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Exercise bike powered electric generator for fitness club appliances

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Keywords

Converter circuit, Energy storage, MOSFET.

Abstract

A generator powered by a stationary bicycle for the purposes of generating electricity for fitness club appliances is considered. A generator is connected to a stationary bicycle in such a way as the circular rotation of the front wheel rotates the coils of wires inside the generator between the poles of the magnets inside the generator. The resulting Direct Current is channeled to the attached battery bank and converted into different usable DC voltage levels as well as AC voltage, just to increase the number of electrical appliances possible to connect.

Introduction

In the modern age, there are more and more electrical devices which do the work that human beings once had to do physically. As more people spend more and more of their days in front of computers or any other equipments without any movements, additional concerns, such as health and the exercise they need for healthful living are often overlooked. From the other side for people who want to be aerobically fit it's not common to spend hours for example pedaling an exercise bicycle that produces nothing but heat, why not have your-my-our workout and generate usable electricity at the same time.
A exercise bike powered electric generator provides a method of generating electricity by means of a modified stationary bike for use in electrical energy storage and running household or other appliances. Human/mechanical energy is converted into electrical by means of a electric generator that is connected to an exercise bike flywheel. As result the energy created by the generator can be stored in various types of lead-acid batteries which may then be tapped at a later time, after dark for example, when the energy is needed to power lights or else. If AC appliances are in place then a inverter must be used to transfer the DC current into the standard 230 volts of AC current for usage by these appliances.
Every one is probably wondering, “can I generate all my needed electricity with a stationary bicycle?”. Tests on exercise bicycles showed that 75W of power is possible to be generated by an average rider at road speed in a one hour time frame. It was also found that at 25kph it is possible to achieve 200W for short periods, while 750W is possible only for a second or so, under extreme load. These results show that human/mechanical energy, if harnessed could be added to novel or existing battery banks and then could be set up to run appliances. Appliances that could be powered, that draw small amounts of

current, include VHF/UHF radios, laptops, stereos, high efficiency fluorescent lightings which allow for example 200W to go a long way (a typical 25W fluorescent light bulb, which replaces a 100W incandescent bulb, will last 8 hours on 200W worth of power) and finally LEDs (Light Emitting Diodes) which are even more efficient and will last days on 200W worth of power (a few minutes of pedaling would be enough to create hours of light).
On the base of above the answer to earlier asked question is yes. Yes, for a household with more than four family members that do not use much electricity, and are in average physical condition. Therefore the perfect place to apply the exercise bike powered electric generator could be a fitness club, where are usually at least few bikes and many energized people who want to be fit.

Example of potential use

This section provides an example of the electrical output that is possible with stationary bike powered electric generator and the energy consumption in exemplary fitness club. On the base of measurements which were made in considered fitness club, we do know that:

- The total electrical energy consumption during 1year (295 working days) is about 4800kWh
- Every single exercise bike works at least 6 hours every day, with average speed of 20kph.

For calculations we assumed the 10kg and 40cm diameter flywheel. For given data we were able to determine the kinetic energy of the flywheel. During 1min that is [2]:

$$K = \tfrac{1}{2} \cdot m \cdot r^2 \cdot \omega^2 = \tfrac{1}{2} \cdot 10 \cdot 0.2^2 \cdot 264^2 = 13939J \qquad (1)$$

where: $\omega = 264\,rpm$.
After simply calculations energy produced by single bike during one hour is [3, 4]:

$$W = 13939 \cdot 2.7778 \cdot 10^{-7} \cdot 60 = 0.232\,kWh \qquad (2)$$

and during one cycle of work (6 hours) 1.38kWh. Considering fact that in “our” fitness club are five bikes, there is possible to produce more than 2000kWh energy during one year, what possibly covers about 42% of the whole energy consumption. Hoverer every one hast to keep in mind that these numbers do not include the loss of efficiency that is created when electricity is converted to different DC voltage levels and to AC voltage.

