

Design of energy generation system by using spinning bikes

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Abstract. This paper presents the design of a system that generates energy by using the work done by a crew on a spinning bike. The builded system is configured by two subsystems: connection and injection of real-time power to the grid connection and power isolation for specific loads. The first subsystem will have twelve (12) units and the second will have six (6) units.

1. Introduction

Escuela de Ingenierías Eléctrica, Electrónica y de Telecomunicaciones (E3T) from Universidad Industrial de Santander (Bucaramanga, Colombia), has been working on the design of different applications [1] in sustainable energy infrastructure, keeping as goal the reduction of electric power consumption from the public. Having this as main aim, it has come up with a design based on the purpose of contributing to encourage the college community to take care of the environment. This paper presents the design of a system that takes advantage of the kinetic energy developed by the legs, part of the human body with more strength, of a crewman on a spinning bike. Generally, this energy is transformed and wasted as heat. At the beginning of the paper, it will be described an overview of the generation and system sizing. Later, it will be presented an energy analysis applied to the design and the system will be monitored in order to understand its function variables. Then, any financial considerations are presented; and finally it will be shown results and conclusions.

2. Overview about the generation system

Doing exercise by using bikes allows improving metabolic functions, cardiovascular system and respiratory system, it also burns a considerable amount of calories while the user is increasing his muscle tone and mass; in addition, cycling adds an emotional benefit by reducing stress [2]. The mechanical operation of the bicycle requires a boost from a pair of pedals with the legs. Its flywheel is the part of contact in charge of transmitting the energy from the bicycle to the generator. According to [3], the average power generated by a person on a bicycle is between 270 W and 400 W [4].

The use of energy will be given by changing the kinetic energy into electrical energy in the DC generator according to its wide range of operation speed, as the limitations of the commercial supply of generators for these applications [5]. Its limitation will lead on the support structure, called the dock.

It should be taken into account the speed developed by a user, in order to determine the behavior of the electrical output variable. For doing this it should be known: (1) the power curve - speed characteristic of the generator and (2) the relationship between the generator shaft speeds and the

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wheel speed. The PV curve is obtained from the data sheet generator, while the relationship between the speeds requires knowledge of the diameters of the involved parties, also the behavior of the user's pedal speed, because it will be conducted a field test to determine its behavior.

2.1. Performance of a user type

The field test was conducted at the Fitness Center Bodytech in Bucaramanga, during an Indoor Cycling [6] class, which lasted 50 minutes. It was taken by three people in average physical condition. Figure 1 shows the cumulative histogram interval and the wheel speed of the bicycle. It shows a dominant range of speeds, 200 rpm to 250 rpm. The average speed is close to 242 rpm, and it will be above 200 rpm for 80% of the time.

