Power Injection To Public Network, From A Permanent Magnet Axial Generator Coupled To An Exercise Bike

Inyección De Energía Eléctrica a La Red Pública, Obtenida De Un Generador Axial De Imanes Permanentes Acoplado A Una Bicicleta Estática

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ABSTRACT

This paper presents the design and implementation of a device capable to manage power delivered by a permanent magnet axial generator, coupled to an exercise bike, in order to inject the generated energy to a residential point of public voltage electrical network, for this purpose an electric and electronic circuit is was developed to generate, manage the store and inject energy. Also, an application based on a microcontroller PIC16F877A was implemented, which manage and regulate the proper operation of all the components implemented. As result of this project, an stand-alone device was created, capable to inject to the public power network an average of 190 Watts (W), 78 Wh of energy with process efficiency of 85.85%, with open possibility to be applied for systems with higher generation capacity.

Keywords: Power Generation, Power Management, Power Batteries, Axial Generator, Power Injection To Grid, Charge Controller, Microcontroller.

RESUMEN

Este articulo presenta el diseño e implementación de un equipo que gestiona la energía eléctrica entregada por un generador axial de imanes permanente acoplado a una bicicleta estática, con el fin de inyectar la energía a un punto de la red pública de baja tensión, para esto se desarrolla un circuito eléctrico que genera, almacena e inyecta la energía eléctrica, también se desarrolla un circuito electrónico de control basado en un microcontrolador PIC16F877A el cual está encargado del funcionamiento de todos los dispositivos implementados.

Como resultado de este proyecto se obtiene el prototipo de un equipo automático que inyecta a la red eléctrica publica una potencia promedio de 170 w, una energía de 78 Wh y una eficiencia en el proceso de 85,1%, Además el diseño implementado es aplicable para sistemas de mayor potencia.

Palabras clave: Generación de electricidad, Gestión energética, baterías eléctricas, Generador Axial, Inyección de Energía Eléctrica a la red, controlador de carga, Microcontrolador.

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Introduction

According to the Interamerican Development Bank (IDB), the energy demand for the next few years in Latin America will increase, making necessary to explore alternative sources of power supply to be responsible for this consumption and serve as support for the distribution network [1].
Distributed generation is an applicative solution which power is produced near to consumption centers, with the purpose of self-sufficiency and sometimes sell surplus energy to the grid [2]. Starting from that definition, this paper presents the design and implementation of a prototype whose function is control the charge of 3 batteries (Lead Acid), getting energy from an axial permanent magnet generator coupled to a stationary bike, later this energy will be injected to the distribution network at end user single-phase of low voltage node.

The system is controlled by a PIC16F877A microcontroller, which programing uses two processes, first is a buck converter to control the current of the battery charge (constant-voltage constant current method) and second is an automatic relay configuration to connect the batteries to the inverter who is connected to the public grid for power delivery. To design this prototype some tests were performed for injection machine modeling and methodology that defined both components as the operation mode.

Finally the results of the machine obtain a power of 78Wh injected and a prototype that works automatically.

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Development Methodology

As result of previous research in laboratory for alternative sources of energy, of the University Francisco José de Caldas in Bogota, an axial permanent magnet generator was implemented, this machine was coupled to a stationary bike and play the role within the prototype as power supply to be stored and later fed into the grid of final user, this generator is constituted for 3 stators, 27 coils and 2 rotors with 36 neodymium iron boron magnets and delivers a sinusoidal signal [3], with the following characteristics equivalent model:

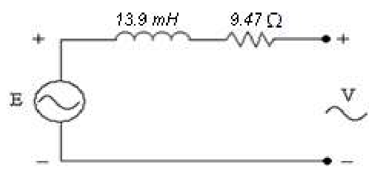

Figure 1 Model equivalent axial permanent magnet generator AC voltage, output terminal: 0-73 V peak
Power frequency: 0-80 Hz
Connection: single phase
Z: 9.47+ (0,087*f)i [Ω]

Since this data, they develop stages for the design and construction of injector device:

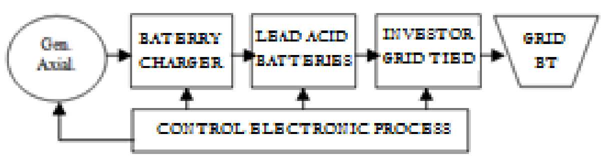

Figure 2. Block diagram of the prototype grid feeding.

Stage signal conditioning

This type of generator have a particular characteristic, voltage and frequency are dependent of rotational speed which gives the user when pedal the bike coupled to the generator, having a potential variability in the mode of pedaling. Aiming to adapt the electrical signal for better control of it, a stage of full-wave rectification is implemented with capacitive filters [4], obtaining a variable DC signal amplitude with ripple of 3%, with the following output characteristics:

DC voltage output terminal empty: 0-53 Vdc
DC output terminal voltage under load: 0-37 Vdc
Maximum output current 1.3 A

Energy storage

Generator tests, found a maximum power of 48W, given the variability of the speed applied for average pedaling routine, the optimal way to store energy is established using lead acid batteries of 12 VDC @ 7.5 Ah sealed.

