Control of Hybrid Wind Turbine and Diesel Generators using PLC

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Abstract. This paper shows path of controlling hybrid system with wind and diesel generators via a programmable logic controller, these systems produce the required electrical power from different sources. This system can be used in different areas that have wind speeds between (10-180) km/h. When the winds are within this range, then the wind turbine generator is starting and suppling the electrical power to the load, if there is any fault is occurred or the wind is not within the working range then the wind turbine generator ceases and the diesel generator will start and supply the electrical power to the load.

1 Introduction

During the last years, the research focuses on green energy sources as a single energy source or a part of a hybrid energy system. Maintaining the TSR at its optimum level ensures that the generator on the wind turbine is operating at its maximum efficiency (1-2). In wind turbine generators, the tip speed ratio (TSR) is defined as the ratio between the speed of the wind and the product of the turbine's radius and the angular or rotational speed of the blade's tip. Another way to say this is that the TSR is the ratio of the wind speed to the angular or rotational speed of the blade's tip to the (Bhandari et al. 2014; Kumar et al. 2017).. All that comes as a result of the increasing demand for the world on energy from any source. The traditional energy sources that depend on oil and gas fuel have a destructive influence on the environment. Green energy sources like solar, wind and other types of green energy sources have less bad effects on the environment. The generation of such type of energy increased year by year despite the high price of renewable energy equipment [3-4].
The dependency on green energy sources starts to increase especially in remote areas that have no other nearby energy source. These areas depend on en
vironmental characteristics such as long hours of sunshine or strong winds in that area. In fact, using green energy sources as the only source of energy is not practical these days or the near future because energy generation is not stable at all times so there must be a backup energy source to be used when the main source fails to produce energy for any reason such type of energy systems named as Hybrid system. The hybrid systems can contain Wind energy sources, Solar energy source, diesel energy source, batteries, and any mix of these sources together [5-7]. Some research are done to propose an economy hybrid system such as in [3], this system is based on designing an intelligent control to reduce diesel usage depending on the load. In [8] Saad et.al. proposed a hybrid system with optimized in this work, PLC controlled Hybrid Wind-Diesel system is proposed to be used in areas that has wind speed within the range of (10-180) km/h. Hadi et al. in [9] show that in Iraq the mean wind speed in the range [17-25] km/h depending on the height of the measuring device and Khan in [10] shows in his study the most frequent wind is in this range. So, this work can be used in the remote areas that has the same wind speed range without any need to use the diesel backup generator unless there is a fault or out of range wind speed.

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The motivation after this work is to study the opportunity of using the power of wind to generate electricity in Iraq. This work proposed a way to control the connection of two different electricity sources (wind turbine and diesel generator) in the far away areas from the national electricity sources. This system will reduce the dependency on the diesel generators, which is planned to

be used as an emergency resource in case of any failure of wind generator. The following sections shows the details of the methodology, results, and the conclusion.

2 Methodology

PLC is used to connect analogue signal came from wind anemometer. It is measuring the wind and it considered as an analogue device, which is connected to the analogue input card of the PLC. According to the PLC program and the measuring speed of the wind anemometer, it will turn the wind generator on or off and the let the diesel generator starting or stoping accordingly. Conceptual maximum efficiency that the turbines rotor blades can extract from the wind energy amounts to between 30 and 45% and which is dependent on the following rotor blade variables: blade design, blade number, blade length, blade pitch/angle, blade shape, and blade materials and weight.

Fig 1. shows a connection of the loop-powered method (4 – 20 mA) for wind anemometer. It is connected to channel one of slot 3. Slot 3 is accommodated by NI4 (analogue input cards) and it contains 4 channels. Channel 2 contains the diesel control's order according to the software code to start the diesel generator in case the wind turbine failure to start or any conditions are not met, while channel 3 and 4 are spares for future use. The analogue inputs to each channel depending on the measurement method, by using a (4 mA – 20 mA) method known as a loop powered method. The controller and probe are connected in series with input channel. so that the current of a value of 4mA considered as a minimum value and 20mA considered as a maximum value flow in the close circuit, above maximum and below minimum considered as out-range measurement. Also, it shows the 240 V AC tagged by N-wind and neutral from A0 bus bar feeds the wind anemometer controller, the output is 24 V (DC). The positive terminals of the controller and the wind probe are connected together, while the negative terminal of the wind probe is connected to the positive terminal numbered 0 of channel 1 slot 3 and the negative terminal numbered 1 of channel 1 is connected to the negative terminal of wind anemometer controller. Four basic steps in the operation of all PLCs; Input Scan, Program Scan, Output Scan, and Housekeeping. These steps continually take place in a repeating loop.

