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A SMART WIRELESS REAL POWER WITH HEALTH MONITORING OF THREE-PHASE GENERATORS

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Abstract:

Load shedding due to a shortfall in electric power is a major issue in Pakistan. Power is continuously required to fulfill domestic and industrial users' needs. Electric generators are a reliable backup source when the main supply fails. In the same way, generators are invaluable for power availability in remote areas. The purpose of this paper is to design an efficient and cost-effective real-power wireless transmitter connected with a user-friendly GUI which can be accessible all over the world. It aims to monitor the health parameters of a three-phase generator like power with the location of the mounting system in the form of latitude and longitude coordinates, the power of each phase, the power factor of each phase, temperature, oil level, and battery level which could be placed in a remote location. This helps to take rapid and effective actions could be taken for troubleshooting, fault tolerance, and preventive maintenance of the generator. Moreover, this system can store all the collected information on the main server for auto record management.

Keywords: Three-phase generator, power, temperature, oil level, battery level

1. INTRODUCTION

Implementation of Generators has become very common in almost every passive infrastructure company, Industries, hospital, township, etc., as well as for domestic purposes. The generator is a device that converts motive power into electrical power. These generators have been considered the best power source when domestic power is cut off or in a power failure. Many alternating current generators are available today, i.e., single phase, multiple phases, etc. While using these Generators, the user faces several challenges. Some of them are maintaining the Quality of grid power, asset protections, human dependency, generator maintenance, fuel theft monitoring, data collection, capturing real-time data, remote monitoring of the generator, and analysis issues [1]. Currently, electromechanical meters are being supplanted by digital electronic energy measurement technology. Undoubtedly, a wireless digital energy meter will make meter reading more convenient [2]. Real-time power monitoring of electrical devices is a need of time. Digital electronics can play a significant role in this area. Voltage and current can be efficiently monitored using digital microcontrollers [3]. Different types of electric loads cause a major effect on the health of generators. The majority of appliances used in today's world are not pure resistive and cause different values between apparent and real power due to the non-unity power factor[4][5]. So, these conditions must be monitored and rectified for continuous faultless operations before any catastrophe. Today's world developing rapidly. Smart and adaptive systems are preferred in all domains of life.

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Systems must have greater operating time, and if there is a need for troubleshooting, then components are easily available and replaceable. This paper focuses on a system that measures three-phase voltage, current, apparent Power, real Power, and Power Factor, along with the health parameter of a three-phase AC generator connected with the running load. The whole project is divided into sections and each section plays a significant role in the whole operation. Remote measuring unit (RTU) based on Open energy monitoring project which is already accepted by a large group of engineers worldwide[6]. This project provides a way to accurately measure current and voltage for single-phase power using embedded microcontroller-based technology. Manual systems have been used in every control system domain, but they are bulky and costly. PC-based control systems are now preferred over manual monitoring and control systems [7]. It is a more user-friendly and reliable way that ensures the mobility of a user. To improvise in recent times, 2G/GSM technology have been used in this aspect where user can send commands in the form of SMS or mobile messages to read the remotely placed generator's electrical parameters[2]. The existing systems also can automatically send electrical parameters of the generator periodically in the form of SMS[8]. This thesis and prototype project is designed to send SMS of alerts whenever threshold of any perimeter exceeds its value and particularly notifying the real power consumption of the respective generator. The proper operation of the electric power system is ensured by a wide array of complex electrical equipment and systems. Continuous development and improvement must be offered for these specific parts using specific equipment and applications suited to the changing technical environment [9]. Conventional method of power measuring is now replacing even now single-phase line power can be calculated efficiently by using digital micro-controller devices. Voltage and current are key parameters to measure system power, power factor and phase angle[10]. To measure all required parameters, the most important is to measure voltage and current accurately. There are many types of voltage and current sensors are available having different working principles[11][12]. Here, galvanic isolation design is selected so there is isolation between measuring and measured circuit. Since, output signal generated by proposed sensors are analog, so it is necessary to digitize it before processing[13]. A micro-controller board Arduino mega is used as a main controller to collect the data process it and apply command to send data to main sever system. This board has not only full filled the hardware and software requirements here but also available all over the world in low cost, compact size, and vast features. Parameters to be calculated by software are RMS current, RMS voltage, Apparent power (S), Real power (P) and power factor. Some health parameters of generator in which temperature, oil level and battery voltages are also included.

