Design and Development of a Power Management System for Kinetic Energy Harnessed through Turnstile Movement

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Abstract: Since the sustainability and inconsistency of small-scale renewable energy resources are the problems nowadays, the researcher conceptualized and created a power management system that could provide clean and sustainable energy supply which focused on kinetic energy as a renewable energy source because of its potential to be a good source of energy for small loads. This could be done through harnessing the kinetic energy from turnstile movement. As people enter gates that use turnstile, their energy would be collected and incorporated in the machine's power management system, thereby converting mechanical to electrical power.

This power management system is capable of identifying the battery that needs to be charged. Its generated power is obtained through the permanent magnet DC motor and the mechanically driven turnstile in which a gear is directly driven through the shaft by the chain. This gear has 52 teeth and its pinion has 12 teeth to produce a velocity ratio of 1:4.33.

The machine's power electronic circuit used a typical design of Linear Technology which can boost the energy harnessed while having the buck converter maintain it to a 12-V, 1-A output even with varying input voltage. A bridge circuit configuration is incorporated in this power circuit to provide the same polarity of output for any polarity of input.

The whole DC operation of the machine is driven by a microcontroller unit that utilized BASIC programming. As a result, the power management system is efficient and effective.

Keywords: Turnstile generator, Power management, Kinetic energy, Linear technology, PMDC motor.

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Introduction

Climate change is the biggest environmental crisis at present. It is a by-product of the overloaded heat-trapping carbon dioxide in the atmosphere that leads to large-scale disruptions in climate with disastrous consequences. Major contributors to this scenario are electric power plants that emit tons of carbon dioxide every year because they are powered by coal which is a dirty fuel. Besides coal, there are existing power plants that are using natural resources like wind, water and natural gas as sources of energy. Problems worsen as environmental hazards are no longer the only predicament of these limited large-scale power plants because they now concern themselves in finding an alternative solution to the inadequate supply of these natural resources. It is through this context in which improving the efficiency of electricity use, shifting power generation of plants to lower emissions of carbon dioxide and expanding renewable energy resources are seen vital in providing solution to the existing problem. However, some options are not seemingly viable and desirable.

Although the most cost-effective way to generate electricity is through a very large power plant due to economies of scale; this however, is not always possible or even desirable. Once the power-generating capacity is concentrated in fewer but larger plants, the distribution cost of reaching the outlying customers increases along with the electrical distribution losses in long power lines. This may not be practical in providing a connection to the distribution grid system of some remote locations. Meanwhile, if renewable energy resources will be used, installations must be located where these resources are available and by their nature, the size of these installations is limited by the magnitude of the available energy flow. Expanding the use of renewable energy resources is another solution being considered. In fact, some of these are now being studied and used because they are sustainable and offer alternative solution. These include wind, water and solar energy. Many small-scale installations are designed to take advantage of these renewable energies. These depend on capturing naturally occurring energy flows from the elements which are intermittent, notoriously unpredictable and liable to wide variations in their intensity when the energy is available. At the same time, because the number of consumers is small, the load too is subject to wide swings in demand. But despite the availability of energy, the small scale of operations limits the average amount of energy which can be captured and the diverse nature of the methods needed to convert it into useful electric energy both result in poor conversion efficiencies.

Considering these various options regarding the existing problem, the researcher decided to focus on kinetic energy as a renewable energy resource because it has the potential to be a good source for small loads. In fact, human power can be converted from mechanical to electrical power by using turnstile. The more people entering the turnstile of gates, the more energy can be harnessed and used.

Objectives of the Study

The study aimed to design and develop a power management system for kinetic energy harnessed through turnstile movement. Specifically, it aimed to achieve the following sub-objectives:

1. To design a power electronics system that will handle the generated power, battery charging, and load consumption
2. To create a power management system that determines the status of power storages and electronically switches the load to the full battery and charging to the empty battery and
3. To test the functionality and reliability of the project.

Materials and Methods

Descriptive and developmental methods were used by the researcher in conceptualizing the project. These methods coupled with various data gathering sources such as interviews and consultations, books, internet and studies and projects conducted in the past enabled the researcher to describe and document its development. Project development focused on the procedures of analyzing, summarizing and interpreting how the conclusion would be attained. During the process, the researcher focused on the designing of the project appropriately, creating the layout, selecting tools and components and determining their availability in the market – size, quality, reliability, effectiveness and durability.

