Design of Energy Monitoring System for Small Scale Wind Turbine Applications

Natalina Damanik¹, Muhammad R. Robiansyah², Almas Apriliana¹, Sahrijal Purba¹

1 PT PLN (Persero) PUSLITBANG Ketenagalistrikan (Research Institute), The Indonesia State Electricity Company, 12760 Jakarta, Indonesia
2 Lentera Bumi Nusantara, Research Centre for Renewable Energy, Ciheras, Kabupaten Tasikmalaya, West Java, Indonesia
E-mail: natalina@pln.co.id

Abstract. In this paper, an energy monitoring system for small scale wind turbine is proposed. The monitoring system process includes measuring wind turbine power output (voltage and current) and storing systems. The measurement results will be stored in a micro SD at the real time. All processes for measuring and storing data in a data logger were carried out by a microcontroller through several sensors and storage media. The data logger were designed and implemented as small as possible to save material and enhance the performance of serial communication between components inside. Hence, most of components are installed by Surface Mounting Device (SMD) packaging resulted a compact data logger size as 7cm x 8cm. Furthermore, by using FAT32 system files, the data logger is able to operate a micro SD with a size of up to 32GB. Finally, this data logger shows a good capability for measuring voltage, current and storing the results into the SD card including the measurement period.

1. Introduction
A limited energy fossil resources and awareness for clean energy resources has encouraged renewable energy technology development day by day. A small scale wind turbine is the best solution for the remote area that far away from the grid power and archipelago country. Hence there arises the need to understand the characteristics of small scale wind turbines. However, the small scale wind turbine are high initial cost, effective placement, wind fluctuation, change in wind direction and also aero-acoustic noise [1]. Therefore, it expected the small scale wind turbines must be cost efficient. Based on cost, the future continuous growth of small scale wind turbines influenced by two major factors that are initial cost per W power and the unit cost per kW-h energy produces. Therefore, an affordable rate of small scale wind turbines is a reason it can become a potential source for power production.

Wind turbine shows their optimum performance when they are sized properly and reliable source energy. A small scale wind turbine containing a compact system that support it reliability that are blades, generators, charge controllers, energy storage systems and inverters. Optimum blades would extract the maximum wind energy at their optimal wind tip speed ratio (TSR). TSR depend on the particular blades design, air foil profile and number of blades [2]. Moreover, an optimum generator would convert the energy kinetic of blades into electric power. Therefore, there is a necessary to monitor the energy kinetic conversion process into electrical power in wind turbine system. On other hands, wind turbines have highly nonlinear dynamics, with a stochastic and uncontrollable driving force as input in form of wind speed [3]. The logging of the wind behaviour is needed to study the dynamic impact parameter of the wind turbine control design under different wind loads [4].

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This study proposes a design energy monitoring system by a compact data logger. The data logger captured data in current and voltage formation that obtained from small scale wind turbine. All of data will be analysed and will be used as the basis of wind turbine design and application based on local wind potency.

2. Data Logger

Data logger is the electronic equipment which can record the formation of data accurately as current and voltage [5]. The data logger developed to support research seeking to better understand link between wind turbine performance and wind energy availability. Reading process data that are voltage and current, and continued by storing the measurement data are managed by microcontroller. Before the voltage measurement was carried out, the analog voltage of charge controller output was set as 24V - 28V which was the working voltage of microcontroller as 5V before being converted into digital data. Another hand, the charge controller output current is measured by current sensor and the output will be converted into digital data by microcontroller. Due to the stored data in analog scale form, the actual value (volts and Ampere) data have to convert when it retrieved from a storage device. Some components of compiling a data logger require a supply of 5V or 3.3V voltage. To supply a 5V voltage, a regulator with a switching-mode type is tapped from the storage system, whereas to produce a 3.3V voltage a linear type regulator is tapped from a 5V of battery step-down voltage. The proposed data logger system consist current sensor, voltage divider, microcontroller, real time clock, storage system and voltage regulator. In this design, most of components are installed by Surface Mounting Device (SMD) packaging. SMD is a small-outline IC package was smaller than its equivalent predecessor the DIP, saving about 30%-50% in PCB area that allowing the creation of much slimmer devices [6].