2. METHODOLOGY

The working starts with the measuring of input of current and voltages. These currents and voltages are then calculated apparent Power (KVA), real power (KW) and the power factor. Some other parameters like temperature, battery voltage level and oil level are also being monitored. All this information is then transmitted wirelessly to main server unit on which LabVIEW based GUI screen display respective parameter with data logging

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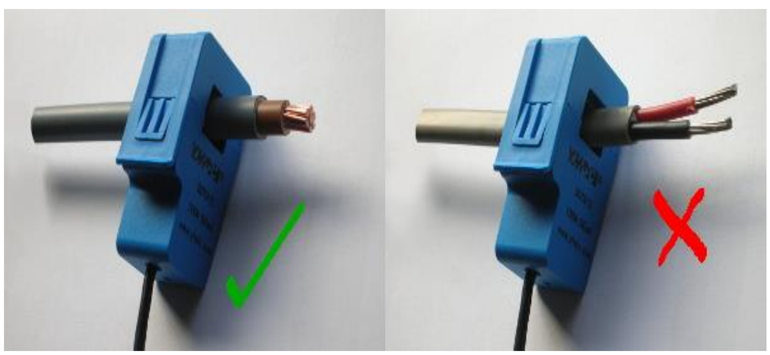
feature. Also, it displays the global location of that RTU unit in GUI screen. First, we will see how to take voltage and current input to the digital microcontroller board along with their signal conditioning since. High AC power cannot directly apply to the low powered digital microcontroller board as measuring signal. Both systems must be isolated, and they should not be electrically coupled.

2.1. Voltage & Current

2.1.1Current sensor

Current Transformers formerly known as CTs are sensors which are used to measure AC current. Like any other transformer CT have primary winding, core, and secondary winding. The split core type CT have used in paper. The split core CT can be clip on any live or neutral wire. Here we are using three different split core type CTs for each three phases. Live or current carrying conductor act as primary winding while the secondary winding is composed on fine wire with many turns which contained in a transformer. Flow of Alternating current in the primary winding produces the magnetic field in the core which in results induces current in the secondary winding. This induced current is proportional to primary winding current. CTs used in project having capability to measure up to 10 Amps of current with the output of max 1 volt.

Figure 1: Correct method of Clamping Current sensor



In fig 1. Shows the left side of picture, it can be clearly seen that single wire is acting as primary winding and this picture shows the right method of clapping CTs. If both wires pass through the sensor than sensor will read the sum of both magnetic field and since, the entering current is equal to the exiting current only with the opposite direction, so the net sensor output will be zero. The output signal which is produced by the CTs must be conditioned consequently that it meets to the input requirement of Arduino ADC (analog to digital converter) analog pins. Arduino analog input can measure positive 0V up to ADC reference voltage. This signal conditioning achieved by using signal conditioning circuit as shown in fig 2.