Establishing the requirements is a common denominator in manufacturing or creating simple to complicated products, machines, or equipment. In the development of this project, the researcher considered the availability of the needed materials and components in the market and the knowledge and skills in terms of their proper installation and troubleshooting and MCU programming to ensure that the project will perform its intended function. The project needs rectifiers, converters, storage batteries, microcontroller and PMDC motor. The selection of these appropriate components as well as designing the electrical and electronic circuits and the mechanical part is the most serious task to be completed. Moreover, programming of the MCU also plays a big role in this project.

The microcontroller unit (MCU) is the center of the project's hardware system because it carries out specific tasks programmed within it. It is responsible for controlling the whole system through which storage batteries were assigned to different functions of the system. The project utilizes renewable energy from the kinetic energy harnessed from people passing through a turnstile. After rectification, a DC to DC conversion was done to step up the small amount of energy harnessed. Converters are among the most important components in this project because they are the ones responsible for the conversions and for boosting voltage.

The design and layout of the components needed served as the foundation towards the assembly of this project. Selecting the MCU, storage batteries and motor allowed the researcher to come up with the most suitable components. The motor and microcontroller are responsible for power generation and control of the operation of the system. The project is mechanically driven; it uses a gear train with a mechanical ratio of 1:4.33. Then the harnessed DC power from the mechanical drive (kinetic energy) would go through the step down DC-DC conversion and would maintain the required DC input to the Boost system. A chain connects the driving and the driven gear. The turnstile is axially connected to the gear at the bottom and the pinion is directly connected to the DC motor. The turnstile drives the gears in one direction in order to have power over the shafting of the DC motor.

The Buck-Boost maintains the DC voltage output from 12V to 15V that would create at least 1A of direct current output. The DC-generated voltage ranges from 3V to 25V of output that depends on the mechanical drive of the turnstile. The microcontroller serves as the brain of the system which delivers task towards its respective parts (components). It is responsible in controlling the flow of the whole system. It controls the storage batteries as it dictates their relaying to ensure continuous supply in the load side. The converters were used to make the kinetic energy harnessed useful and be stored in the batteries.

Results and Discussion

The developed Power Management System for Kinetic Energy Harnessed through Turnstile Movement provided at least 1 A current output and supplied voltage ranging from 3V – 25V. A microcontroller served as the brain for the system's entire operation because it directed the switching of three batteries once the battery on the load side has insufficient supply. These batteries are capable of delivering continuous supplies because their maximum capacity is 7Ah. A permanent magnet DC Motor, 24V DGM-0043-2A, having dimensions of 60mm square x 39mm thick for gear head, 50mm long x 36 mm diameter for motor and 6mm axle diameter x length 30mm was used in the project. The speed of rotation depended on the turnstile movement. And since the output voltage is proportional to its speed in PMDC motor, a buck-boost was used to respond to input voltage variations. The buck boost and buttons are the main components to operate the tasks of the microcontroller unit (MCU). This MCU displays information to the Light Emitting Diode (LED) in order to identify the operation.

From the MCU, the relay connects and disconnects the battery from the connection to the AC load if power uncertainty is found. To control the charging system, the relay sets the batteries from the Charging, Spare, or Load status which also determines the power needed. The default connection of the power inverter is on the Load battery status. Three (3) battery status indicators are shown in the MCU through LED; thus, it can identify if Battery 1, 2, or 3 are in the status of Charging, Spare, or Load.

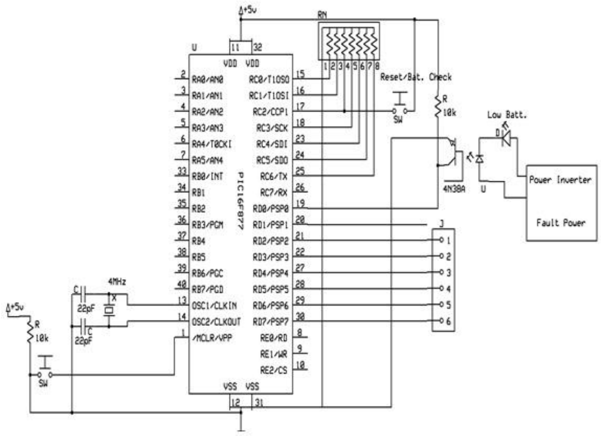

Figure 1. Microcontroller Unit Core

The function of the microcontroller is to control the input-output interfaces. Output interfaces are connected to J1 with number connections from 1 to 6; J1 is connected to the PORTD of the MCU while input interface is directly connected to PORTC and is set to pull down resistors with a value of 10K ohms. Low battery signal indicator is directed by the Power Inverter Fault Power which is connected to opto-isolator IC 4N38A to switch the MCU input. A crystal oscillator is set to 4MHz as frequency clock for the MCU core. In Figure 2, there are six (6) switches (SW) connected to three (3) batteries. SW represents the 6 SPDT relays. Step-down DC-DC conversion was used to regulate the power; 12V was used to charge lead acid type batteries; and 5V was used to power the micro-controller unit.

