Development of a Power Monitoring System for Backup Lead-Acid Batteries

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***Abstract*—In this paper, a power monitoring system intended for verifying backup lead-acid batteries parameters such as voltage level, battery temperature and charge capacity is developed. Such system is capable of doing the following: 1) switching between available bad and good conditioned lead-acid batteries without interrupting power service, 2) automatic charging of lead-acid batteries, 3) integrate a power/demand analyzer for determining appropriate power rating before switching lead-acid batteries. The setup experiment consists of five 6V (4Ah for 10 hours) and five 12V (5Ah for 10 hours) lead acid batteries which can be configured indifferent series or parallel connections and various lighting loads. Experiments show successful switching between batteries without power interruption, lead-acid parameter monitoring and automatic charging.**

***Index Terms*—power monitoring system, lead-acid batteries, power demand analyzer**

I. Introduction

In order to maintain smooth operation of industrial plants and commercial establishments, it is a must that a reliable power system should be in place. In any case that a primary source (i.e. the local electric power utility) failed, a secondary source or some type of DC backup batteries should be available. [1]

Lead-acid batteries as backup power source, particularly in telecommunication systems has been well-established. Several studies involving the usage and optimization of Valve-Regulated Lead-Acid (VRLA) batteries have been carried out. [2] - [4]. Indeed, lead-acid batteries are still the popular choice for power system backup.

Incorporating monitoring schemes in order to maintain the efficiency of the power system is indispensable.[5],[6]

Existing methods on power monitoring quality are staggered under sampling [7] and mathematical morphology method [8].

This study was able develop a power monitoring system for backup power supply, which can monitor the capacity for automatic switching and charging using lead-acid batteries, PIC16F877A microcontroller, and Visual Basic software.

Manuscript received May 10, 2013; revised September 7, 2013.

In order to determine the power needed by the load, a power/ demand analyzer was integrated.

The temperature, charge and discharge voltage levels, and current levels of a battery bank composed of deep cycle lead acid batteries of different power ratings for a continuous time period were monitored. These data were used for computation of the battery bank capacity, or the actual percent charge of the battery versus its nominal voltage.

Using a computer hard drive as memory storage, time stamped data can be stored and past data can be reviewed at any time for real-time data comparison.

With this simple yet reliable power monitoring system for backup lead-acid batteries, continuous and optimum performance, especially in the world of twenty four-hour trading, are guaranteed.

II. Power Monitoring System And Battery Configurations

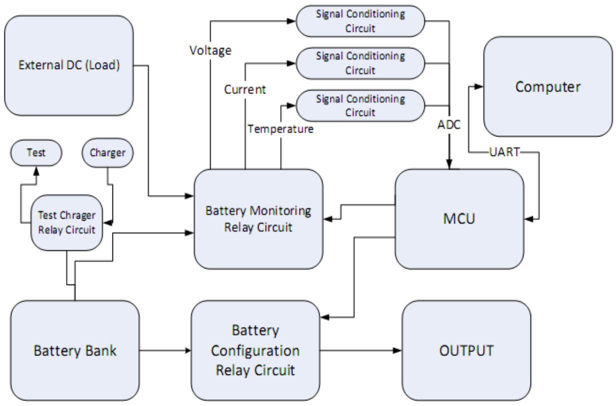

Figure 1. Power monitoring system block diagram

The general hardware block diagram of the system consists of three monitoring subsystems for voltage, current, and temperature, one output system for the load, a control system composed of the PC and the microcontroller, a battery configuration relay circuit for the different battery connections, and a battery testing and charging system. Fig. 1 shows the overall hardware block diagram of the system.

The graphical user interface for the power monitoring system is shown in Fig. 2. The upper left hand corner contains the battery parameters such as voltage and

doi: 10.12720/joace.2.1.99-102

current readings, temperature and battery status. The lower left corner displays the current configuration of the lead-acid batteries while the upper right hand corner contains the status, alarms and readings of individual batteries. Notice that there are a total of ten monitoring windows since a total of 10 lead-acid batteries were used, five 6Vdc and five 12Vdc.

Lastly, the lower right hand corner contains the various controls and functions of the power monitoring system such as type of operation, either manual or automatic mode, connection to the microcontroller and data logging activities. Plotting the gathered data can also be done for easy data monitoring and analysis.