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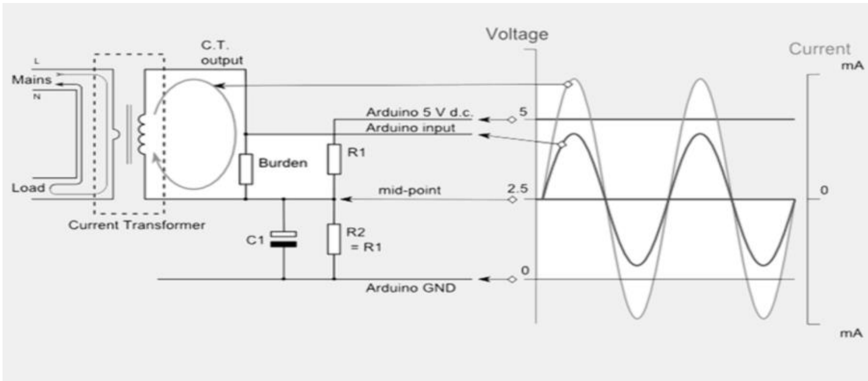
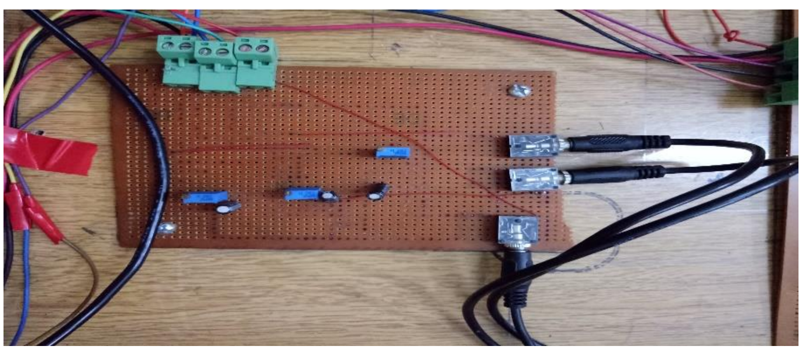
Figure 2: Current signal conditioning



The sensor SCT-010 is used here for current sensing which output in voltage form. The burden resistor is built-in in the sensor package. Output generated by the CT is the proportional voltage to the current passing through the phase wire. As analog input pin cannot measure negative voltage of input AC sinusoidal signal, this signal must be shifted in positive quadrant by introducing some value of DC voltage. Voltage divider circuit with the capacitor in parallel is used for this purpose as shown in fig.3.

Figure 3: Actual current conditioning circuit



2.1.2 Voltage Sensor:

Voltage measurement is required to compute real power, apparent power, and power factor. This measurement can be achieved simply by using a potential step-down transformer. This potential transformer provides isolation from high voltage of main supply to our measuring unit.

Like CT section, the output of potential transformer PT also required signal conditioning to full fill the input requirement of Arduino analog ADC. Arduino analog can read from 0V to ADC reference voltage.

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Figure 4: Voltage signal conditioning

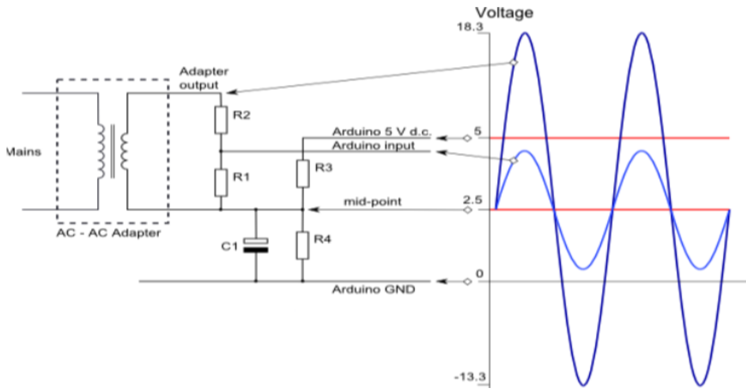
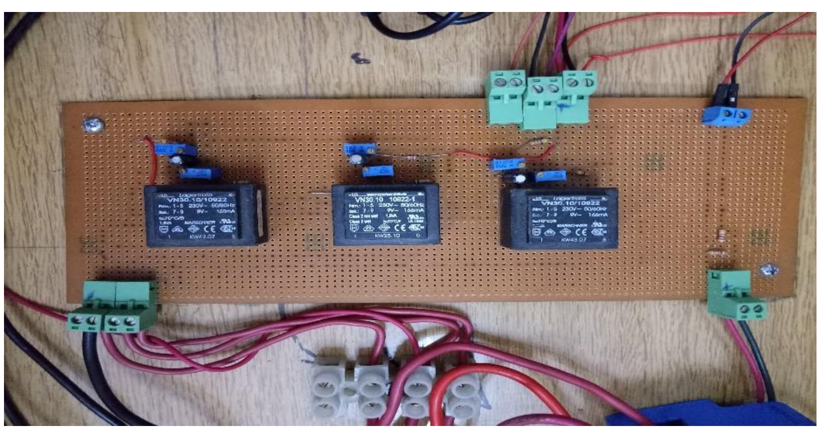


Fig. 4 shows that three phase Voltage inputs have taken using voltage sensors which is separately designed for each phase. The step-down transformer first steps down the voltage to 18 volts peak. This voltage is then further reduced to 2.5 volts peak using a voltage divider circuit.

