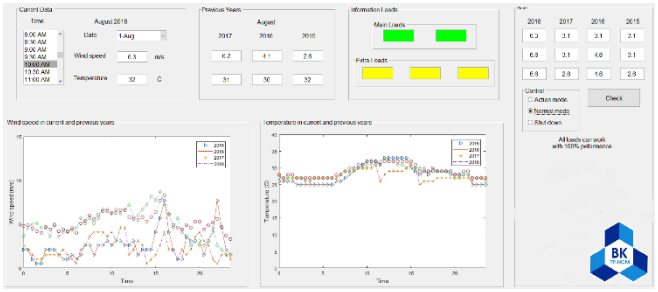


Figure 6. *Weather data interface*

This figure illustrates the total interface about the weather data. It shows wind speed and temperature information. There are two charts expressing these data and they are match with day we choose in August. Additionally, the previous year data at the same time also is displayed (2017, 2016, 2015). User can choose active mode or still in normal mode or even shut down mode, if they want.

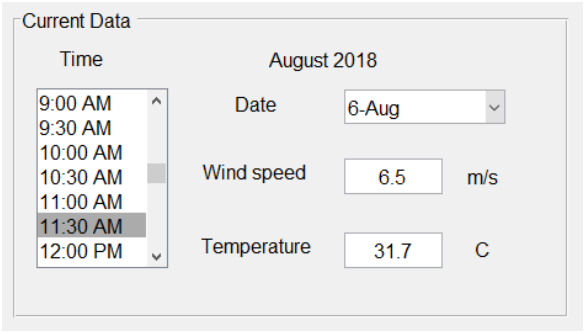


Figure 7. *Current data panel*

In current data panel, when we pick the date and time, we can get the value of wind speed and temperature at that time. Moreover, in previous year panel, there are wind speed and temperature data at the same time in previous years.

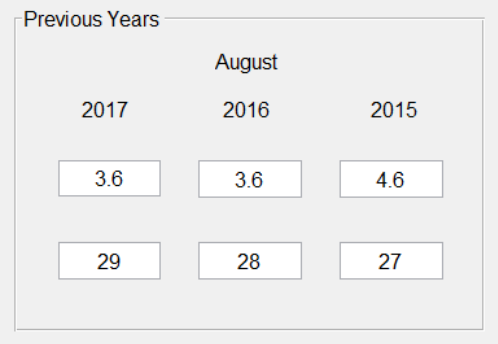


Figure 8. *Data in previous year*

In figure 8, the first cell in each column is wind speed value. The second cell is temperature value. When the time and day are picked in the current data panel, these value in this panel are change too.

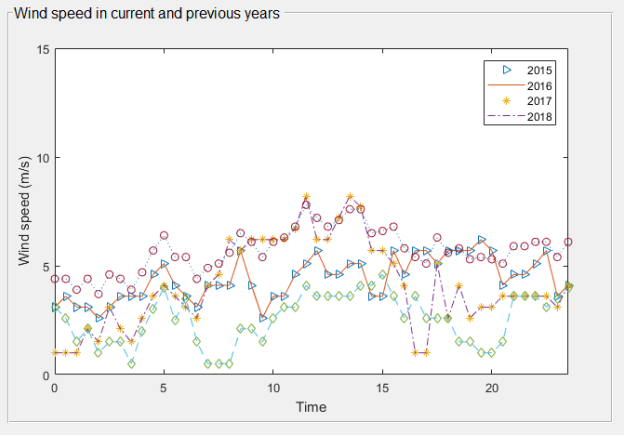


Figure 9. *The wind speed in current and previous years*

Figure 9 illustrates the chart showing the variation of wind speed in a day. There are the different between these years, but with this chart, we can see more visually how difference data is. From this point we can make decision easier.

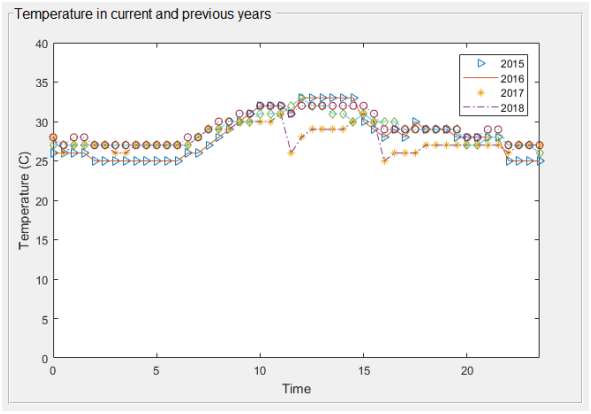


Figure 10. *The temperature in current and previous years*

Figure 10 illustrates the chart showing the variation of temperature in a day and this chart has a same purpose with the chart in figure 9. It gives the user a more general view of the day's temperature changes.