Battery charger

A battery charger was implemented using the method of "constant current constant-voltage" suitable to the voltage and current levels of generator described to charge a lead acid battery efficiently.

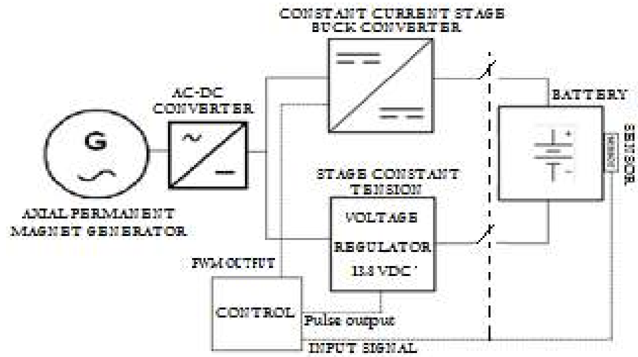

Figure 3. Electrical connection diagram battery charger

A battery charging circuit is designed and implemented using a cycle of constant current from DC-DC Buck converter [5], which it is governed by a standard PWM, generated and controlled by PIC16F877A. For constant voltage stage is used a regulator electronic circuit for13.8 VDC.

Figure 4 shows the superposed chart of current and voltage applied to each battery controlled by the charger.

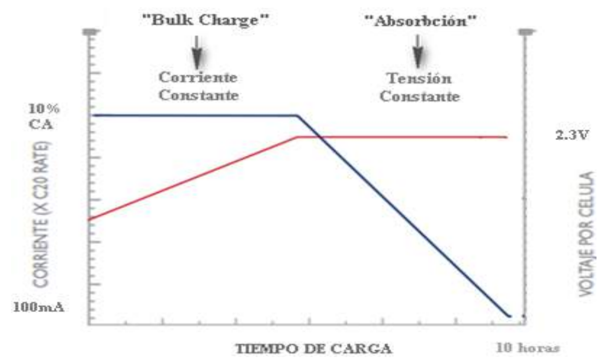

Figure 4. Stages for battery charge

Injection to the network:

For the conversion DC-AC an inverter with factor of 0.9, with average power injection to the network of 150 Watts, is chosen for Grid Tied inverter DC-AC AEP WPI-36V150W120, equipped with synchronization tools. Common inverters on the market have DC input power levels greater than 24VDC, for this reason was necessary that the voltage level supplied for storage devices, in this case, lead-acid batteries, reach a level of 36 VDC, in the first instance, was considered to use a type DC-DC converter Boost [5], which allow to raise a 12VDC battery to the required level. However, coupling problems with the other devices, reflected in substantial efficiency losses, for this reason, was decided to perform an array of contacts automated and controlled by a microcontroller to connect in series three 12-volt batteries.

Additionally, for this implementation, was necessary to consider low levels of voltage, current and power, delivered by generator, this is why the battery charger is only able to deliver energy to one battery at the time, to solve this, a switching mechanism was developed allowing to perform functions of battery connection and charger control for each cell. An automated way governed by the programmable control device.

The prototype developed has he following two functions:

- Load control of 3 lead acid sealed batteries, 7.5Ah 12VDC. Battery charger implemented switches each battery autonomously, once load level is reached, move to the next. The same control device coupled to the A/D converter determines that loading point remains constant current or constant voltage complying with the charging requirements specified by the manufacturer. In Figure 5 upper part, the connection diagram shows the contacts used.

- Discharge lead-acid batteries and injecting energy into the inverter. This process is performed by another group of contacts set to connect in series the three storage systems commanded by an external signal that also connect it to Grid Tied inverter, with its output connected to the low voltage network at end user node. In Figure 5 bottom, the connection diagram for this stage.

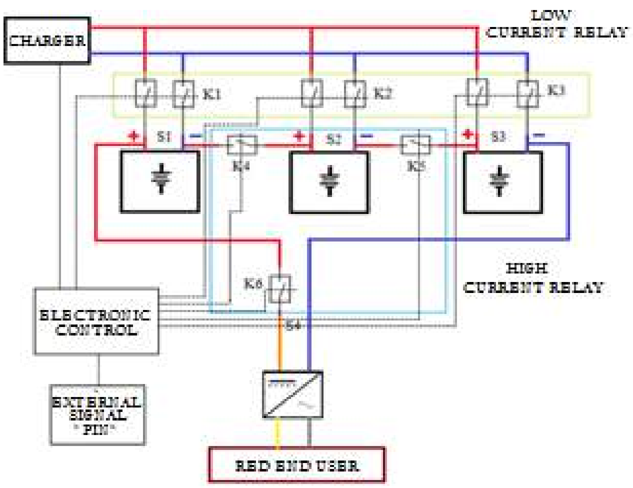

Figure 5. Relay connection for automatic switching of battery charging and connection to the Grid Tie Inverter.

Power injection period to LV network

The time of energy injection process is determined theoretically by the ability of batteries to deliver continuous power; this value is set from the discharge curve determined by the manufacturer [4], with reference to the rate of discharge of the battery which in this case is 0.66. The ICA value shows a time range of battery discharge of 30 to 60 minutes [6].