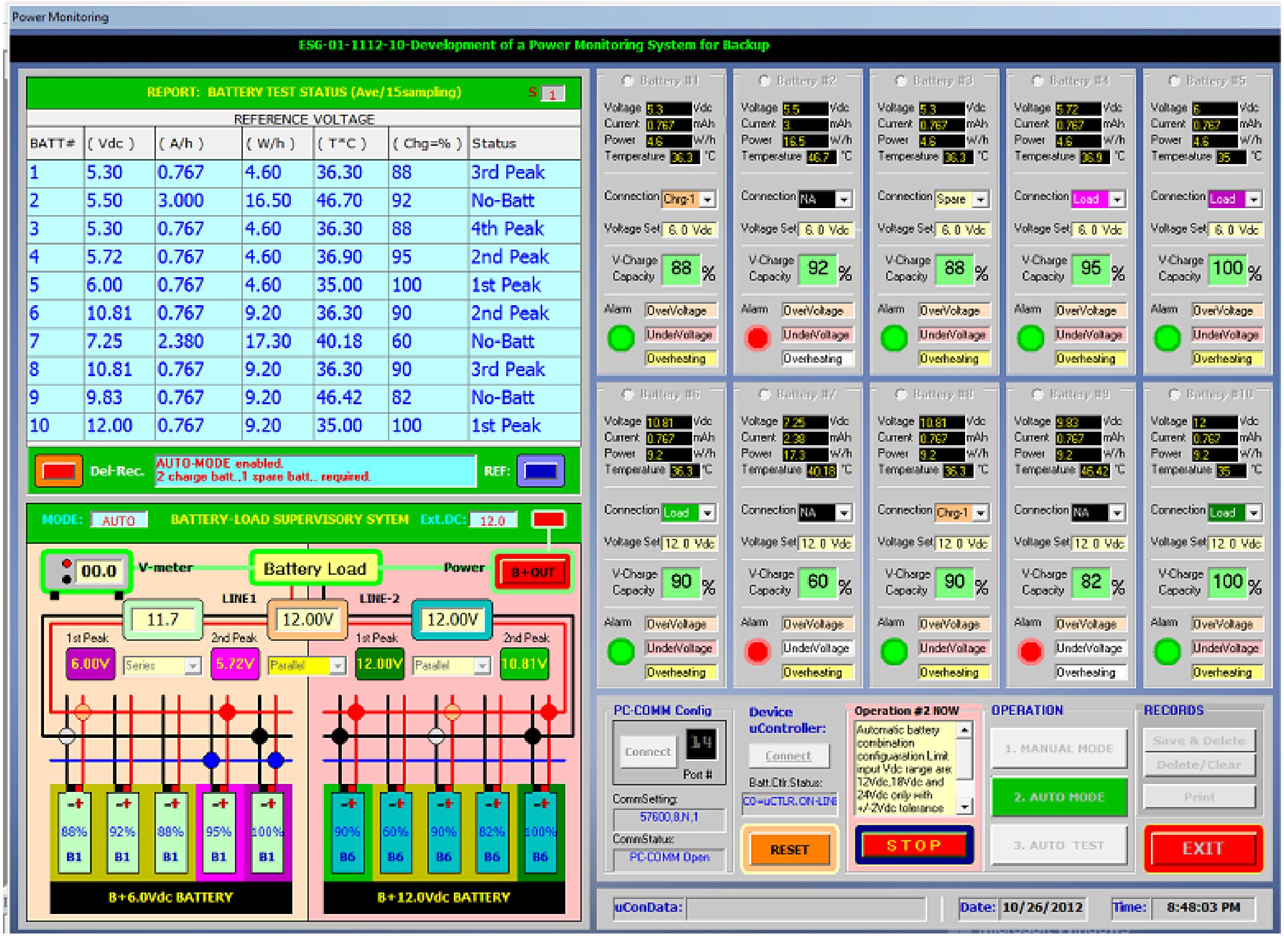

Figure 2. Power monitoring system graphical user interface

The three different modes are described in Fig. 3.

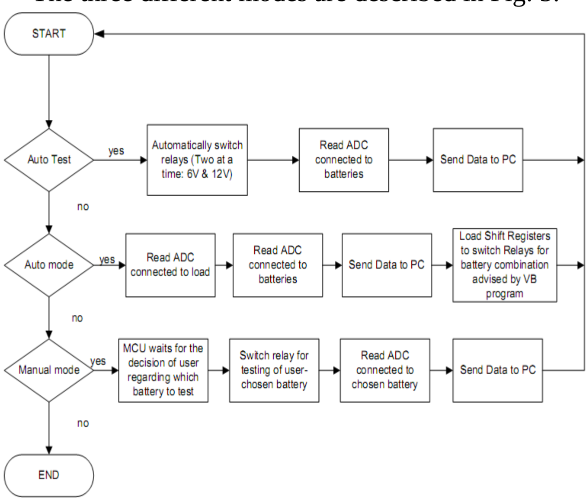

Figure 3. Operation modes of the power management system

In the program, alarm signals would also be seen. A battery would be considered over-voltage if its voltage value falls above 2V from its rated voltage. On the other hand, a battery would be considered under-voltage if its voltage falls below 2V from its rated voltage. Otherwise, the battery would be considered in good condition and would only be charged if it falls within 2V below its rated voltage. It will be considered over-heating if it reaches 45℃.

