Development and performance evaluation of a self-sustaining electric generator with automatic control

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Abstract: Energy plays an important role globally. Industrial growth, coupled with high system losses, has resulted in a major demand-supply imbalance resulting in an energy shortage with a devastating effect on the economies of countries. The pollution brought by the combusting energy source and the price-increasing-motion of fuel tends people to explore and use greener and cheaper alternatives. Combining solar sources with Thermoelectric Generators (TEGs), and Piezo-Electric Generators (PEGs), and the concept of using a prime mover and secondary mover of the electric generator, in which, the idea of a self-sustaining electric generator with an automatic control system has come to exist. The self-sustaining electric generator with an automatic control system is compact based on the positioning of the components. The system is acceptable for households used. The noise level of the project passed the Class 1 noise level standard of the Philippines stated in NPCC Memorandum Circular No. 002, Series of 1980, vibration level is concluded to be better with enclosure, and the temperature rise is of normal temperature. The generated power yielded an above-average efficiency. The produced mathematical model validated the Seebeck effect theory, showing the proportional relationship between electrical power and temperature difference.

Keywords: *Piezo-electric generator, Renewable energy, Self-sustaining, Thermoelectric*

1. INTRODUCTION

Energy plays an important role in the lives of individuals and in the activities of the economy [1,2]. It is considered both a scale of economic and social development as well as a basic humanitarian need. Asia comprises many developing countries and in development, the energy needed is extremely high and growing. Industrial growth, coupled with high system losses, has resulted in a major demand-supply imbalance resulting in an energy shortage with a devastating domino effect on countries' economies. Energy shortages create blackouts, and without energy to run industries and commerce, companies either shut down or production is reduced greatly.

Fueled electric generators could possibly solve the issues. The mere fact that the fuel is in the price-increasing-motion turns people to think of other sources to power up machines, lights, and among others. The pollution [3] brought by the combusting energy source tends people [4,5] to explore and use greener and cheaper alternatives.

The idea of combining solar sources with Thermoelectric Generators (TEGs), and Piezo-Electric Generators (PEGs), and the concept of using a prime mover that also has electricity as the fuel of the secondary mover of the electric generator, in which, the idea of self-sustaining electric generator with automatic control system has come to exist.

1.1. Literature Summary

Putting the concepts, the researcher came up with the following synthesized presentation of ideas valuable to the study. Motors can be used in motoring and/or generating [6] which the project is taking advantage of. The project used the motoring capability of the motors as the primary mover while the generating feature was used in the production of electricity. Converting AC power to DC power [7,8] was a useful concept in the project since it uses electrical banks which are DC by design while the load is AC oriented. The component/device called inverter was injected into the system for better conversion of AC to DC. The emission of carbon monoxide gas from fuel-power generators has been addressed in the design of the project. The increasing price of petrol [9,10] is one of the reasons that make the idea of doing the project. The different cables/wires are also considered in the realization of the project. This is one of the components needed in the construction of the project. Efficient Autonomous Solar Panel [11] and Thermo-Electric Generator (TEG) Integrated Hybrid Energy Harvesting System [12] projects differ from this study in the sense that the source of harvest is solar and heat while in the project it is the primary mover or the mechanical movement of the electric motor. The Joule thief circuit [13] is the concept used in the voltage booster in the required part of the project. Moreover, the hydrostatic-driven electric generator of Wang and Zhou [14] is more or less the same as the study in generating electrical energy but differs in the primary mover, where in the comparison is the hydrostatic and mechanical driven. Both projects fabricated prototypes and also tested them under both no-load and loaded conditions. In the study of Yuan, et al., [15] compared to the self-sustaining electric generator with automatic control, the temperature of the system is not disregarded in the configuration and installation of the system. The two studies differ in the power source that power up the whole system. On the other hand, the developed full-field wind electric generator of Yeh, and Li-Yu [16] has nothing in common with the study but the results of the study were held needed in the development of the current study due to the fact that it is also a source of renewable energy. The difference relies on the source of mechanical energy which winds in their project while in this project is the motor. The project definitely needs a cooling system and the report of Hartono, et. al. [17] was of great help in the establishment of the project. The project surely dissipated more heat since the design has two electric motors. More so, the QWTEG project [18] makes use of the thermoelectric generator to convert the waste heat of the gas turbine. Renewable energy is safe and economical [19]. The project used the thermoelectric generator to capture and convert the waste heat produced by the motors during the operation. The piezoelectric generator

used in the study conducted by Woo-Suk et. al., [20] produces a tremendous amount of electricity in which the authors stressed the power output of the project. Similar to the project, it was used the piezo technology as an additional source of renewable energy in the project, in case the solar panel is unable to produce electricity. The concept of a joule thief circuit was a great help in boosting output voltage to satisfy the needed voltage supply of such components. Finally, mathematical modeling was used to assess the underlying concepts and mathematical computation, and numerical values for the function and application of TEG.

2. METHODS

We aim to develop and evaluate the performance of the self-sustaining electric generator with an automatic control system. Conceive, design, implement and operate (CDIO) approach [21] is used in the development of the output after analysis of the problems and issues regarding alternative and renewable energy.