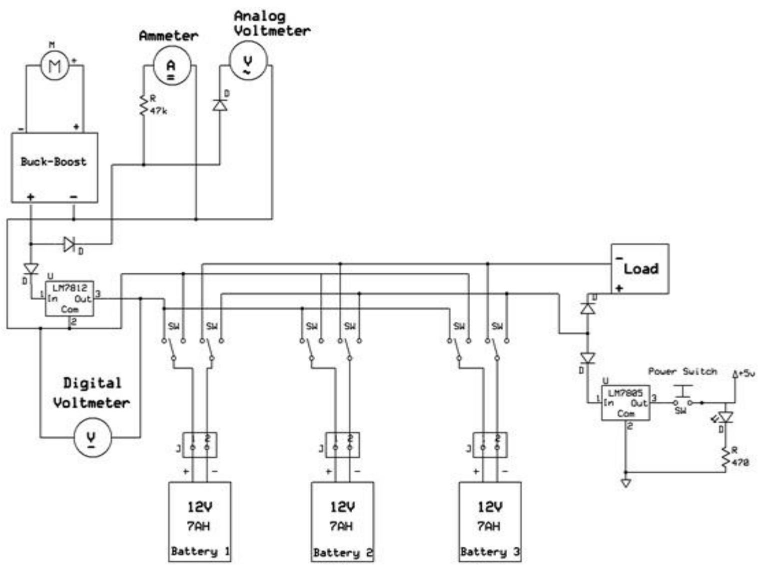

Figure 2. Schematic Diagram of the Batteries

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Ammeter and voltmeter were utilized to display the harnessed power from the output of Buck-Boost Circuit. Diodes were intended for forward bias function in order to limit the loop current for each battery circuit.

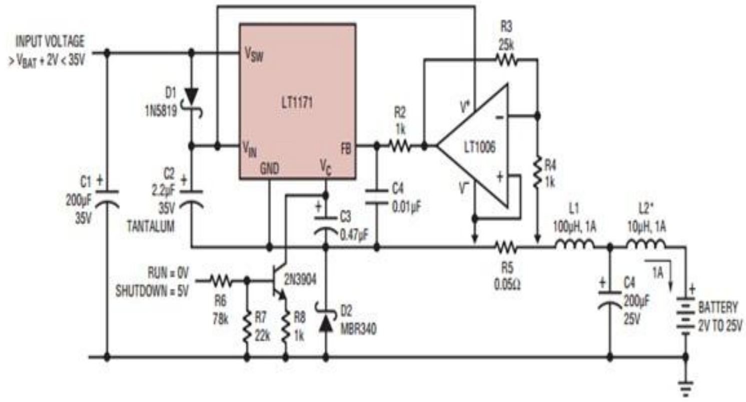

Figure 3. Schematic Diagram of Buck-Boost

LT1171 is a current mode switcher. This means that the switch duty cycle is directly controlled by switch current rather than by output voltage. As shown in the diagram in Figure 3, the switch is turned “on” at the start of each oscillator cycle. It is turned “off” when switch current reaches a predetermined level. The control of output voltage is obtained by using the output of a voltage sensing error amplifier to set the current trip level. This technique has several advantages. First, it has immediate response to input voltage variations unlike ordinary switches which have notoriously poor line transient response. Second, it reduces the 90° phase shift at mid-frequencies in the energy storage inductor. This greatly simplifies closed loop frequency compensation under widely varying input voltage or output load conditions. Finally, it allows simple pulse-by-pulse current limiting to provide maximum switch protection under output overload or short conditions.

A low dropout internal regulator provides 2.3V supply for all internal circuitry on LT11711. This low dropout design allows input voltage to vary from 3V to 60V with virtually no change in device performance. A 100 kHz oscillator is the basic clock for all internal timing. It turns “on” the output switch via the logic and driver circuitry. Special adaptive anti-sat circuitry detects the onset of saturation in the power switch and adjusts driver current instantaneously to limit switch saturation. This minimizes driver dissipation and provides very rapid turn off of the switch. The system was tested and evaluated by monitoring the system. Tables 1 and 2 show the result of the researcher’s tests on functionality and reliability. She tested the system in different conditions many times. It is conveyed in the table that functionality and reliability are dependent on the system’s expected output compared to the actual output of each input operation. The results show that the system is accurate in performing the input operations of the system.