2.1. ACS712 Hall Effect Based Current Sensor

ACS712 is an efficient and precise current sensor for industrial or commercial AC and DC sensing currents and communication systems. These sensors have some features include motor control, load detection and management, switch-mode power supply, and overloading. Moreover, this device consists of a series of linear low-offset and precision Hall with copper conduction lines that located close to the die surface. When the current applied through this copper conduction path resulted a magnetic field. Accuracy of device measurement was ensured by optimization distance between magnetic signal and hall-transducer. Moreover, proportional and precision voltage is produced by BiCMOS Hall IC and it stabilized by chopper and low offset. The internal resistance on the conductive path is around 1.2mΩ that impact to low losses [7].

2.2. Voltage Divider

Voltage divider is an electrical circuit that has capability to reduce the output voltage. Figure 1 shows scheme of voltage divider, which is the output voltage is obtained by dividing the input voltage by two or more resistor components. The voltage distribution ratio is determined by ratio of resistance value each resistor as shown in equation (2.1).

\[ V_{out} = \frac{R_2}{R_1 + R_2} V_{in} \quad \text{..(2.1)} \]

Figure 1. Scheme of voltage divider
2.3. **ATMega 328 Microcontroller**

Atmel® PicoPower® ATmega328 / P is an 8-bit CMOS low-power microcontroller based on AVR® that enhanced the Reduced Instruction Set Computing (RISC) architecture. When the ATmega328 / P executed, the output will close to 1MIPS per MHz. Therefore, this system will optimize power consumption to speed [8].

2.4. **DS3231 Real Time Clock (RTC)**

DS3231 is a very accurate real-time clock with temperature-compensated crystal oscillator (TCXO) and crystal. This device combines battery input and maintains accurate timekeeping when the main power to the device. The resonator crystal integration enhances the accuracy of the device in the long run as well as reducing the number of parts in the assembly line. DS3231 is available in a commercial and industrial temperature range, and it offered in a 16-pin, 300-mile SO package [9].

RTC maintains information on seconds, minutes, hours, days, dates and years. The date at the end of the month is adjusted automatically for months less than 31 days, including corrections for leap years. Clock operates in a 24-hour or 12-hour format with an AM / PM indicator. There are two time-of-day alarms and a programmable box wave output. Address and data are transferred serially through a bidirectional PC bus.

2.5. **Micro Secure Digital Card**

Secure Digital Card (SD card) is a flash-based memory card specifically designed to meet security, capacity, performance, and environmental needs in line with the emergence of consumers of audio and video electronic devices. The SD card includes a copyright mechanism that complies with security in the SMDI standard, fast and reliable at greater memory capacity. The SD card security system uses shared authentication and a "new cipher algorithm" for protection against illegal use of card contents. Access without security for the users themselves is also available. Physical form factor, pin placement and data transfer protocol follow according to the SD card, with a few additions.

SD card communication is based on nine-pin interfaces such as clock, command, 4xData and 3xpower lines and it designed to operate at low voltage ranges. Communication protocol is defined as part of the specification. The SD card interface can be easily integrated into various designs including whatever the microprocessor is used. For compatibility with existing controllers, SanDisk SD cards accept as alternative protocol based on serial peripheral interface (SPI) standards [10].

2.6. **File Allocation Table 32 (FAT32) File System**

FAT32 is computer file system architecture and standard file systems for industrial. The FAT file system is an advanced standard that carries the source code of the original system files and has proven to be simple and sturdy. Due to this file system is compatible with all operating systems, this file system also developed for personal computers and the many roles of mobile and embedded systems. The maximum size of a FAT32 volume is 4GiB minus 1 byte or 4,294,967,295 (232 - 1) bytes and capable to handle SD card with capacity up to 32 GB.

2.7. **LM2576 Voltage Regulator**

The LM2576 series regulator is a monolithic integrated circuit that provides all active functions for step-down (buck) switching regulators. This regulator is capable for 3-A loads handling with perfect path and load regulation. This device is available with a fixed output at 3.3V, 5V, 12V, 15V and an adjustable version of output. Requires minimal external components, this regulator is simple to use, including failure protection and a fixed-frequency oscillator. The LM2576 series offers high efficiency replacements for the popular linear three-terminal regulator. It reduces a lot of the size of the heat sink, and in some cases no heat sink is needed [11].