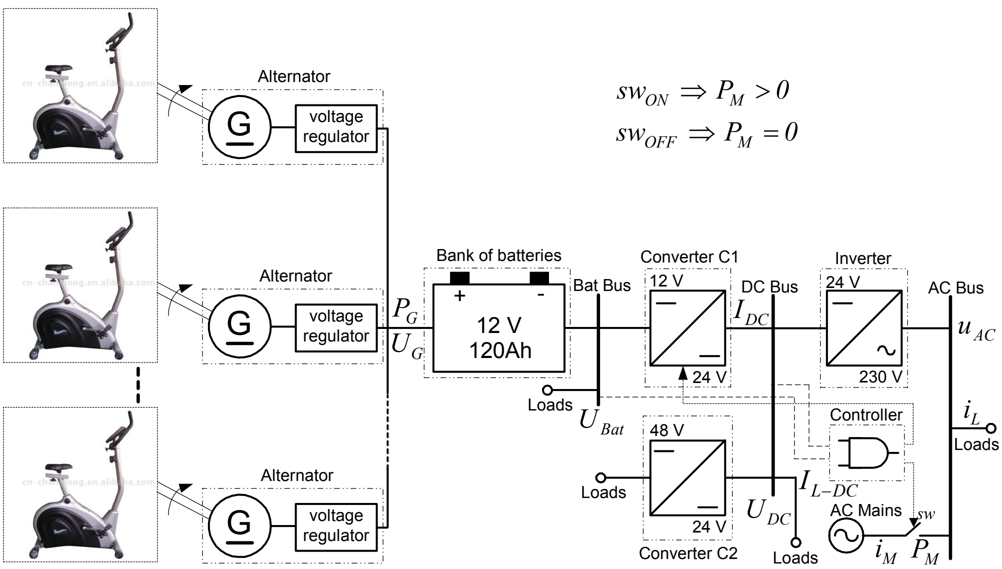

Fig. 1: Exercise bikes powered electric unit

Exercise bike powered electric generator - construction

Now that the potential power output has been defined this is possible to design a human powered electrical energy generator. Components needed to build the DC and AC unit, see Figure 1, include: i) exercise bike: a front mounted wheel with a channel, the generator pulley is at 5cm diameter; ii) generator: 750W and 12VDC auto-alternator with voltage regulator (limits amount of current flow when battery reaches full charge to prevent damage to battery) where the level of load is varied through generator's excitation current changes [1, 5]; iii) 12V and 120Ah lead-acid auto battery; iv) set of DC/DC converters: the first one 12/24VDC (1.5kW) keeps (during $P_M=0$ mode) constant DC Bus voltage, therefore directly secures proper operation of the 24VDC loads and indirectly 48VDC loads as well as 230VAC loads; during $P_M>0$ mode C1 converter is turned off; the second one 24/48VDC (0.5kW) is supplied from the common DC Bus and provides power to 48VDC loads during both operation modes ($P_M>0$ and $P_M=0$); v) the inverter (1.5kW) changes the 24VDC into standard 230VAC and provides power to the AC loads; the challenge with using the inverter and keeping it in the off-line operation mode ($P_M=0$) is to hold the DC Bus voltage above level, or else the inverter will go into on-line operation mode ($P_M>0$).

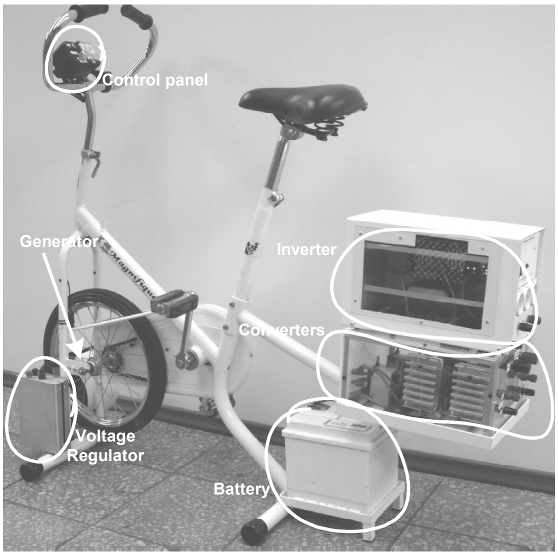

Fig. 2: Laboratory model

DC/DC converters

Both 12/24VDC and 24/48VDC converters are built on the base of the same boost structure (thus we