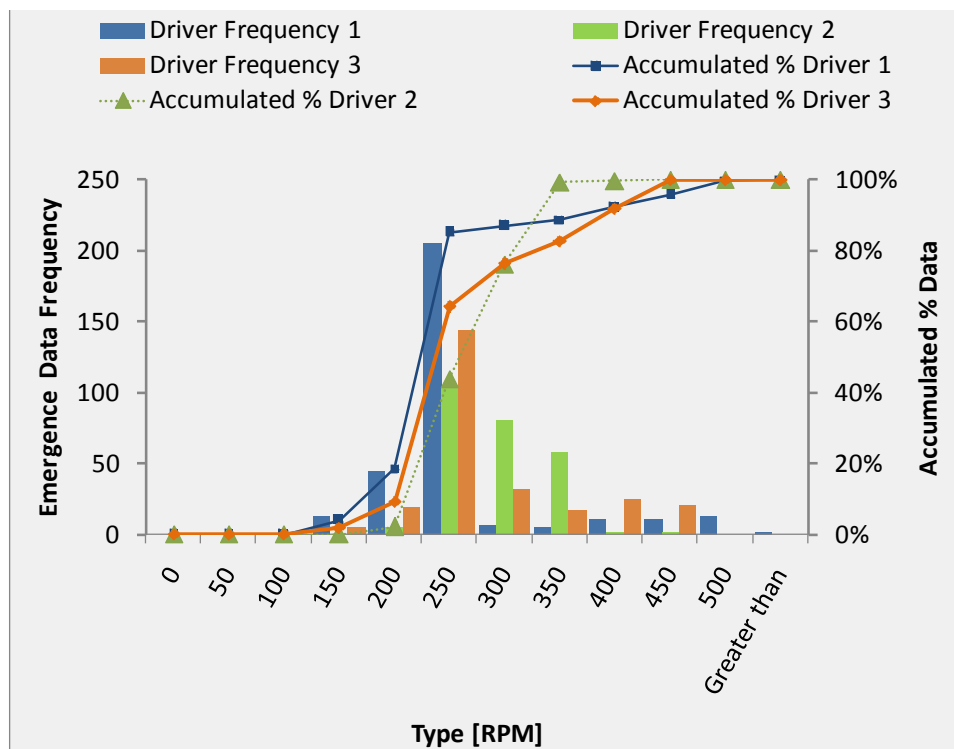


Figure 1. Histogram of the wheel speed of the bike during a spinning session.

2.2. Selection of spinning bicycle and coupling-generator

The bike was a Spinning Stainless previously selected based on the price and technical characteristics from AHP (Analytic Hierarchy Process) [7]. The generator shaft speed and steering wheel of the bicycle are related to its diameters, with a ratio 1:12. Therefore, it is the dominant operating range 2 400 rpm to 3 000 rpm and an average of 2 840 rpm, for which electrical power is close generated to 300 W, as in Figure 2.

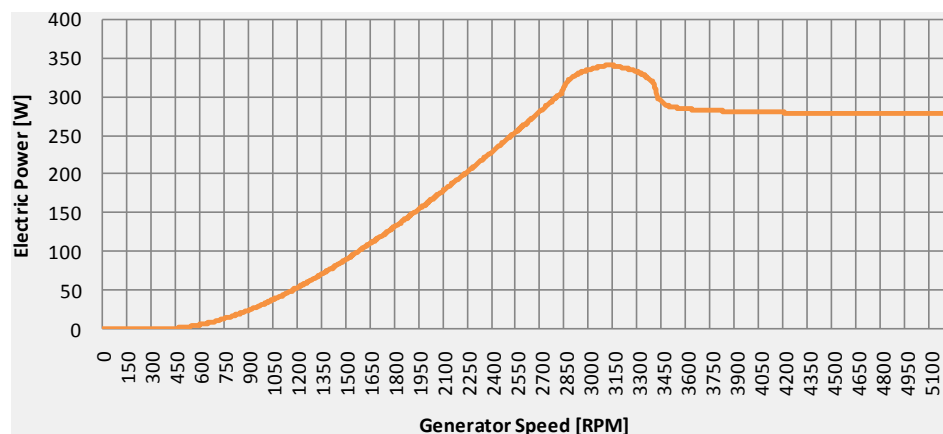


Figure 2. Maximum power vs. RPM (direct drive generator and the crew) [8].

The power generated for a given speed will depend on the strain imposed by the Management Unit and Power Conditioning (Grid Tie Inverter for the subsystem connected to grid and regulator for the isolated subsystem). Table 1 presents the characteristics of a "direct" coupling-type.

Table 1. Technical feature of the coupling.

Figure	Scheme	Characteristics [8]
	Spinning bicycle [9] + Generator	300W 15V 20A 2 800 rpm 85%

2.3. System configuration

The complete system is a group of 18 independent generating units, as shown in Figure 3.

