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Design of Controls, Monitoring and a Energy Storage System for a Energy Harvesting Gymnasium Equipment

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Abstract. The energy harvesting development was to monitor, control and optimize the output power from the gym equipment. The designed utilized Arduino and LabVIEW based Battery Energy Storage System (BESS) that incorporated switchover capability according to the load power. The manual gears-shifting mechanism was improved with the aid of a DC geared motor and L298N controller to be automatically controlled by the user's input via a keypad.

1 Introduction

The gym weight-lifting machine is a potential application to use human's exercising energy to generate power. The key area for power generation stability is based on an efficient Battery Energy Storage System (BESS), monitoring system, gears-shifter controlling system, and the brand-new concept of fully DC gymnasium. Currently, there are several ESS technologies such as: superconducting magnetic energy storage (SMES) [1], batteries (BESS) [2], electrochemical double layer capacitors (EDLC) [3], compressed air energy storage (CAES) [4] and flywheels [5]. The most promising solution in the renewable energy storage area is that NiCd and Li-ion batteries are preferred due to their high energy density, power capability and accepted economic value [6]. The proposed research carries a comparison between the power losses in different topologies of multilevel inverters. It analyzed dominant multilevel inverters; power losses due to the semiconductors were first calculated and then simulated to confirm the findings. There are four types of multilevel inverters that were used to conduct the research. Having a minimum of 8 switching modes within the circuit increases the total power losses [7].

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2 Methodology

2.1 Battery Energy Storage System (BESS)

Fig 1 shows the block diagram of the BESS with switchover capability; two batteries, two SPDT relays, voltage sensor and Arduino Uno. The source block refers to the output power from the generator connected to the weight-lifting machine, and the load block is meant to be any DC device. Battery 1 is under charging mode and Battery 2 is discharging to the load. The voltage sensor on the load side will continuously detect the voltage across the discharging battery and send the information to the controller. When the voltage sensor detects 10V, the switchover between the batteries will occur. This is controlled by the Arduino which decides the modes of both relays when detecting the switching condition from the voltage sensor. After switching, Battery 1 will be connected to the load side and under discharging mode while Battery 2 is charging from the source. A Graphical User Interface (GUI) is also designed using LabVIEW and connected to the Arduino output to monitor the batteries operation. The main reason of integrating a switching feature in the BESS is to avoid heating-up the batteries from overcharging that can affect the lifespan of the batteries.

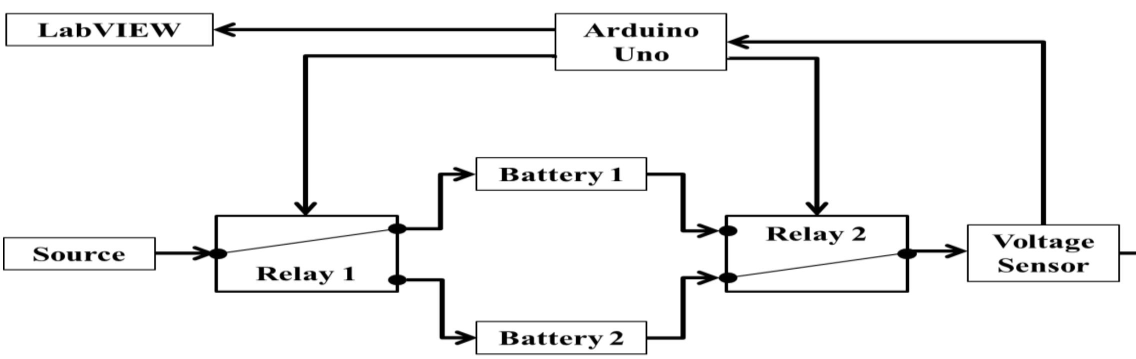

Fig. 1. BESS Block Diagram.

2.2 Gears-Shifting Mechanism Controlling System

The second objective of the research was to control the gears shifting mechanism which is coupled to the generator. The aim was to simulate the user's desired kilograms to be lifted by selecting the equivalent gear. The gears shifter is controlled by constructing an Arduino-based system which consists of a potentiometer the L298N controller, a DC geared motor and keypad. The Arduino reads the potentiometer value and sends a command to L298N Motor Controller to rotate the DC motor clockwise or counter clockwise. The shaft of 12V DC motor is attached to the 10kΩ potentiometer, which means any rotation in the motor shaft will cause a change in the potentiometer, in other words, it is used as a locator of the DC motor shaft's position. According to Table 1, when the Arduino receives a potentiometer value within the expected range, the motor's rotation will stop.

Table 1. Key and Corresponding Potentiometer Range.