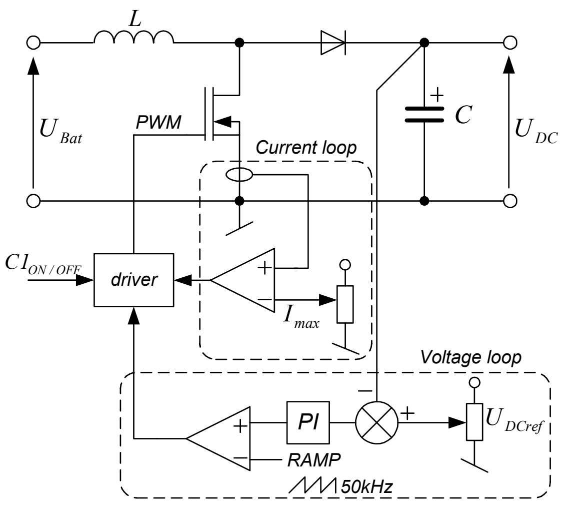

Fig. 3: The boost converter and its controller

will concentrate on the first one – converter C1) and because the insulation is secured by the inverter's output transformer, thus in both converters there is no need to confuse with this [6, 7]. The simplified structure together with its controller is presented in Figure 3. The 12/24VDC converter adjusts voltage between the 12VDC battery and the DC Bus (24VDC) and as one can see its controller consists of two loops: voltage and paramount current. Voltage loop secures stabilized and load independent output voltage U_{DC} only if converter's input voltage is above its minimum value $U_{Bat\text{-}min}$ (if U_{Bat} is below its minimum value, then the converter is turned off; in this way this is possible to secure the battery). Paramount current loop secures converter by limiting its peak current.

Inverter

Inverter operates in two major modes: off- and on-line. During the first one arrangement secures sinusoidal and stabilized AC Bus voltage, while during on-line operation mode guaranties constant DC Bus voltage (24VDC) directly and indirectly invariable 48VDC. Because to the AC Bus inverter is connected permanently through the 24/230VAC transformer, thus this is possible to use MOSFETs to construction. That pays off with high switching frequency (in our case 50kHz) what together with output transformer enables utilization of the smaller size output filter [8].
Inverter's controller consists of two loops: current and voltage. The current loop secures arrangement against the peak current. Because in the voltage loop additionally output filter's capacitor current is measured, thus this is possible to determine much more quicker the instantaneous output voltage [6, 8]. This then results with shorter reaction time on load changes what during off-line operation mode leads to load current shape independent AC Bus voltage.