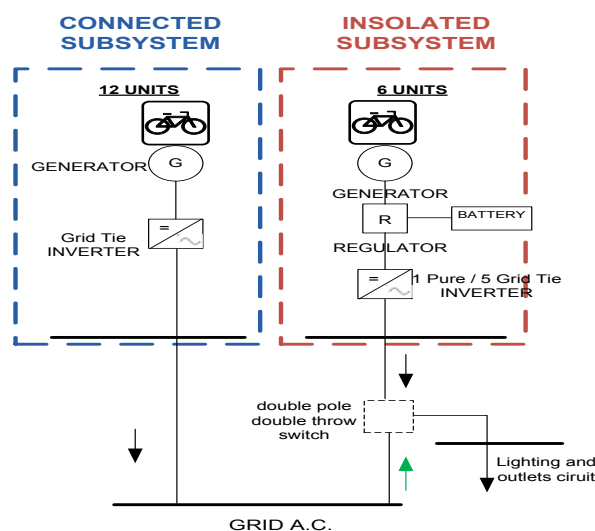


Figure 3. Basic diagram of the two subsystems.

The units of the first subsystem will inject real-time power to the grid, while the units of the second subsystem will supply power loads. All the settings will work independently, since it is not possible a parallel connection of generators, due to the variability in the speed of pedaling according to each user. The sizing and selection of conductors, ducts and protections were conducted under the guidelines of RETIE, NORMA ESSA and the provisions of the NTC 2050 [9] - [13].

2.4. Sizing the subsystem connected to the main grid.

Figure 4 shows the outline of a generating unit connected to the grid type.

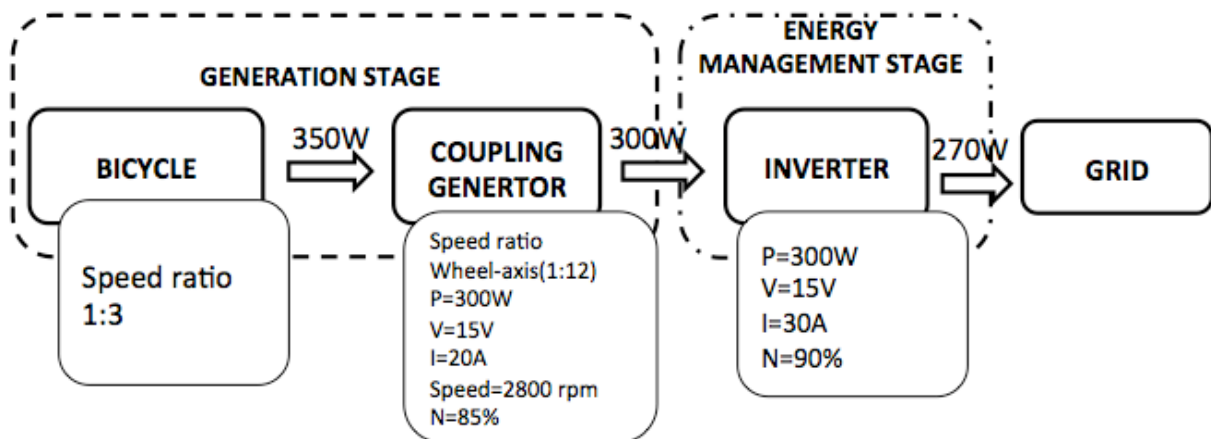


Figure 4. General diagram of the subsystem connected to the grid.

The management and power conditioning will be performed by a type *grid-tie* inverter with MPPT (Maximum Power Point Tracker), which will ensure the maximum possible power of extraction obtain at any time, since a smooth fit in the terminal voltage. Figure 5 shows the line diagram.

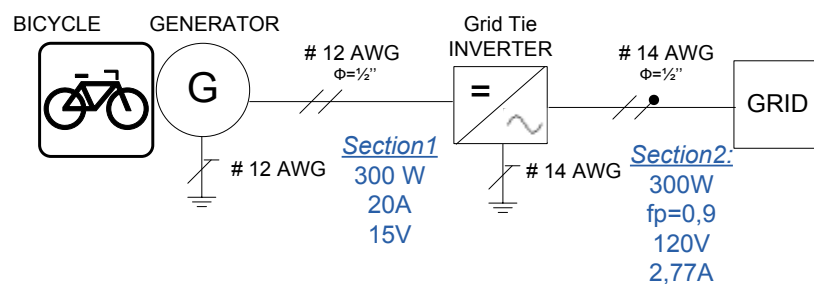


Figure 5. Line diagram of the generation unit – connection to the grid.