Keypad Key	Kilograms	Potentiometer Range
1	21.2	646 – 663
2	22.9	566 – 585
3	25.5	508 – 525
4	27.3	463 – 482
5	29.9	400 – 425
6	32.8	300 – 345

2.3 Derivation of Theoretical Running Time

In the testing section, several experiments were conducted to determine the actual running time of the AC and DC devices when using Lead Acid or Li-Ion batteries. Before the testing, the theoretical expected running time of each device was calculated. The devices are 2Ah Lead Acid and Li-Ion batteries, 20W CFL and LED, 30W AC and DC exhaust fans, and an inverter. Eq 1 was to find the running time of each device in minutes when supplied by the 2Ah 12V batteries, until the battery voltage reduces to 10V which is the BESS switching voltage, thus the discharged voltage (V_{dis}) was 2V. Eq 2 was to determine the Battery Energy (E_B) in Wh which is to be substituted in Eqp 1; battery capacity (C_B) value is 2Ah.

$$\text{Device Running Time (T)} = [\text{ Battery Energy } (E_B) / \text{ Load Power (L) }] \times 60 \quad (1)$$

$$\text{Battery Energy } (E_B) = V_{dis} \times C_B \quad (2)$$

$$E_B = 2V \times 2Ah = 4Wh$$

Before determining the running time of the AC devices, the current consumption of the DC-to-AC inverter from the 12V 2Ah batteries should be calculated by using Eq 4. The inverter consumption will vary according to the supplied load current, therefore the current for the CFL and AC exhaust fan is found using Eq 3 then substituted in Eq 4 and Eq 5. Eqp 5 is used to find the total AC load power consumption when both inverter and AC load are supplied by 2Ah battery; calculated values for CFL only.

$$\text{Load Current } (I_L) = \text{Load Power } (P_L) / \text{Load Voltage } (V_L) \quad (3)$$

$$I_L, \text{CFL} = 20 / 12 = 1.667 \text{ A}$$

$$\text{Inverter Current } (I_{inv}) = \text{Load Current} / \text{Inverter Efficiency} \quad (4)$$

$$I_{inv} \text{ (CFL)} = 1.667 / 0.90 = 1.852 \text{ A}$$

$$\text{Total AC Load Power Consumption} = \text{Battery Voltage } (V_B) \times (I_{inv} + I_L) \quad (5)$$

$$\text{Total AC Load Power } (L_{TOT}), \text{ CFL} = 12 \times (1.852 + 1.667) = 42.228\text{W}$$

The running time of each AC/DC devices can be found by substituting the total AC/DC loads power and the Battery Energy (E_B) in Eq 1; calculated values for LED only. Table 2 is a summary for the derived running times for all devices.

CFL (T_{CFL}) = [4 Wh / 42.228 W] x 60 = 5.68 Minutes
LED (T_{LED}) = [4 Wh / 20 W] x 60 = 12 Minutes

Table 2. Theoretically Derived Running Time for Devices.

Device	Running Time (Minutes)
CFL	5.68
LED	12
AC Exhaust Fan	4
DC Exhaust Fan	8

3 Design Implementation

3.1 Battery Energy Storage System (BESS)

Fig 2 shows the BESS circuit with detailed connections. It is important to note that the SPDT relays are connected to the same digital pin in Arduino (Pin 12). The relay needs a signal from Arduino to switch, whether it is HIGH or LOW, thus completing the full circuit. Relay 1 accepts one input and can connect to two outputs, but relay 2 can receive two inputs and connect to only one output. This results in relay 2 being connected in the opposite direction of SPDT default connection. When the Arduino sends digital signal to Pin 12, both relays will switch and complete different circuits charging and discharging circuits as desired.

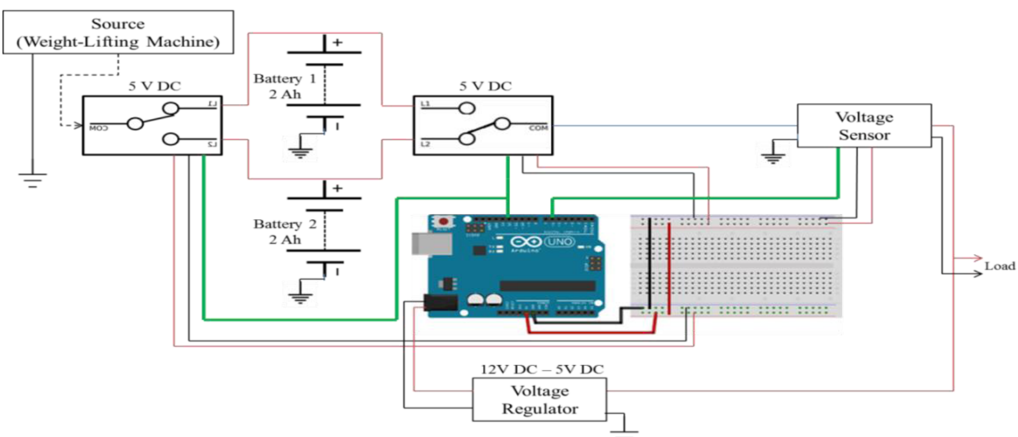

Fig. 2. BESS Circuit.