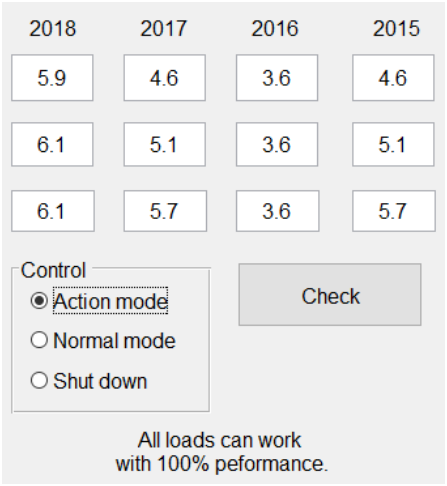


Figure 11. *Control panels and more detail data*

Figure 11 shows the data in threes next hours from the time we pick in the above panel (from 2015 to 2018). In this panel, there are some options, user can choose they use active mode or another mode. When all needed information is available, system actives Active mode, if not this mode is in enactive. When Active mode is on, all the loads in Loads panel turn on green, if Normal mode is on, all the extra loads turn on yellow, that mean they are cut off to keep power supply for the main loads. The final option is shut down all the load, in case the weather condition is too bad to operate or cause damaged.

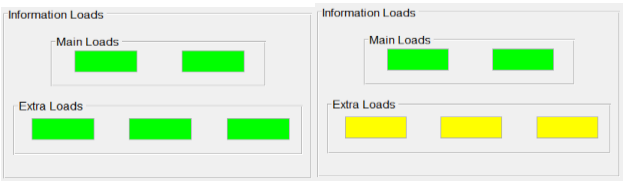


Figure 12. *Information loads panel*

Moreover, figure 11 shows the main function which represents for first tab in this GUI. When all weather data is displayed on every cells, the system collects and make some calculation base on the above algorithm. If the wind speed in three-next-hour are in allowed range, the active mode in enable to set on. Otherwise, this mode is unable to set on.

When all the weather information is set up, the next tab is about management, control the wind power, solar power and show them in user interface like Figure 7.

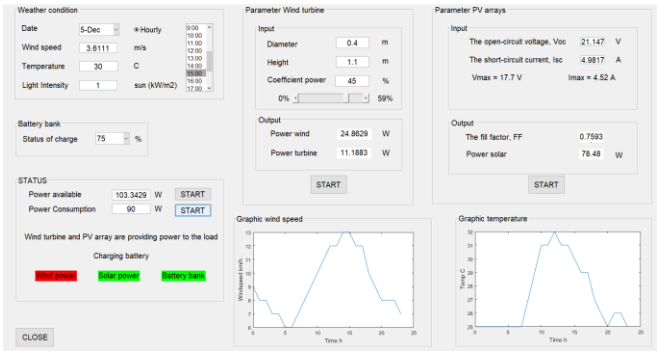


Figure 13. *GUI interfacing*

Weather condition panel shows weather information and also the status of battery. Wind speed, temperature and light intensity are displayed corresponding to the selected time as the below figure. When the date and time are chosen

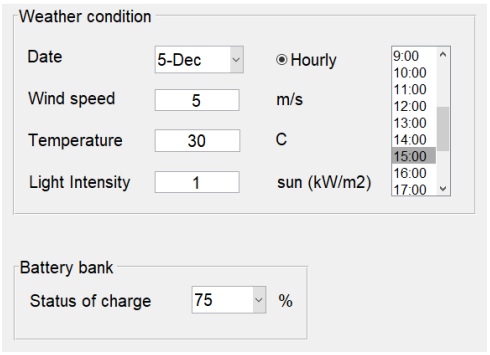


Figure 14. *Weather condition panel*

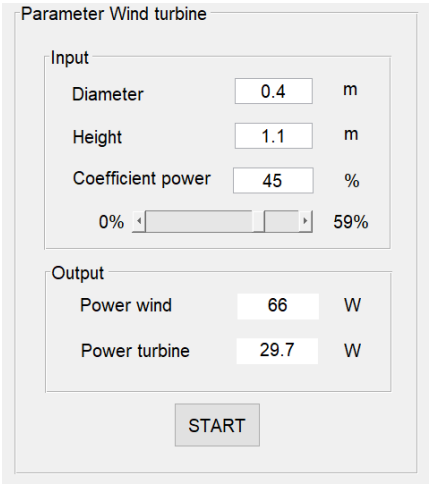


Figure 15. *Parameter wind turbine panel*

Figure 15 shows parameters of wind turbine. There are two panels in this figure. Tab input let user choose diameter, height and coefficient power. Based on the Bezt laws, the coefficient power cannot beyond 59,3%. Following (1), diameter and height of blades wind turbine have strong impact on output power. The larger front area of wind turbine, the more output power.