Process Control and Peripherals

A control system is implemented based on a PIC16F877A [7] microcontroller, which its PWM feature is used, also A/D converter and ports, to perform routines that govern the different devices, sensors and monitor signals necessary to implement various processes, such as:

- Charging and discharging of batteries
- Injection of energy to the grid
- Turning the controller equipment
- Audible and visual informative signals about battery status and use of the machine to the user
- Control of idle operation of the prototype

Also support devices and peripherals as implementation informative display of voltage and current of battery, front control for bicycle user, auxiliary system Li-ion battery as power source for electronic devices equipped with external charger and a charge indicator incorporated.

Experimental Results

Of the construction of the machine (Figure 6), tests were performed to determine the proper operation of devices for power injection to the network, this consist in:

Figure 6. Main parts of the prototype machine storage and injection of electricity network.

Testing the battery charger

Those tests verify that Buck converter makes the change of magnitude maintaining constant current in each battery charge, also, PWM normal operation of the electronic components and, check the actions taken to control different situation for machine use, ensuring proper operation of the PIC software.

Battery charge – Time test

According to test with control the obtained time an average time of 12.25 hours.

Grid feeding test

Injection of energy stored in the batteries was done, this download is deep, and the power curve defined the injection that can deliver the inverter.

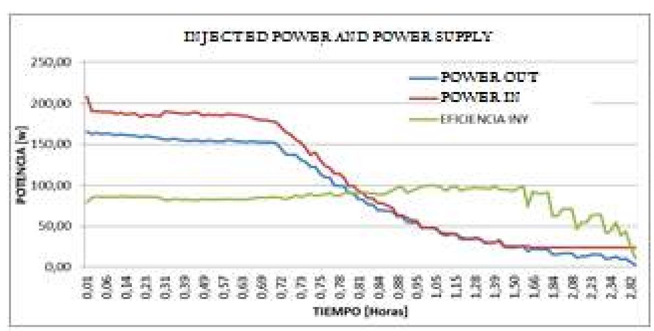

Figure 7. Power fed into the grid

For the description of this curve is divided into 4 parts, resulting in the following function:

$$f(x) = \begin{cases} 17{,}77x^2 - 29{,}474x + 164{,}54 & 0 < t \leq 0{,}71\ h \\ 2656{,}7x^2 - 4731{,}3x + 2173{,}3 & 0{,}71 < t \leq 0{,}84\ h \\ 151{,}23x^2 - 407{,}36x + 305{,}18 & 0{,}84 < t \leq 1{,}42\ h \\ 3{,}3289x^2 - 27{,}569x + 58{,}054 & 1{,}42 < t \leq 3{,}64\ h \end{cases}$$

Equation 1. Characterization Curve injection to the grid

This function determined the injected energy value at 78 Wh, the total energy that is able to inject the prototype is 190 Wh and the instantaneous maximum power that was injected was 192 W.

Energy Balance

The energy balance is based on a consumption which requires the prototype for a charge cycle versus injection and energy supplied to the grid.

Energy consumed by the prototype: The prototype have a lithium ion battery (Li-ion) [8], which feeds the control electronics and switching on the loading and feeding operation; this supplies energy to auxiliary services as prototype battery charger and power injector to the network.

Energy injected into the network: The network delivery investor an energy of 78 Wh.

Ending Balance: The power resulting from this process is:

$$78\ \text{Wh} - 10.248\ \text{Wh} = 67.752\ \text{Wh}$$

This represents an efficiency of 86.86%, in each cycle.

Conclusions

• A design and implementation methodology was for very low power generators.

• According to electrical performance tests, was found that permanent magnet axial generator used is a machine that delivers a very low power, pushing to use an energy storage processes by battery pack for long charging time of each cell.

• The charging method for lead acid batteries was the MSRP, but was necessary to limit the initial charging current of the battery at 0.1C capacity storage device, since the generator has to deliver higher current limiting to 1.3 A.

• For optimum operation of the inverter was necessary to present alternatives to increase the DC input voltage, evidencing that serial interconnection of batteries was the optimal arrangement. Alternative of Boost converter is presented but was discarded due to the inefficient operation at this implementation.

• Using a battery pack was viable, since its control does not demand a significant power in the energy balance of the prototype.

• The device is capable of deliver up to 45 minutes of constant energy at a high level, but this value should be restricted because of the ability to deep discharge, in order to avoid premature damage of batteries.

• Injection tests network shown no variations or peaks, due change of the equivalent impedance which is reflected in the injection site, because the variation of load required on site.

• Control for power delivered was designed for specific variables of generator, but this charger can be used to deliver up to 2 amps of load and certain modifications can be applied to processes of higher currents and voltages.

• Charge controllers with low power batteries are not commercial but are required to build the design with all component sizing, Special attention must be taken with the design of it, because oversized devices makes arise inefficiency.

• This project could be implemented in a fitness center or gym with high number of rotary motion machines, in order to implement the same type generators over different machines equipped with any electronic system similar. It will benefit to add the power generated by users to charge batteries in a controlled quick and efficiently way.

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