2.8. **AMS1117 Voltage Regulator**

AMS1117-ADJ and AMS1117-1.2, -1.5, -1.8, -2.5, -2.85, -3.3, and-5 are three-terminal low-regulator regulators with output capability of 1A. This device has been optimized for low voltage transient...
response and important minimum input voltage. The 2.85V version is specifically designed to be used in Active Terminators for SCSI buses [12].

3. System Design and Modelling
The data logger was designed and modelled for wind turbine capacity as 500 watts that has maximum current and voltage of the charge controller output as 28V and 20A respectively. The data logger has designed to carry out the measurement periodically as per second and stored the results into data storage system directly.

3.1. Voltage Divider Circuit
Data logger installed on the charge controller output with a voltage measurement range at levels around 24V to 28V. The voltage level must be adjusted to the microcontroller voltage level at 0 - 5V. Based on formula (2.1), when ratio input and output resistance of circuit assumed as 10: 1 and R1 value is 47kΩ, then the value of R2 is as follows:

\[ \frac{1}{R2} = \frac{R2}{47k + R2} \]

\[ R2 = \frac{47k \times 10}{1 + 10} = 5.2k\Omega \]

After that, based on the above calculation and the availability of components on the market, resistor R2 is chosen with a value of 5.6kΩ. With a combination of R1 and R2 with a resistance of 47k and 5.6k, therefore the secrecy between Vout and Vin is:

\[ V_{out} = \frac{5.6k}{47k + 5.6k} \times V_{in} \]

\[ V_{out} = \pm 0.1064 \times V_{in} \]

3.2. Simulation of Circuit
Figure 2 (a) shows the schematic of simulated circuit of a voltage divider. The circuit was simulated by SI Metrix software. This simulation has a purpose to ensure a safety of microcontroller by maintain the voltage of Analog to Digital Converter (ADC) pin would not exposed more than 5.5V or below -0.4V. Therefore, the voltages at ADC terminal of microcontroller are designed to provide the output in range -0.4V to 5.5V. Thus, when the voltage exceeds or less than the range resulted an error in the microcontroller. Figure 2 (b) shows the simulation result, which are confirmed all of voltage input response sequences have been met the requirement the voltage output range as -0.4 V to 5.5 V.

![Figure 2](image_url)

**Figure 2.** (a) Schematic of simulated circuit for -5V, 24V, 28V and 60 V of voltage input
(b) Response sequence of voltage input
3.3. Hardware Design

Figure 3 shows block diagram of design hardware. During monitoring process the data logger is installed after charge controller and before the battery. Generally, all components in the data logger are supplied by the LM2576-5V regulator which adjusts the battery charging voltage to a voltage of 5V. The 5V voltage will be adjusted to 3.3V on AMS1117 to supply the voltage to the SD card. In this study, it applied 32 GB SD card memory capacity. The DS3231 real time clock is used as a reference for time measurement with hours and minutes used as a measurement time indicator, while the date, month and year are used as the names of the data files resulting from the measurements. Figure 4 shows data logger device both of sides that had produces by compact feature as 7cm x 8cm.

![Block diagram of design hardware](image)

**Figure 3.** Block diagram of design hardware

![Data logger device](image)

**(a)** 1st side  **(b)** 2nd side

**Figure 4.** Data logger device (a) 1st side (b) 2nd side

3.4. Flow Chart Design

Figure 4 shows design of the program algorithm embedded in the MCU. The data logger would not work if SD card initialization process failed that could be due to there is no SD card or invalid file system. If initialization process is succeed, system will create an .xls extended file as the current date name file. Furthermore, the data logger current sensor’s and voltage sensor’s analog outputs would be converted to digital by microcontroller. The data will saved into SD card during the measurement process and it equipped by time data from real time clock (RTC) in every second. In addition, the data would be converted into voltage and current by formula (3.1) and (3.2) respectively.
Figure 5. Design of the program algorithm embedded in the MCU

\[ \text{Voltage} = A \times \frac{5}{1023} \times \frac{52.6}{5.6} \] (3.1)

\[ \text{Current} = \left( (A - 511) \times \frac{5}{1023} \right) \] (3.2)