2.5. Sizing isolated subsystem

Figure 6 shows the nominal values of the components for each unit.

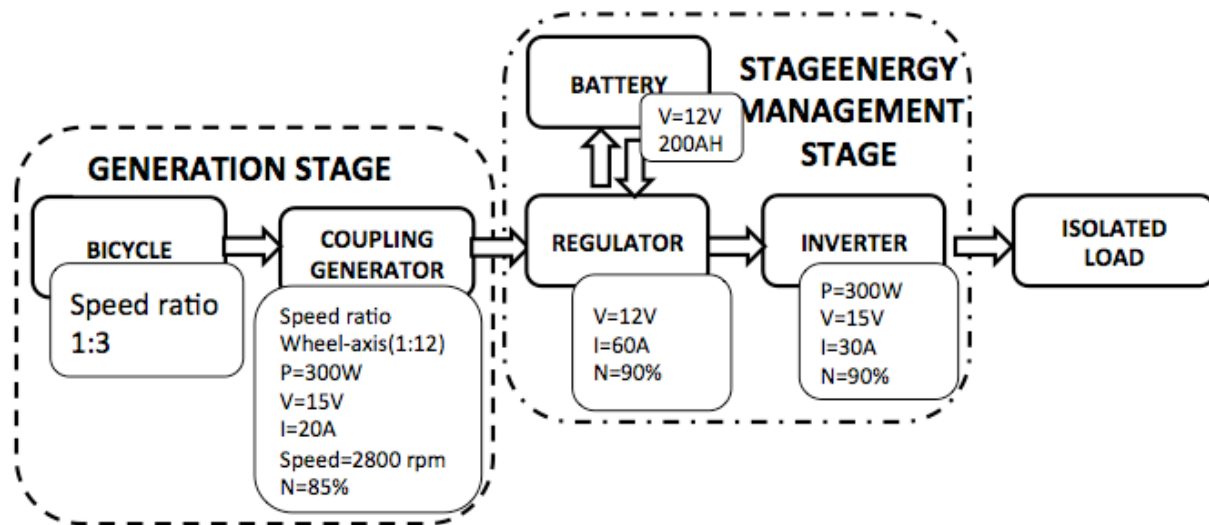


Figure 6. General scheme of the isolated subsystem.

The isolated subsystem must target specific power loads with an installed load of 1.8 kW from the energy generated in real time by spinning bikes and/or the energy stored on batteries. This power management subsystem will be made by regulators MPPT, inverter type Pure (to establish the conditions of operation: 120V and 60Hz) and five (5) Grid Ties (to be synchronized with the first inverter). The charge will supply the backup power grid in the building, which must be done by manual switching. Figure 7 shows the diagram.

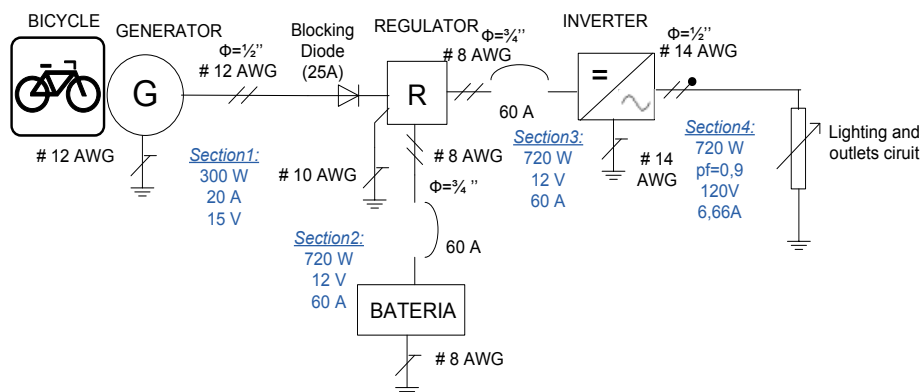


Figure 7. Direct driveline diagram with batteries.