As the Arduino only takes positive voltages so a clamper circuit is used to clamp these voltages to positive quadrant. The clamper shifts the voltage reference level up. This Voltage waveform is now fed into the analog pins of Arduino board. These two are key parameters, which are responsible to extract out all types of AC power from the electrical system. Waveforms of AC voltage and current clearly show that they are continually alternate with respect to time. For reading the voltage and current on microcontroller, both parameters have sampled over high frequency. We have made 50 samples per 20 milliseconds of both current and voltage as shows in fig.5.

Figure 5: Actual Voltage circuit



2.1.3. Calculation of Real Power:

Average of Instantaneous power is real power, so that calculation is linear. First Instantaneous power is calculated by multiplying instantaneous voltage with

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instantaneous current than sum up this instantaneous power up to no. of samples and divide it by total no. of samples by equation (1).

$$P \equiv \frac{1}{N} \sum_{n=0}^{N-1} u(n) \times i(n) \qquad \text{------ (1)}$$

Where,

u(n) is the instance of u(t).

i(n) is the instance of i(t).

n is the no. of samples.

2.1.4. Measurement of RMS voltage & current:

The RMS (Root Mean Square) voltage is measure according to its name. First the measuring quantity is squared, then mean is calculated and finally take the square-root of the resultant value.

RMS voltage can be measured using the following equation,

$$U_{rms} = \sqrt{\frac{\sum_{n=0}^{N-1} u^2(n)}{N}} \qquad \text{------ (2)}$$

Similar method is used for the measurement of RMS current. The RMS (Root Mean Square) current is measure according to its name. First the measuring quantity is squared, then mean is calculated and finally take the square-root of the resultant value in equation (2).

2.1.5. Measurement of RMS power:

The RMS (Root Mean Square) power is measure with the RMS voltage and RMS current. The product of U_RMS and I_RMS is RMS power or apparent power in equation (3).

$$\mathrm{S} = \mathrm{Irms} * \mathrm{Urms} \qquad \text{------ (3)}$$

Where,

S = apparent power

2.1.6. Removing DC offset

Input signals of voltage and current, both contain DC bias of 2.5volts. This bias is not required for power calculation. Due to this reason, a software filter is needed to remove this DC shift. Solving this problem by applying following technique shows in algo 1. This software filter will take sample, and first calculate the offset by subtracting the previous offset value from actual sample than divide this by 1025 which is 2^10 and then addition of previous offset. Finally, this offset value is subtracted from actual input sample filtered output used for calculation of real, apparent and reactive power.