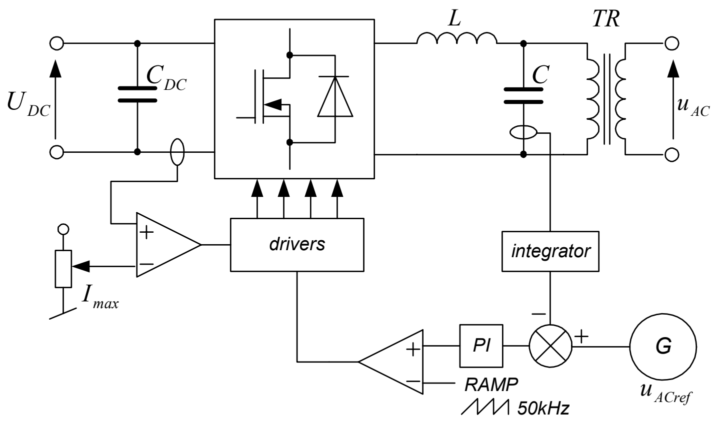

Fig. 4: Inverter and its controller

Controller

Controller consists of two independent arrangements, from which first one controls 12/24VDC converter and second one *sw* static switch. Concerning the principle of operation. When energy delivered by the exercise bike generator causes the U_{Bat} battery voltage increase above the U_{C1ON} value, then the 12/24VDC converter is turned-on (the $C1_{ON/OFF}$ signal changes from low to high) and because of that this is possible to distribute the generated energy to the DC Bus and then further (time t_1 in Fig. 5). In opposite situation, if energy supplied by the bike generator is not sufficient enough to cover all energy needs, converter is turned-off, time t_3 in Fig. 5 (in this way this is possible to secure the battery against to low voltage level).
The second controller, on the base of DC Bus voltage measurements, turns-off or -on the *sw* static switch, thus turns-off or -on the whole system. For example turning-on in time t_1 converter 12/24VDC causes the DC Bus voltage increase and when this voltage exceeds U_{swOFF} level, then the *sw* static switch will be turned-off and the whole system will work off-line. During this type of work the whole energy delivered to the DC as well as AC loads is supplied by the battery. In situation when there is not enough energy to cover loads needs the DC Bus voltage will drop and if reaches $U_{DC\text{-}min}$ level the *sw* switch is turned-off and the whole system will work on-line (time t_4 in Fig. 5).
One should notice that times when 12/24VDC converter is -off and *sw* switch is -on are different, responsible for that is energy stored in inverter's DC link capacitances. For the same reason moment

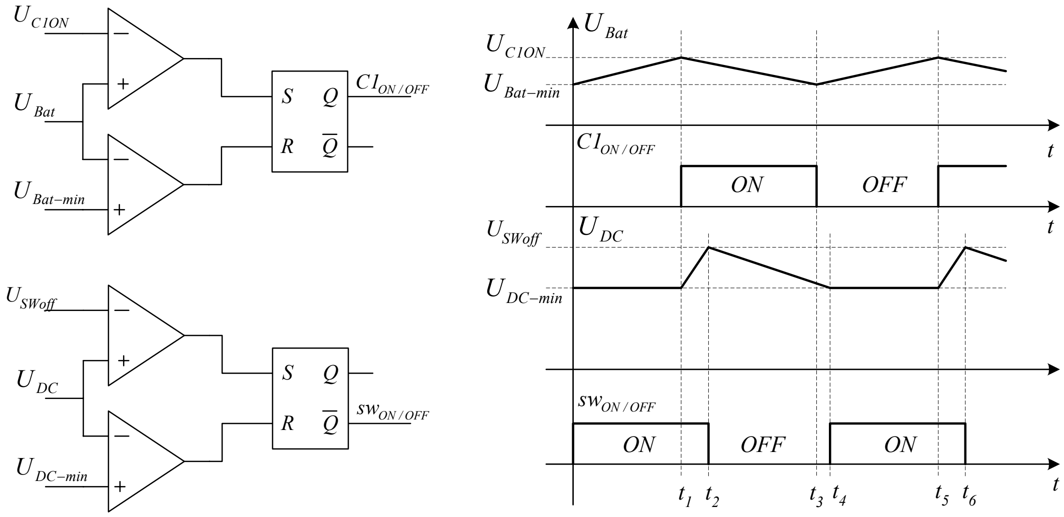

Fig. 5: Controller and exemplary waveforms

when the whole system is off-line is delayed in relation to the moment when 12/24VDC converter is on- (this is the time needed to complete the energy on inverter's DC link capacitances).