3. Energy analysis

The following is an analysis of the energy behavior of the subsystem generator. Its purpose is to make an estimate of the power generation system.

3.1. Subsystem connected to grid

As presented in Figure 4, each unit will add 270 W to the grid approximately in average conditions (pedaling speed 2 800 rpm and a total efficiency of 76.5%). Therefore, it expects a surge of power of 3.2 kW for 100% occupancy.

3.2. Isolated subsystem

The analysis of this subsystem is more complex due to the battery charging and discharging. Therefore, we have six possible cases of operation per unit, as presented in Table 2.

Table 2. Cases of operation per unit in the isolated subsystem.

Case	Bicycle	Battery	Load	Source
1	Generate	Save	-	Bicycle
2	Generate	Save	>0	Bicycle
3	Generate	Full	>0	Bicycle
4	Generate	Delivery	>0	Bicycle + Battery
5	Generate	Save	>0	Grid
6	Not Generate	-	>0	Grid

In cases 1, 2, 4 and 5, the generator will operate at maximum efficiency, delivering the maximum power available at each moment, due to the system controller MPPT. If the batteries are fully charged (case 3) and there is an energy demand, the regulator will go off MPPT, and it will force the generator to operate less efficiently. In case of non-energy demand, the regulator will automatically stops its work, and the generator will open a circuit. When the unit (generator + battery) is unable to fill up the demand (cases 5 and 6), manual switching should be done to make the mains supply the request. In short, it means that the efficiency per unit will be 65.4%, in average conditions, and it will generate 230 W.

3.3. General behavior

In order to establish a representative analysis, it was assessed the behavior of 18 units during one-year period, considering two annual regimes: University schedule for a 22 days per a month for a 8 months-period and at the gym for a 30 days per month for a 12 months-period with two different types of daily operation (10 hours and 16 hours). Regimes and schedules are determined based on the dynamics of the use in the university and in the private gym. Table 3 shows the effective annual generation (real energy saving) per subsystem, unit, system and schedule.

Table 3. Estimated annual generation in MWh.

		<i>Regime University</i>		<i>Regime Private Gym</i>	
		<i>10 hours</i>	<i>16 hours</i>	<i>10 hours</i>	<i>16 hours</i>
Connection grid	Unit	0,47	0,76	0,97	1,56
	Subsystem	5,70	9,12	11,66	18,66
Isolated	Unit	0,41	0,65	0,83	1,32
	Subsystem	2,46	3,90	4,98	7,92
Total (MWh)		8,16	13,02	16,64	26,58

4. Design of a monitoring system of the energy behaviour

In order to know the energy performance, we designed a system that first monitors and displays variables, then, the data is analyze in a computational tool developed in National Instruments [14] called LabView. Due to its friendly interface to manage multiple visual signals and instrumentation at the same time. The visualization of the system behavior is possible for both staff and users. The set design has an intensive use of sensors and graphical display because it is a pilot case for research.

4.1. Data acquisition

For each unit connected to the sensor network are 5 and 9 sensors to isolated units, as they are shown in Figures 8, for a total of 114 signals.