A : analog to digital value conversion result

4. Testing and Implementation
Table 1 lists the data that had recorded by SD card of data logger through charge controller output. It shows the measurement carried out smoothly and data in every second can be captured. SMD has the small component size, therefore this data logger more compact compared to existing data logger in market as 67%. A small size of component impacted to distance among components of circuit are close. Short distances among components improve component integration in serial communication.

| Time (s) | Voltage | Current | Time (s) | Voltage | Current | Time (s) | Voltage | Current |
|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0:00:01 | 577     | 527     | 0:00:08 | 576     | 587     | 0:00:15 | 579     | 539     |
| 0:00:02 | 578     | 526     | 0:00:09 | 576     | 602     | 0:00:16 | 577     | 560     |
| 0:00:03 | 579     | 555     | 0:00:10 | 577     | 559     | 0:00:17 | 575     | 559     |
| 0:00:04 | 578     | 590     | 0:00:11 | 576     | 572     | 0:00:18 | 578     | 572     |
| 0:00:05 | 582     | 547     | 0:00:12 | 579     | 576     | 0:00:19 | 582     | 572     |
| 0:00:06 | 581     | 575     | 0:00:13 | 559     | 582     | 0:00:20 | 582     | 567     |
| 0:00:07 | 576     | 515     | 0:00:14 | 578     | 526     | 0:00:21 | 575     | 531     |

However, the data on Table 1 is not the actual current value, but the analog to digital conversion value of current sensor output and voltage divider. Therefore, equation (3.1) and (3.2) are converting the data into the actual voltage and current as shown in Table 2. Finally, based on the Table 2 data’s, the power of wind turbine in real time are calculated and shown in Figure 5.
Table 2. Actual voltage and current

| Time (s) | Voltage (V) | Current (A) | Power (W) | Time (s) | Voltage (V) | Current (A) | Power (W) | Time (s) | Voltage (V) | Current (A) | Power (W) |
|---------|-------------|-------------|-----------|---------|-------------|-------------|-----------|---------|-------------|-------------|-----------|
| 0:00:01 | 26.49       | 0.78        | 20.71     | 0:00:08 | 26.44       | 3.71        | 98.23     | 0:00:15 | 26.58       | 1.37        | 36.38     |
| 0:00:02 | 26.54       | 0.73        | 19.45     | 0:00:09 | 26.44       | 4.45        | 117.61    | 0:00:16 | 26.49       | 2.39        | 63.44     |
| 0:00:03 | 26.58       | 2.15        | 57.16     | 0:00:10 | 26.49       | 2.35        | 62.14     | 0:00:17 | 26.4        | 2.35        | 61.93     |
| 0:00:04 | 26.54       | 3.86        | 102.46    | 0:00:11 | 26.44       | 2.98        | 78.44     | 0:00:18 | 26.54       | 2.98        | 79.11     |
| 0:00:05 | 26.72       | 1.76        | 47.01     | 0:00:12 | 26.58       | 3.18        | 84.45     | 0:00:19 | 26.72       | 2.98        | 79.66     |
| 0:00:06 | 26.67       | 3.13        | 83.43     | 0:00:13 | 25.66       | 3.47        | 89.05     | 0:00:20 | 26.72       | 2.74        | 73.13     |
| 0:00:07 | 26.44       | 0.2         | 5.17      | 0:00:14 | 26.54       | 0.73        | 19.45     | 0:00:21 | 26.4        | 0.98        | 25.8      |

Figure 6. Power data of wind turbine based on real time monitoring

5. Conclusion

Energy monitoring system by a compact data logger has been designed, produced and tested. During all the process some conclusions have been taken as follows:

- A compact data logger for energy monitoring has been designed and produced as 7cm x 8cm.
- The data logger running by FAT32 file system and storage data by SD cards up to 32GB.
- Based on testing result, the data logger is capable to measure voltage and current. Moreover, it capable to store measurement results into the storage system (SD card) along with the measurement time.
- There is a fluctuation of around 1V in the voltage measurement at several sampling points that caused by a lack of capacitance on the analog pin used for voltage reading.

6. References

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