Experimental results

Now this is possible to define the output electric power that is possible to achieve with build laboratory model of the bike powered electric generator, see Figure 2. From Figure 6 this is possible to say that for average speed of 20kph, unit produces about 250W what during one cycle of work gives 1.5kWh ready for conversion input electrical energy (above numbers are in great accuracy to the results obtained during theoretical considerations).
Next Figures 7, 8 and 9 present selected wave-time curves for AC and DC loads, obtained during on- and off-grid operation modes and DC Bus load changes. As one can see when starting pedaling, the DC

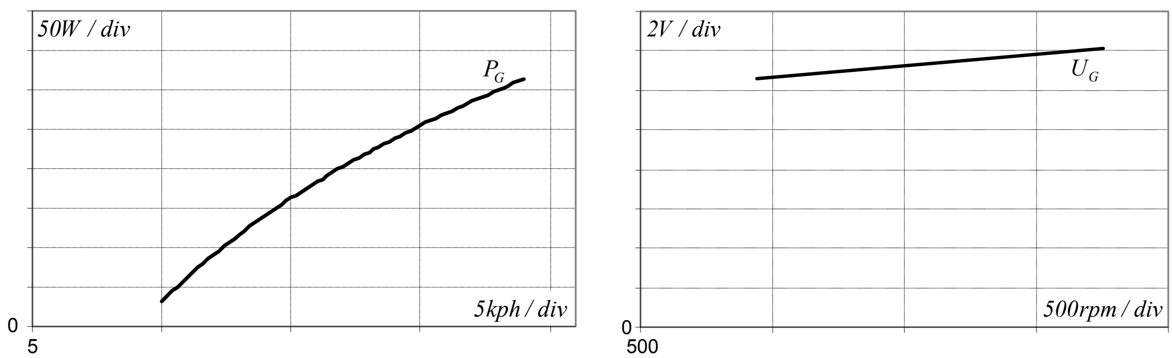

Fig. 6: Experimental characteristics, from the left generated electric power as a function of speed; output voltage as a function of rotations

Bus voltage goes above 22VDC level and the unit switches from on- to off-grid mode. Despite of passage from one to another operation mode, unit secures uninterrupted and unchanged amount of supplied power. The same situation occurs during opposite change of state. Examined unit additionally secures synchronized, uninterrupted transition and unchanged amount of delivered electrical power during mode operation and load changes.

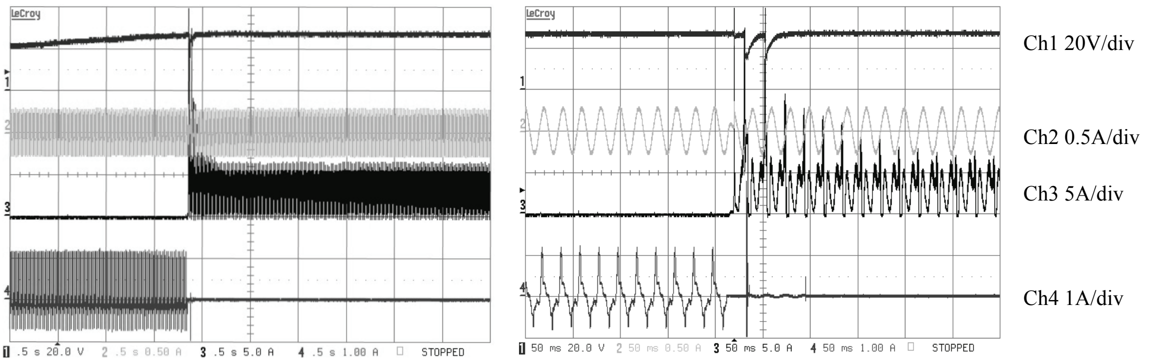

Fig. 7: The change from $P_M>0$ to $P_M=0$ mode, where: Ch1 – U_{DC}; Ch2 – i_L; Ch3 – I_{DC}; Ch4 – i_M