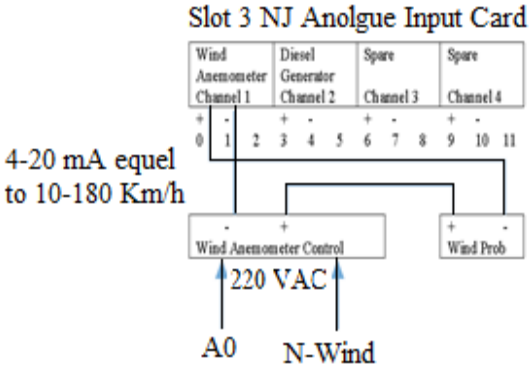

Fig.1 The Loop Powered Method for Wind Anemometer.

Figure 2 shows the outputs of the PLC from slot four, terminal 0 of slot 4 is connected to the interface relay's coil R1 means terminal 0 represents control feeding, as a result, the contact of R1 closes, causing the supply 24 VDC (X3 -cont.) feeds the coil of the wind contactor through the contact of R1, as a result of the wind contactor activation, the 240 V (AC) from wind turbine (A2 AC voltage) feeds Al the AC bus bar, which feeds the load bus bar. The wind turbine feeds the A1 bus bar by means of wind contactor and wind overload to protect the system from any overcurrent. When any reason the wind turbine has not working for any reason like out-of-range operating range for wing generator or any failure, then the diesel generator according to control program.

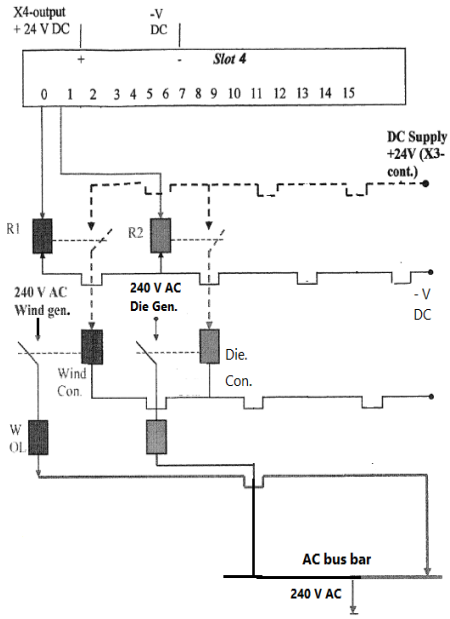

Fig. 2 Slot 4 (outputs) and Final Control of AC Voltage

Figure 3 shows that in the normal operation of the wind turbine b3/11 and b3/12 both are not working (below range and over the range values), then SCL instruction scales the reading from the wind anemometer N9: 15 (source) and transfers it to the destination N9:0. SCL it does the scaling depending on the rate and offset between the scaled range and input value of the wind anemometer.

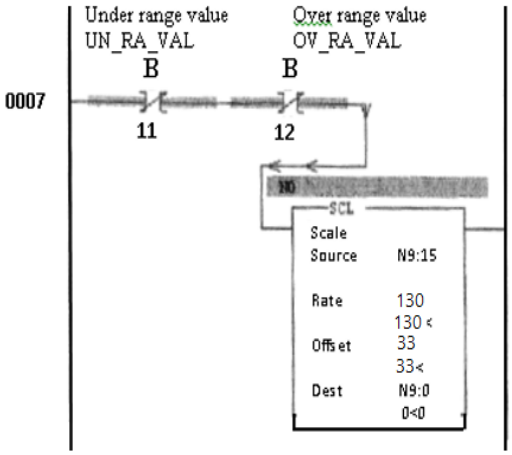

Fig.3 Scaling the input of the wind anemometer

Figure 4 shows the PLC construction of the I/O boards (slots 1 - 7). The processor card is located in slot 0, input cards which consist of digital and analogue cards; the digital switches, optional contacts, push buttons are located in slots 1 and 2, the analogue wind anemometer is located in slot 3, and the output card is located in slot 4, the 4-20 mA loop-powered method is used, means the analogue inputs are connected to the PLC in series. For example, a reading of 4 rnA (lowest value) equals to an integer number 3277, and 20 mA (highest value) equals to an integer number 16384. There are 13 digital inputs to slot 1 (24 V DC) with extra spares. Slot 2 has 6 digital inputs (24 V DC) with extra spares. The co-relation of both analogue and digital inputs according to the code priority will determine the correct selection of output wind contactor, as a renewable wind turbine generator will activate first (e.g., wind speed), and accordingly the processor through slot 4 activates the coil to that wind generator.