State-of-charge (SOC) is simply computed by (1).

$$SOC(\%) = \frac{V_{OC} - B}{A - B} \tag{1}$$

where:

V_{OC} = open circuit voltage
A = voltage at 100% charge
B = voltage at 0% charge

The charge capacities of each of the 6V and 12V battery types used in the experiment are computed by Equation (2) and (3), respectively.

$$Capacity_{6V}(Ah) = \left(\frac{60.6287}{I_{Batt}^{\;1.3}}\right)\left(\frac{V_{Batt} - B}{A - B}\right) \tag{2}$$

$$Capacity_{12V}(Ah) = \left(\frac{81.0328}{I_{Batt}^{\;1.3}}\right)\left(\frac{V_{Batt} - B}{A - B}\right) \tag{3}$$

where:

V_{Batt} = current battery voltage
I_{Batt} = current battery current
A = voltage at 100% charge
B = voltage at 0% charge

In order to change the battery configuration to either series or parallel connections, different types of relays and drivers were used. Three pins from port D were connected to the clock, data and strobe pins of the 4094N 8-output shift register. To be able to accommodate 40 SPST relays for the battery configuration circuit, port D were connected to five shift registers and five ULN4003 relay drivers.

There were also two sets of ULN4003 that were connected to the microcontroller's ports B and C and were also used to drive the 4PDT relays that control which battery connects to the measurement circuits and the DPDT relays that connect the batteries to either the test or charger.

Four SPST relays for each of the battery and a neutral were used to accommodate series connection between the batteries. To connect the 12V and 6V batteries to the output, DPST was used for choosing Line 1 or Line 2 and also for parallel connection. Meanwhile, a 4PDT switch was used for series connection between the two battery packs. Each battery was connected with a diode to protect the battery from experiencing load reflection when connected in parallel with other batteries.

III. Experimental Results and Discussion

Various experiments have been performed to determine the effectiveness of the developed power monitoring system intended for backup batteries. These tests are the accuracy and precision test, and switching test. The switching test will also determine the capability of the system to adapt to any load.

TABLE I. Percent Difference Between Using Power Monitoring System and Multimeters and Thermometer

Battery	VDC	IDC	PDC	Temp (in OC)
1	3.40	5.22	1.82	4.38
2	3.11	2.20	0.91	4.43
3	2.31	5.88	3.57	4.35
4	4.61	1.77	2.84	4.47
5	2.41	4.08	6.49	4.43
6	4.60	2.32	2.29	4.29
7	0.42	4.40	4.82	4.25
8	1.37	1.38	2.75	4.51
9	0.51	2.90	3.41	4.38
10	2.77	2.50	5.27	4.47

In the accuracy and precision test, each of the batteries was tested using the manual mode operation of the system prototype. The process was done in a per second basis in a period of 30 seconds, after which the 30 measurements were averaged. This is shown in Table I below.

While the manual mode operation of the system prototype was being done, each battery was also connected to millimeters and a digital thermometer in order to measure the voltage, current, and temperature parameters using actual calibrated measuring devices in order to compare whether the readings from these devices were near the measurements done by the system prototype. It can be seen that the highest percentage error is only 6.49%, an indication that the power monitoring system is accurate and precise to certain levels.

In the switching test, an external load with a required 12V voltage level with varying current requirement was used. It is to be noted that as each battery was used, its charge is depleted thus prompting the power monitoring system to switch between discharged and fully charged battery packs. This test will confirm such capability of the developed power monitoring system.

Fig. 4 shows the orientation of the batteries during auto mode test. To produce the required 12V, the power monitoring system combined two 6V batteries in series and two 12V batteries in parallel, and then it connected the two combinations in parallel. As can be seen, battery 5 and battery 4 are the Peak-1 and Peak-2 respectively in the 6V battery bank therefore they are directly connected to the load. Battery 1 is monitored as Peak-3, thus it is connected to the charger. Battery 3 is in good condition but has lower voltage ratings than the first three batteries and therefore labeled as "spare". Battery 2 is over-heating; hence, it was automatically disconnected from the system.