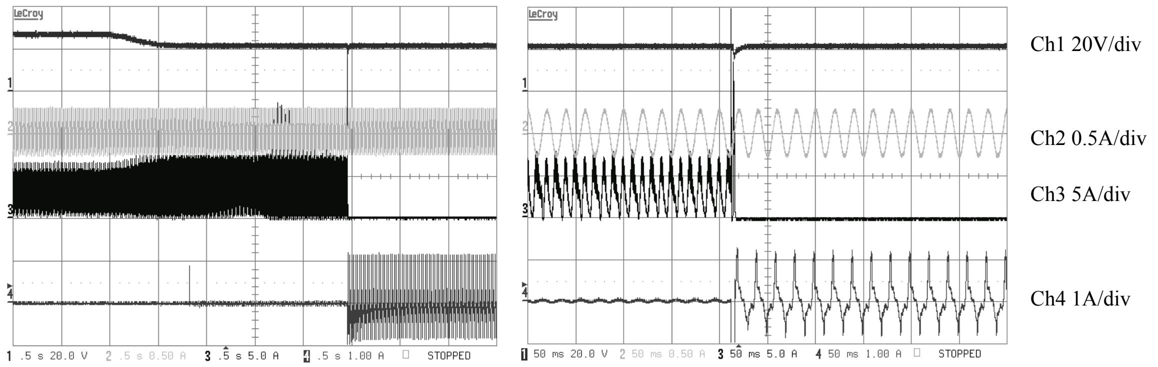

Fig. 8: The change from $P_M=0$ to $P_M>0$ mode, where: Ch1 – U_{DC}; Ch2 – i_L; Ch3 – I_{DC}; Ch4 – i_M

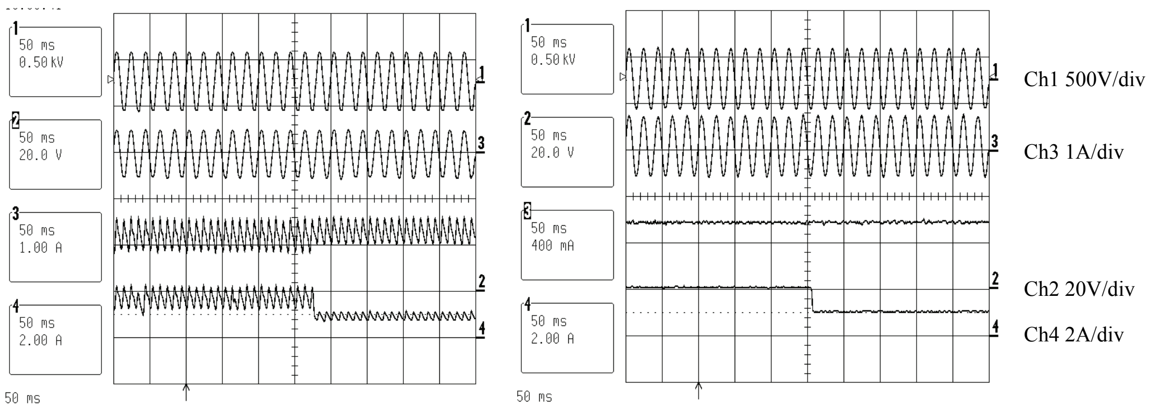

Fig. 9: The DC Bus load change, where: Ch1 – u_{AC}; Ch2 – U_{DC}; Ch3 – i_L; Ch4 – $I_{L\text{-}DC}$; left side $P_M>0$ operation mode, right side $P_M=0$ operation mode

Costs estimation

Economic evaluation is a useful tool to determine the relative merit of the proposed system with different characteristics, thus the results of this evaluation help to choose the alternative that is most profitable for the considered fitness club. System consists of the following elements:

- Exercise bikes
- Alternators
- Battery
- Converter C1
- Converter C2
- Inverter
- Controller

Also, to alleviate the problem of savings variation with time, we choose to express the various cost not in euro or other official monetary units, but in an arbitrary unit which is the cost of 10kWh = 1p.u.