Power Supply for SLC 500	Slot 0 Process	Slot 1 Input	Slot 2 Input	Slot 3 Analog Input	Slot 4 Output	Slot 5 Spare	Slot 6 Spare	Slot 7 Spare

Fig. 4: PLC's Controller Boards Layout

Figure 5 shows hybrid wind and diesel system wind turbine and diesel generator. If wind speed is within the specified range; then wind turbine generator will produce 240 V AC as a result of this it will supply the electrical power to the output busbar.

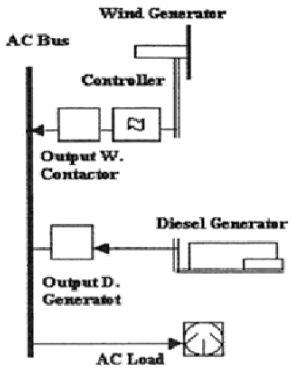

Fig. 5. Shows Hybrid System of Wind-Diesel Generators

Figure 6 shows the control method for renewable energy system, which consists from AB SLC 500 as a controller. By sending the digital inputs to slot 1 and 2 (1–slot addressing), The processor addresses one chassis slot as one logical group, each slot is sequentially assigned one word (16 bits) of the SLC module's input and output image, each terminal on the I/O module is assigned a bit within the word, beginning with the least significant bit. I-slot addressing is primarily designed to accommodate I/O modules whose image size is less than or equal to one word but more than one byte. 13 digital inputs are connecting to 13 terminals in slot 1, 6 digital inputs are connecting to 6 terminals in slot 2. These digital inputs are start or stop push button or normally close or normally open auxiliary contacts or normally open switch.

Slot 3 is the analogue input module NI4. Each input of the NI4 is addressed as a single word in the input image table. The NI4 uses a total of 4 words in the input image table; the converted values from channels 0 through 3 are addresses as input words 0 through 3 respectively for the slot where the module resides. Wind anemometer is addressed as I:3.0 in channel 0, channel 3 is a spare. Slot 4 is the digital output. Digital outputs are connected to terminals in slot four, terminal 0 is connected to output wind turbine generator contactor, terminal 1 is connected to output terminal 3 is connected to output diesel contactor. Each terminal is assigned a bit beginning with the least significant bit.

Control method has been achieved by the combination of these analogue and digital inputs, and digital output (slot 3, 1, 2, and 4). Software has been built in slot 0 (the processor) from this combination to run the renewable energy system, so that if the wind velocity is strong enough (more than 10 Km/h and less than 180 Km/h) then the output wind contactor will activate, as a result it will connect the wind generator to the output AC bus bar. The control method is developed to connect the hybrid wind-diesel generators to the load as a stand-alone power generating system to supply any load in a remote location.

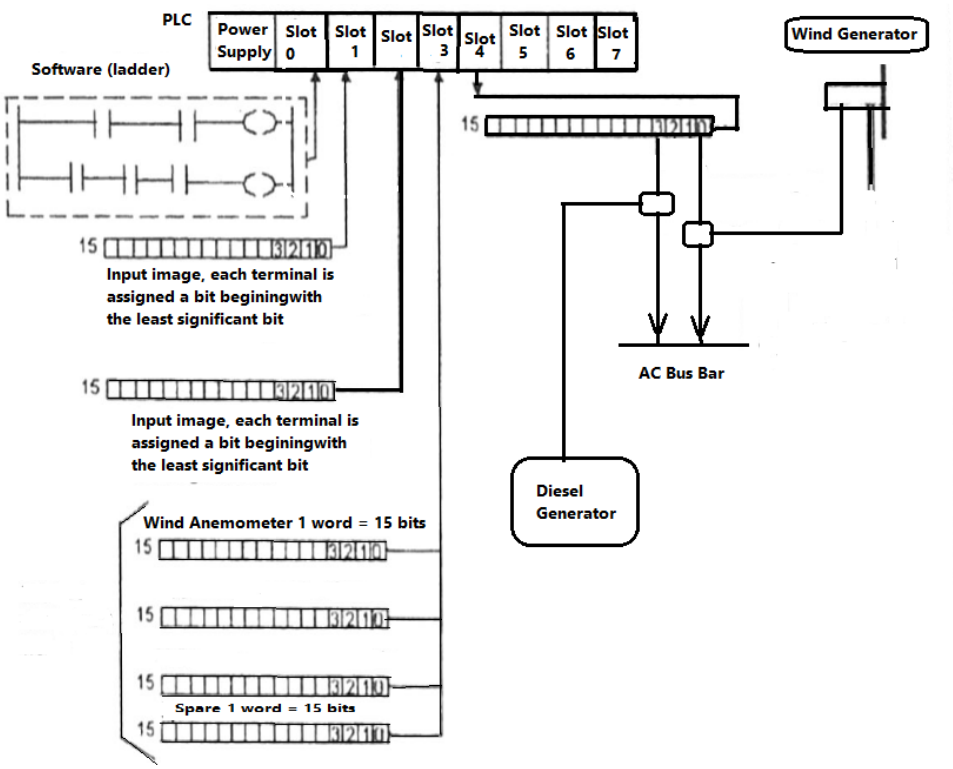

Fig.6. Control plan for hybrid system for wind-diesel generators

A linear relationship is the method that has been used to calculate rate and offset and can be achieved as shown below Figure 7 shows two coordinates, the horizontal coordinate shows the current values while the vertical coordinate shows the scaled range in km/h the real measured, the formulas linear relationship between these two values are expressing the formulas below:

$$Slope = \frac{Scaled\ Range}{Input\ Range} \quad ...(1)$$

$$Offset = min\_scale - (min\_input\ value * Slope) ...(2)$$

$$Rate = Slope * 10000 \ ...(3)$$

The values Slope, Offset and Rate for wind turbine of 10 km/h to 180 km/h is:

$$Slope = \frac{180 - 10}{16384 - 3277}$$

$$Offset = 10 - \left(3277 * \frac{170}{13107}\right) = -32.503$$

Because the floating point values are not accepted so the final integer value is Offset=-33

$$Rate = \frac{170}{13107} * 10000 = 129.7$$

integer file does not accept non-integer values, so Rate=130

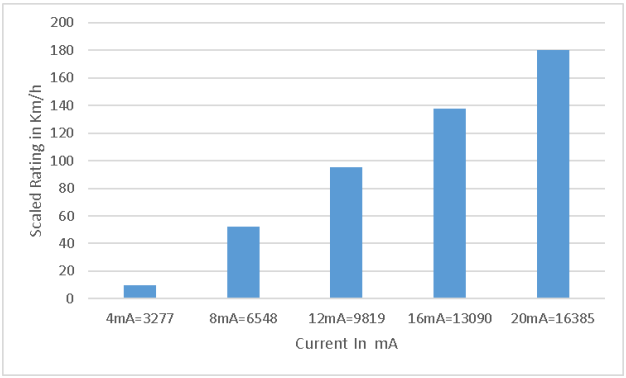

Fig. 7:. scaling graph of wind anemometer

Table 1: Comparisons with previous works

Reference	Maximum Wind Speed	Current in mA
Ref [5]	200 km/h	20 mA
Our work	180 km/h	20mA

Fig. 8. shows the calculated average output power or seven day starts from 20/11/2023 till 26/11/2023 as shown below.

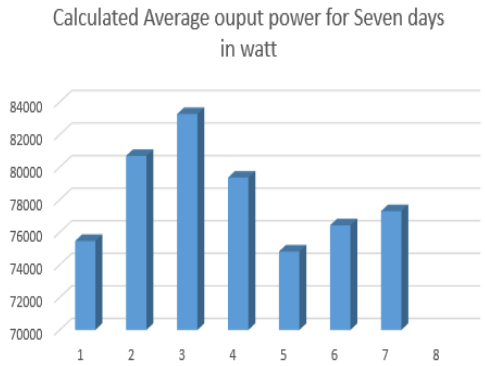

Fig. 8. Calculated average output power for seven days**.**

3 CONCLUSIONS

The wind turbine worked under wind speed variation between 10 -180 km continuously for one week, and a diesel generator is stayed off as a standby. According to the above tests, we found the voltage produced by wind speed varies between 10 -180 km continuously for one week. The produced voltage feeds the busbar, which is supplied the main bas bar and feed the PLC. Hybrid system can be used in the area that has multiple electricity sources such as in Iraq. Our system used both the wind turbine and diesel generator, which can be used in the areas that are far away from the national electricity sources .This voltage is varying between 230 V – to 240 V for 6 hours working from 7 AM till 1 PM. Electricity generation in remote areas of some rural part of Iraq still depends on diesel fuel. Economically viable production of electricity in areas of high wind speeds and high cost o f diesel and its transportation can be realized. Any reasonably high wind speeds and its remoteness and not connected to the national grid and still using diesel generators has made it a natural choice to start experimental wind power farms in Iraq and this what I believe it is the new of our current study. The controlling device is done by Allan Bradley PLC/ SCADA combination that achieved our research and control the hybrid system of renewable energy resources-diesel generators.

RECOMMENDATIONS

Electricity generation in remote areas of some rural part of Iraq still depends on diesel fuel. Economically viable production of electricity in areas of high wind speeds and high cost of diesel and its transportation can be realized. Any reasonably high wind speeds and its remoteness and not connected to the national grid and still using diesel generators has made it a natural choice to start experimental wind power farms in Iraq and this what I believe it is the new of our current study. Power is measured by a power transducer can be added for another test or analysis in the near future.

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