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```
offsetV = offsetV + ((sampleV-offsetV)/1024);
filteredV = sampleV - offsetV;                    ------ (algo 1)
offsetI = offsetI + ((sampleI-offsetI)/1024);
filteredI = sampleI – offset;
```

2.1.7. Power Factor

Power factor is the ratio of Real Power to apparent Power. Real power is calculated by taking average of instantaneous power and RMS power is getting by multiplying RMS voltage and Current. Finally, we get power factor by taking ratio of both quantities [14]. This equation returns value from 0 to 1. When it returns value=1 means load is pure resistive and when it is less than 1 than load is reactive nature in equation (4).

$$\mathrm{COS}\emptyset = \frac{\text{Real Power}}{\text{Apparent Power}} = \mathrm{P/S} \qquad \text{------ (4)}$$

2.1.8. Battery Voltage:

Battery provide power to self-starting motor of generator. This battery is responsible to energize motor when power failure occurs to start generator backup, without any involvement of human i.e. automatically. This battery start charging as AC generator turns ON. Battery should be charged enough to maintain more than 10.5 volts across its terminal which is necessary to bear the load of self-starting motor. If battery discharge and having low voltage on its terminal than it requires to remove from generator, charge with some external source or replace by new one. It is important to monitor the health condition of battery for long and efficient utilization. Our system is continuously monitoring the voltage level of backup battery. When battery voltage cross threshold value, this system show alert that battery should be charge or replace to smoothly run the self-starting feature of AC generator. Battery charging voltage is approximately 14v and discharging is around 11v. It is needed to be measure with analog input of micro-controller; therefore, signal conditioning circuit is used to linearly convert battery voltage limit up to analog input voltage limit. For this purpose, a voltage divider circuit is employed which is responsible to convert battery voltage into analog input voltage linearly. After getting input, software algorithm corrects the voltage input level and display them on screen.

2.1.9. Temperature Measurement

Generator is machine which converts mechanical energy into electrical energy. The basic structure of generator is consisting of two main parts. One is engine and another is generator. Due to the internal combustion engine, its outer body also get hot on fuel burning. This temperature should be monitored to prevent any damage. Normally in generators, there is a cooling mechanism either in form of single fan or a complete

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radiator mechanism employed to prevent high temperature damage. Continues monitoring and sending them to the main server, of engine's temperature has also made here. Server is responsible to make log of each reading of temperature. This log information reading can be used for preventive maintenance of respective generator before any damage. A solid-state temperature sensor i.e., LM75 is used here as sensing element for temperature of engine. This sensor produce voltage proportional to the temperature of body by with it is attached. This sensor has three pins.

1. Pin 1: VCC
2. Pin 2: Analog Out
3. Pin 3: GND

This sensor produce change of 10mV at its analog output pin on the change of one degree of temperature.

2.1.10. Oil Level measurement

Another important parameter of AC generator is the condition / level of lubricant motor oil in engine part. This motor oil is used as a lubricant agent for internal combustion engines. The key function of motor oil in generator is to reduce friction and wear on moving parts and keep clean the engine from sludge and varnish detergents. It improves sealing of piston rings and cools the engine by carrying heat away from moving parts. The level and quality of motor oil should me maintain for better efficiency of generator. This project has mechanism to continuously monitor oil level and keep update main server. If the oil level reduces below from some threshold value than system alert generates to maintain level of oil or oil replacement. Oil level measurement is done here using Ultrasonic sensor. It is easy and cost-effective manner. This Ultrasonic sensor first generates some waves of ultrasound which travel in a facing direction, after strike with any obstacle they reflect. The time duration between this phenomenons is calculated and then calibrated as distance between that object and sensor.

2.1.11. Global Positioning System (GPS)