In Table 1, given the time for each turn, the voltage and current outputs drawn by the PMDC motor were measured as well as the outputs drawn at the buck-boost converter which served as the charge delivered to the battery in charging status. The half-turn (one-way) for 4 hours–each turn is about 3 seconds–requires at least 4800 door passers. Similarly, one turn (two-way) for 4 hours needs at least 2400 door passers while a turn for 8 hours necessitates 1200 people entering the gate. A 7Ah battery is needed to be charged for at least 8.2 hours.

Table 1. Functionality Test of the Project

Hrs. of Operation/ Condition	PMDC Motor Vout/I	Buck-Boost Vout/I	Battery Charge	Time to Full Charge
½ turn/4 hrs.	3.24V/0.5A	10.94V/ 1A	1.2 Ah	22.1 hrs.
½ turn/8 hrs.	7.85V/ 0.9A	11.12V/ 1A	3.4 Ah	15.6 hrs.
1 turn/4 hrs.	8.72V/ 1.1A	11.95V/ 1A	3.6 Ah	14.8 hrs.
1 turn/8 hrs.	11.94V/ 1.2A	12.02V/ 1A	6.5 Ah	8.2 hrs.

The project determined the sustainability of the supply. Calculations were made. An initial load of 11W DC bulb with operating current of 560 mA which is desired to operate for 12 hours was used. The 11 W from a 12-V source required the battery to deliver 0.916 ampere DC. With these data, it can be assumed that an 11W DC-bulb could be used at approximately 7.68 up to 8 hours. Likewise, adding more loads, i.e. using 2-11W DC bulb discharges the battery in 4 hours. The results indicated that the continuous use of turnstile for at least 8 hours per day could make the project sustainable.

Table 2. Reliability Test of the Project

Hours of Operation	Buck-Boost	MCU Input	Remarks
4	12 V	Algorithm A/B/C	Reliable
3	12 V	Algorithm A/B/C	Reliable
5	12 V	Algorithm A/B/C	Reliable

Reliability is the ability of the system to perform and maintain its functions in a routine or in unexpected circumstances within a time through the Buck Boost and MCU. Unreliability, on the other hand, means that the system cannot determine the unexpected circumstances or circumstances within a time of operation through the Buck Boost and MCU. It also means that the overall time of operation is not same with the expected output. In Table 2, a reliable result was evident through the series of trials performed as to interchanging of batteries for charging, spare or load status. The overall time of operation is fully functional.

The project is 100% functional based on the functionality test done on the project. It was proven that the project can harness kinetic energy through turnstile movement, store the energy in the storage batteries and provide a usable supply in the load area for at least 11W. With the reliability tests done on the project, it was proven that the project is 100% reliable in maintaining the 12V, 1 A output in the buck-boost design and relaying the batteries in the power management system. The project was 100% reliable in switching electronically to the battery that needs to be charged.

Conclusion and Recommendation

Based on the findings, the following conclusions were drawn:

1. The capacity and speed of the turnstile are based on the number of people passing through the turnstile. The proposed system used renewable energy and the energy harnessed could be used to power DC loads.
2. Buck Boost design using Linear Technology is capable of maintaining the output current of 1A.
3. MCU was programmed using BASIC programming. Such program controlled the whole operation of the DC system. The power management system could determine which

battery storage needs to be charged. Its MCU could control the switching algorithm. As a result, the design of the power management system is efficient and is found very effective.

4. Through the technical review method and iterative testing in this study, the result on testing is appropriate to the expected output which is equivalent to 100% functionality and reliability. The system has been tested with different conditions and based on the results of the tests the output design is fully operational.

Although the current features of the output project will help for saving energy, still there are things to be done. The following are the recommendations for future enhancement:

1. Gear trains should be used to improve the mechanical gear system and to gain higher ratios from the direct shafting drives.
2. The DC load may be driven to at least 50W.
3. At least 22AH of 12V batteries for bigger capacity and storage should be used.
4. Buck boost that can provide more than 1A current output should be incorporated in the project.
5. An MCU that has LCD display to identify or determine the status of batteries in a readable form can be utilized.
6. The power management system may use 6 battery banks for additional storage.
7. Turnstiles may be separated and assigned on entrances and exits.
8. A flywheel balancer on the gear system may be used to continuously drive the generator.

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