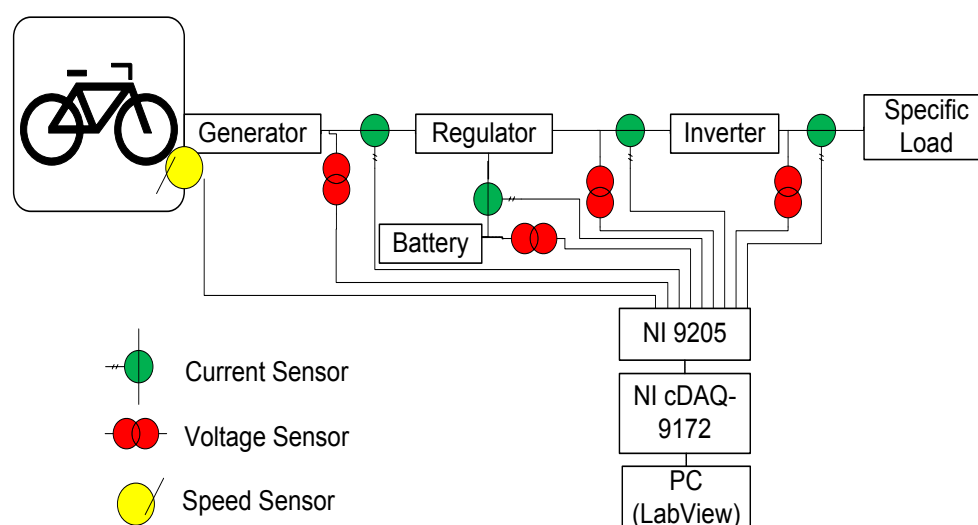


Figure 8. Block diagram of connection of the isolated subsystem.

To collect signals from the sensors 122, 8 of which are associated with injected and measured total power consumption of the network, we selected a data acquisition device called CompactDAQ NI-9178, with 8 acquisition module E / S OR 9205 of 16 entries.

4.2. Human machine interface

The interface consists of 7 tabs, which are presented in Table 4.

Table 4. Composition designed interface.

Tab	Visualized information	Beneficiary	Tool
A	Balance energético del subsistema conectado a la red	Technic personal	PC
B	Comportamiento detallado de cada unidad conectada a la red eléctrica	Technic personal	PC
C	Balance energético del subsistema aislado	Technic personal	PC
D	Comportamiento detallado de cada unidad aislada	Technic personal	PC
E	Balance energético del sistema	Technic personal	PC
F	Velocidad de pedaleo, de la potencia instantánea generada y la energía eléctrica generada durante la sección por usuario	User 1 al 9	TV LED
G		User 10 al 18	TV LED

The interface shows a warning, which is given in order to notify the staff that the when the isolated subsystem is insufficient to fulfill the energy demand for specific loads. This is detected when the voltage level or storage of all battery reaches its operating peak. The graphical interface requires an administrator to address the action and indicate the location of the bike user, which will be assigned automatically by the interface.

5. Financial analysis

For financial purposes, it was not taken into account the bikes price, their maintenance expenses. Therefore, the amount of investment to be considered is M \$ 40. Table 5 determines the amount of investment required, the operation and maintenance costs, financial savings product harnessed the

power generated, along with financial indicators, NPV (net present value) and IRR (internal rate of return).

Table 5. Financial indicators.

Regime	Daily intensity (hours)	Annual saving USD	Average annual cost of operation and maintenance	VPN		TIR
				0%	5%	
University	10	1 430	1,05	-7 800	-9 900	-9,80%
	16	2 360		700	-3 350	0,70%
Gym	10	2 910		7 030	1 540	6,80%
	16	4 650		24 430	14 995	20,60%

The table shows that the invested money will be paid back after a ten-year period.

6. Results and Conclusions

Based on a test, it was concluded that a person will get an average pedaling speed closer to 242 [rpm], which has a potential energy close to 300 [W] at the output of a generator. It was designed a system of power generation of 5 [kW] of installed capacity, comprised of 18 independent generation units. The grid-connected units have 76,5% of efficiency and the isolated units have 68,8% of efficiency working without any connected battery. The total cost of the designed system is explained in the following table 6:

Table 6. Cost and efficiency per unit.

Units	Efficiency (%)	Lower cost (USD)
Grid-connected	76,5	1 200
Isolated	65,4	2 000

In short, the setting and management per unit will cost an amount of USD 1 000, which could generate between 0,4 MWh and 1,2 MWh per year, as a result it will save between \$ 70 and \$ 200. Additionally it requires an annual cost of operation and maintenance of approximately USD 35.

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