The Arduino code was developed to read voltages from 0 to 5 volts, while the voltage sensor is reading from 0 to 12 volts. When the Arduino receives the voltage from the voltage sensor, it converts the voltage from 0 to 5 volts. The Arduino has a 10-bit analog-to-digital converter that maps the analog input (0 to 5V) to 1024 (2^{10}) integer values from 0 to 1023. Voltage Sensor variable will store the integer value (0 – 1023), and ActualV variable is the voltage that is actually sensed by the voltage sensor. In ActualV formula, the ratio (5/1023) is multiplied by Voltage Sensor integer which gives a voltage range from 0 to 5 volts. To convert the voltage to 12V range it is multiplied by (2.4) which is the conversion ratio (12/5). When testing the code, the ActualV variable doesn't exactly show the correct voltage as compared to the multimeter reading (connected to the tested battery terminals), thus a calibration was needed. This was modified by multiplying 2.0797 to Voltage Sensor value after several trials to find the suitable value to correct the code. LabVIEW was used to develop a GUI to monitor the conditions of the BESS two batteries by using VISA Resource block as shown in Fig 3.

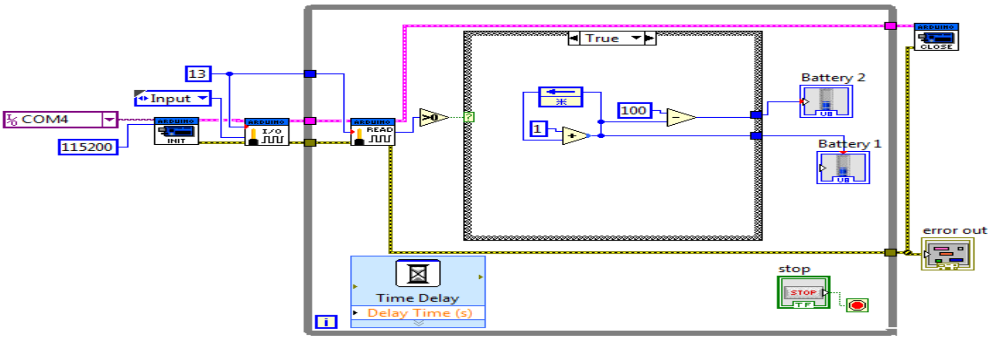

Fig. 3. BESS Block Diagram in LabVIEW.

3.2 Gears-Shifting Mechanism Controlling System

As shown in Fig 4, the constructed circuit for the gears-shifter controlling is mainly dependent on the L298N motor controller module and Arduino. The program consists of initialization of 3x4 keypad and L298N, then switch-case statement that includes six cases according to Table 1, and three if-statements in each case. To read the potentiometer value, the variable PMvalue holds the analog value from Arduino analog pin A0. Three if-statements are there to test the potentiometer value, if within or equal to 646 – 663 the code will go to MSG1 label to show the confirmation message. If the PMvalue is less than 646, the counter clockwise function will be called, the potentiometer value will be displayed and delaying of 1500ms between each change. Then, the code will go to label readPM which reads the new potentiometer value after the DC motor rotation caused by the counter clockwise function. When the PMvalue is greater than the acceptable range, the only difference will be calling the clockwise function.

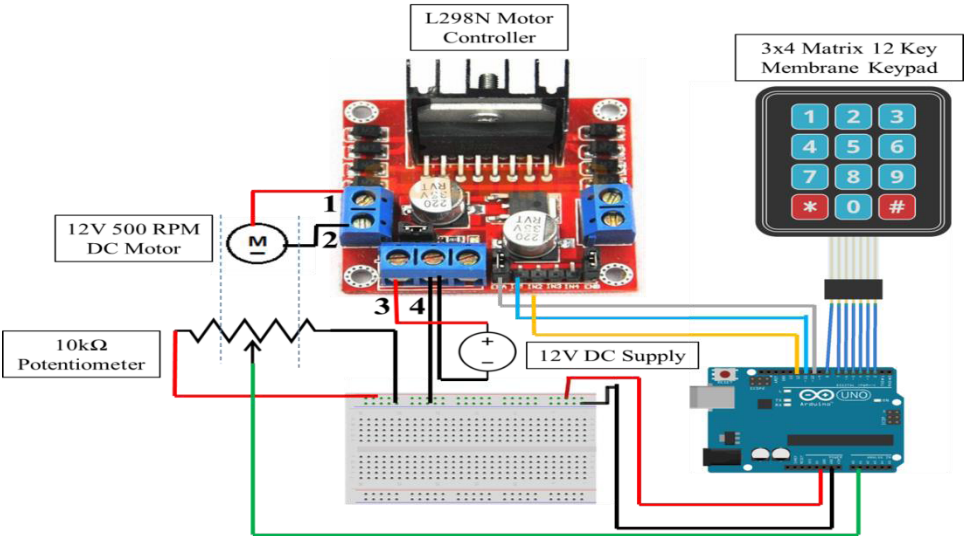

Fig. 4. Gears Shifter Controlling Circuit.

4 Conclusions

The Battery Energy Storage System (BESS) productive design was attained by developing a battery switchover controlling and monitoring scheme with the aid of Arduino and LabVIEW programming. For the Gears-Shifting Mechanism Controlling System, the prototype was efficiently designed using a Arduino-based scheme with a DC geared motor and the L298N Motor Controller Module.

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