The global positioning system is originally known as Navstar GPS. It is space-based radio navigation system which is owned and operated by United State Air Force. It is a global positioning system which offers geolocation and time information on GPS receiver anywhere on Earth. In this project, GPS feature is used to find the location of respective generator from which all parameters are collected. It is possible that the generator may be in remote areas or location is unknown by the maintenance crew. This system sends the global location of generator in the SMS form along with the other parameters to the main server as shows in fig.6. This location can be easily observed on GUI screen. Each RTU have its own co-ordinates with respect to global location so if we have many RTU systems than they can be easily distinguishable.

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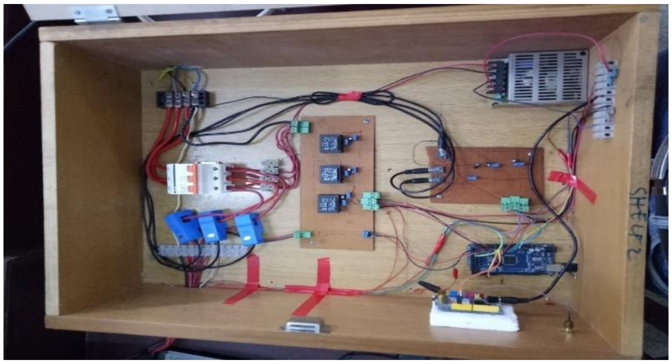
Figure 6: Hardware model of the system



3. RESULTS

Graphical user interface (GUI) screen is essential for display all the measured parameters of respective three phase systems in a main server room. In this project, LabView platform is used as a main tool for GUI which is responsible to display all parameter of generator / three phase system remotely. Also, it is performing data logging continuously. This data can be use in future for analyzing performance of system and prediction of system behavior. In LabVIEW all parameters from RTU can be easily seen on the main GUI screen. Each RTU generates SMS packet. This packet contains following parameters:

1. Location of mounted system in form of latitude and longitude coordinates.
2. Real power of each phase.
3. Power factor of each phase.
4. Temperature.
5. Oil level.
6. Battery level.

All above parameter received on GSM module and then using serial port, and NI VISA tool, these parameters read by NI LabVIEW platform. Once data arrived, it is in a stream of string character. It is required to separate each data so that each parameter can be display distinctly. For this purpose, “match string” tool is used which separates each data according to provided sequence. After separation, data which is still in string format need to convert into numerical numbers. It is done by using “Fract/Exp String to Number Function” tool. After that, every parameter can be display in graph form with respect to time or in a numeric value.

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Figure 7: Main GUI with results

Fig. 7 shows the output screen panel of the main GUI in which three phases power along with their power factor is displaying in form of graph. Also, there is thermometer on the right-hand side of the GUI screen which display temperature of respective remote unit. Another tank with the blue color filled is displaying the oil level. Battery voltage is displaying in meter on left top side of screen. All these parameters are not only displaying on GUI, but all parameters are simultaneously saving in a single file and making log of every value for future use. The whole GUI system is divided into different Tab screen. Each have its own importance. Another tab contains map which locate the position of system globally.

Figure 8: GPS MAP Location

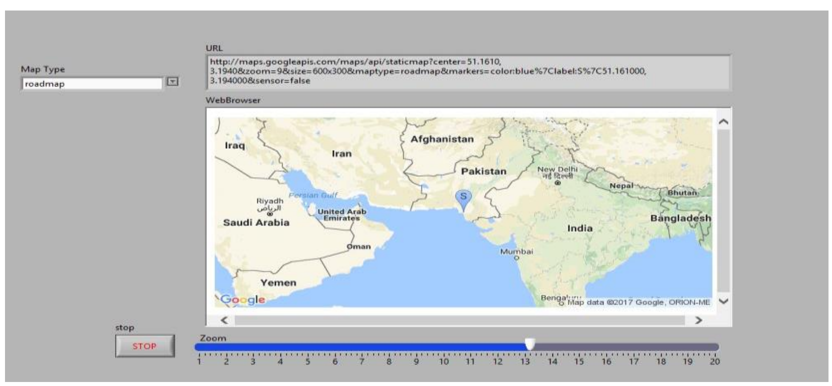

Fig. 8 shows the tab window having map which display exact location of RTU system within 10 meters. Also, it allows user to display map in three different formats following

1. Road map
2. Terrain
3. Satellite

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User can see this location with zoom-in and zoom-out feature. This allows user to not only locate the exact position but also provide map to reach required location using shortest path. This saves both time and money and provide no excuses to the field worker.

4. CONCLUSION

The world is transforming towards new and advanced method by utilizing modern tools of technology. For faster and good quality, it is essential to become part of this transformation. If we do not transform our methods, we will leave behind, but technology will not wait. This method is an example of technology transformation. It can be implemented on any three phase or single-phase system. Remote monitoring is a need of time. This system will not only update its user but also autonomously record all the data in separate files which may be useful when required. This work can be extended for renewable energy sources. Similar devices with some little bit modification can be design for fast monitoring and maintenance of solar system and wind turbine as well. Also, saved parameters in a log file can be used with artificial neural network for the prediction of new values in a certain environment. This may be helpful to find approximate useable time of sensors in different types of environments.

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