Then the output panel gives the power by wind and power by turbine. The wind power is calculated by the follow equation [6] [11]:

$$P_{wind} = \frac{1}{2}\rho A v^3 \quad (11)$$

After obtaining the P_{wind} elevation value, the system will show the actual power that the turbine can produce relative to the selected power factor. From (1) and (12) the equation for coefficient power is as follow [11]:

$$C_p = \frac{P_{turbine}}{P_{wind}} \quad (12)$$

Figure 16, parameter arrays panel illustrates the open-circuit voltage and the short-circuit current. These figures are affected by temperature and in some case, the condition sky have an impact on the output power of this solar panels. Another figure in the output panel is the fill factor have effect on panel power.

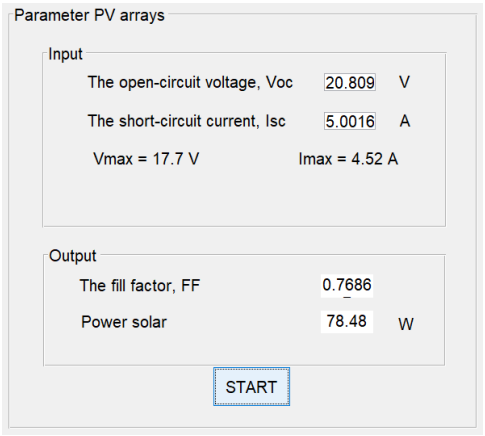


Figure 16. *Parameter PV arrays panel*

The open-circuit voltage is affected by temperature follow the below equation [7] [8]:

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{I_L}{I_0} + 1\right) \quad (13)$$

Where:

I_0 – dark saturation current
I_L – light generated current
n – ideality factor
T – temperature
V_{0C} – open circuit voltage

The short-circuit current, I_{sc}, increases slightly with temperature. However, this is a small effect and the temperature dependence of the short-circuit current from a silicon solar cell [9]:

$$\frac{1}{I_{sc}}\frac{dI_{SC}}{dT} \approx 0{,}0006 \quad (14)$$

The temperature dependency FF for silicon is approximated by the following equation [9];

$$\frac{1}{FF}\frac{dFF}{dT} \approx \left(\frac{1}{V_{OC}}\frac{dV_{OC}}{dT} - \frac{1}{T}\right) \approx -0{,}0015 \quad (15)$$

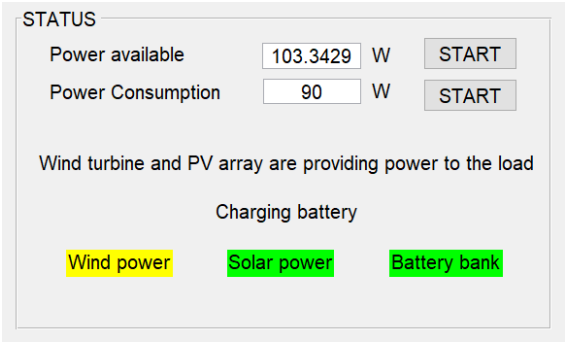


Figure 17. *Status system*

And the figure 17 shows status of all system. After aggregation data from two resources and back up sources, the system shows power available and power consumption. In power consumption cell, user can adjust how much power their loads need. Then, the system compares these figures and give the status how system work.

The second tab focuses on observing and controlling the output power. When the first tab notifies about the status active mode, this second tab illustrates the status system. How much power is created by the renewable sources and how much consumption power, user consider this information and make a choice.

In summary, we have built an interface that allows users to know the operating status of the system and an algorithm that calculates which time of day the system can operate at maximum performance. With time-based predictions, users can actively activate the 100% performance mode at appropriate intervals, or they can choose to use the load at moderate power, or when a backup power supply is needed [10].

V. CONCLUSION

Obviously, no one can deny the key role which RE system play in the energy industry recently. With all the advantages RE have, human rate is now changing their mind to make full use of it as a Noah's ship for the sustainability of their civilization. The only problem we have here is their over dependence on weather characteristic that leading to differentiate between supply and demand in electricity market. That is the reason why we propose this algorithm so that we can optimize all of those systems to get a better balance operating in the utilities.

In the future, we would like to apply another algorithm like ARAM. This algorithm can be used for short-term predict. It's simple and not require a huge amount of historical data, most importantly they have a greatly improved performance.

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