Costs modeling

In this study we assumed that the cost of one exercise bike is constant, therefore in our case cost of all bikes depends only on number of units:

$$C_{Bikes} = C_{OneBike} \cdot n \tag{3}$$

where: C_{Bikes} – total cost of all bikes [p.u.]; $C_{OneBike}$ – cost of one bike [p.u.]; n – number of units.
The cost of the alternators is proportional to the total generated electric power P_G [W]:

$$C_{Alternators} = P_G \cdot UC_A \tag{4}$$

where: $C_{Alternators}$ – total costs of all alternators [p.u.]; UC_A – unit cost of alternator per W [p.u./W].
The cost of the battery is based on the energy capacity of battery E_{Batt} [Ah]:

$$C_{Batt} = E_{Batt} \cdot UC_{Batt} \tag{5}$$

where: C_{Batt} – total costs of battery [p.u.]; UC_A – unit cost of battery per Ah [p.u./Ah].
The costs of the inverter and converters are calculated on the base of the following dependency:

$$C_{ICs} = P_{Inv} \cdot UC_{Inv} + \sum_{i=1}^{n} P_{Conv\_i} \cdot UC_{Conv} \tag{6}$$

where: C_{ICs} – total costs of inverter and converters [p.u.]; UC_{Inv} – unit cost of inverter per W [p.u./W]; UC_{Conv} – unit cost of converter per W [p.u./W]; P_{Inv} – inverter's power rating [W]; P_{Conv_i} – i[th] converter's power rating [W].
On the base of above the total cost of the whole exercise bike system is given by the following equation:

$$C_{Total} = C_{Bikes} + C_{Alternators} + C_{Batt} + C_{ICs} \tag{7}$$

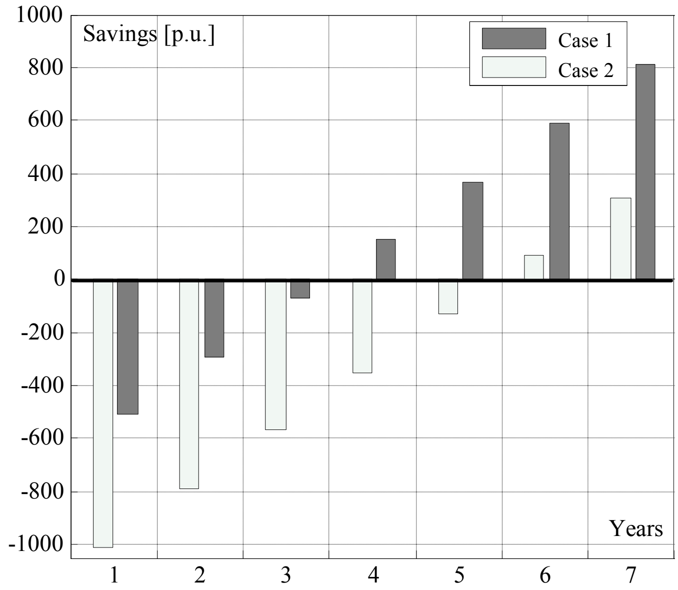

Fig. 10: Savings estimation results

Thus the estimated costs using the basic cost assumptions (labor costs for assembly are not included; the unit costs were determined on the base of average prices) are given in Table I.

Table I: Costs estimation

Case	Costs [p.u.]							
	Exercise bikes	Alternators	Battery	Converter C1	Converter C2	Inverter	Controller	Total
1	0	62.5	37.5	125	105	175	5	510
2	500	62.5	37.5	125	105	175	5	1010

On the base of given data and fact that using five bikes during one year this is possible to limit electrical energy expenses from 480p.u. to 260p.u. – that gives savings of 220p.u. a year. Thus depending on chosen scenario the whole investment pays-off in less than four years, see Figure 10.

Conclusions

A electric generator powered by a stationary bicycle was considered. On the base of experimental measurements one bike generator which works with an average speed of 20kph for 6 hours a day can produce 1.5kWh of the input electric energy. In result five generation units in average size fitness club can cover about 45% of the whole energy consumption.
The most practical application of such unit would be battery charging and then power appliances or tools that can perform their functions with hundreds of watts up to few kilowatts of input power, depends on number of units. Good candidates are TVs, radios, lighting systems, backup generators for solar electric systems, ventilation fans, pumps, watering system etc. The bike generator could be an excellent addition to an existing battery system that may already be charged from the photovoltaic panels, 230VAC grid power or wind power. Summarizing, a bicycle generator can be a practical addition to an energy-conserving household or fitness club.

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