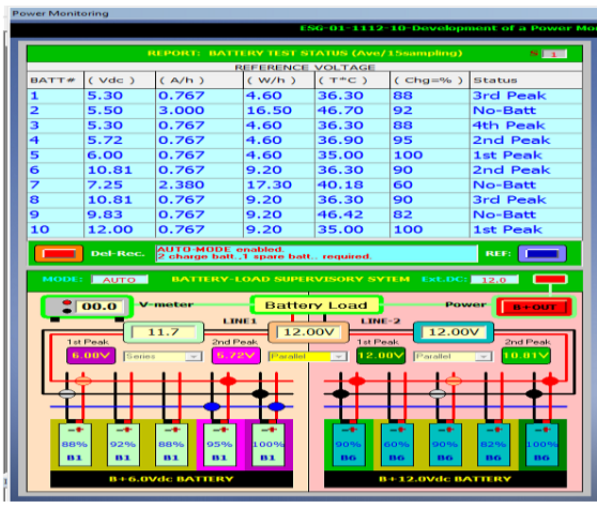

Figure 4. Power monitoring system ui during switching test

On the 12V battery bank, battery 10 and 6 are the Peak-1 and Peak-2 respectively. Battery 8 is Peak-3 and is on charge mode. Battery 7 is under-voltage while battery 9 is both under-voltage and over-heating; therefore, they were both disconnected from the system.

The power monitoring system is also capable of presenting logged data either in tabular or graphical format. In either of these ways, data are stored and time stamped for future analysis and reference. Fig. 5 and Fig. 6 show screenshots of the data logging capability of the developed power monitoring system.

LOG#	VOLTS (Vdc)	CURRENT(A/h)	POWER (W/h)	TEMP (T°C)	TIME / DATE
1	12.62	0.153	1.90	29.20	7:19:46 PM--10/26/2012
2	10.87	0.153	1.70	22.50	7:19:47 PM--10/26/2012
3	9.78	0.113	1.10	22.85	7:19:48 PM--10/26/2012
4	12.18	0.153	1.90	22.55	7:19:49 PM--10/26/2012
5	10.37	0.133	1.40	22.55	7:19:50 PM--10/26/2012
6	13.87	0.113	1.60	22.26	7:19:51 PM--10/26/2012
7	11.21	0.113	1.30	22.20	7:19:52 PM--10/26/2012
8	13.71	0.133	1.80	22.20	7:19:53 PM--10/26/2012
9	13.09	0.133	1.70	22.55	7:19:54 PM--10/26/2012
10	12.40	0.113	1.40	22.80	7:19:55 PM--10/26/2012
11	12.90	0.113	1.50	22.85	7:19:56 PM--10/26/2012
12	13.81	0.113	1.60	22.80	7:19:57 PM--10/26/2012
13	13.75	0.113	1.60	22.85	7:19:58 PM--10/26/2012
14	13.84	0.113	1.60	22.20	7:19:59 PM--10/26/2012
15	12.53	0.133	1.70	22.80	7:20:00 PM--10/26/2012

Figure 5. Logged data presented in tabular format

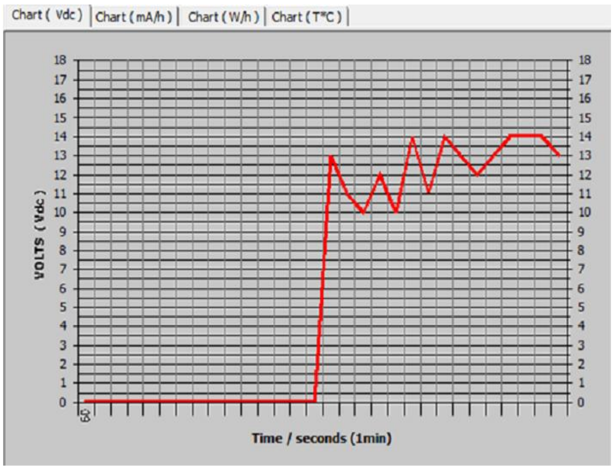

Figure 6. Logged data presented in graphical format

In the graphical format, notice that at the topmost section, chart tabs each for voltage, current, energy and temperature are seen. Clicking each tab will show the plot for the desired battery parameter which needs to be seen and observed.

IV. Conclusion

This paper has successfully presented the development of a power monitoring system for backup lead-acid batteries. Specifically, the developed power monitoring system was able to show its capabilities such as: 1) measure accurately battery parameters such as voltage, current and temperature to be used in computing for the state of charge of a battery, 2) perform switching efficiently between good (charged batteries) and bad (discharged, overheated, etc.) batteries and 3) log, store and present data for future analysis and discussion. It is also capable of automatically charging the batteries that are discharged or is below than 2V of its rated voltage.

As for future directives, further result verification through experiments must be accomplished. Other types of batteries can also be incorporated to the power monitoring system such that a database of available and useful batteries can be used and monitored. Also, the analysis of the real state-of-charge of batteries maybe undertaken.

Acknowledgment

The authors wish to thank Joel Dale I. Evangelista, Djon Paolo T. Nacario and Anne Kristianne C. Santiago for the implementation of this project.

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