The project is anchored to the succeeding conceptual framework and other literature. Requirements are also considered in putting and designing components as well as the placement of particular components in the project. Safety measures in using and implementing the project are considered. The study follows the CDIO in the development of the proposed project.
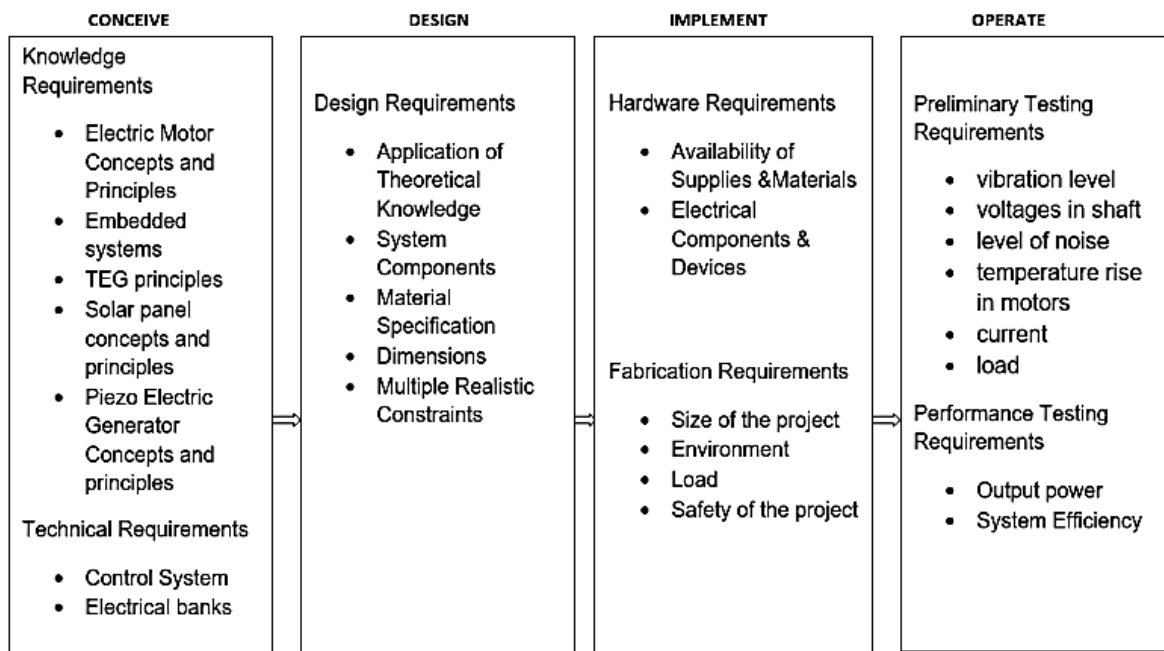

Figure 1. The block diagram of the research paradigm.

Fig. 1 shows the different phases of the CDIO paradigm that is used in the development of the self-sustaining electric generator with an automatic control system. In the conceive phase; knowledge requirements and technical requirements are reviewed. By reviewing the literature about the concepts and principles of electric motors, embedded systems, TEGs, and PEGs, this phase is realized. In this phase, also understanding concepts and principles of operating electric generators are very helpful in for the new ideas in working for the improvement and development of the self-sustaining electric generator. Important requirements with regard to project development and its automation should be well understood as a consideration in the project design.

In the design phase of Fig. 1, considering the conceived data, requirements are considered in the design while applying the theoretical data and knowledge. Material specifications, system components, and project dimensions are prioritized in designing the prototype.

In the implement phase, the design is put into a prototype by considering the hardware requirements, and fabrication requirements. In hardware requirements, consideration of the availability of supplies and materials and electrical components and devices for the fabrication of the self-sustaining electric generator is in mind. Fabrication requirements as to the dimensions of the project and the proper places of the components are also given much attention. In this phase also, preliminary and performance tests are performed. Preliminary testing of vibration level, level of noise, temperature rise in motors, current, and load running current test are conducted. Performance tests as to output power and system efficiency are tested in this phase.

3. FINDINGS

The dimension of the project is 83 cm x 39 cm x 34.5 cm according to Fig. 2. A ¼ horsepower primary motor with an attached 15.24 cm in diameter pulley is evident on the side of the project while the 800 W secondary motor is on the other side with an attached 5.08 cm pulley. The 27.94 cm in diameter flywheel with two 15.24 cm in diameter pulleys attached was at the center. The pulleys are using rubber v-belts. The developed self-sustaining electric generator was tested for vibration level using a vibrometer. Vibration testing near the primary motor resulted in an average 6.2 MMI (50 cm/s^2), near the flywheel is 6.4 MMI (50 cm/s^2), near the secondary motor, is 5.9 MMI (50 cm/s^2) and with the enclosure is 5.6 MMI (25 cm/s^2).
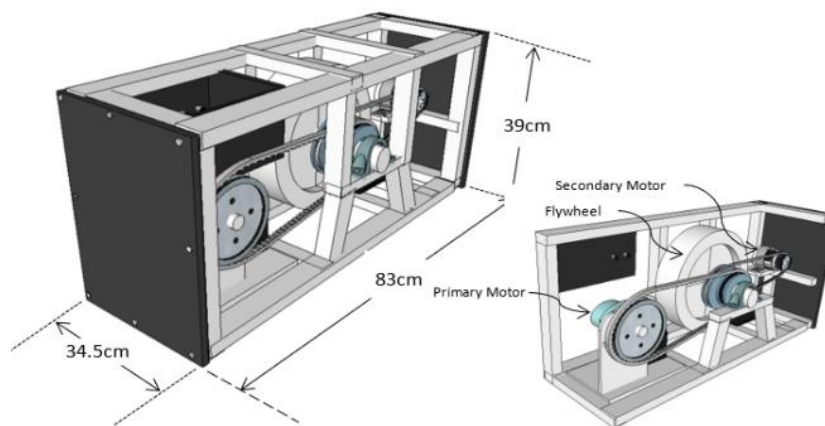

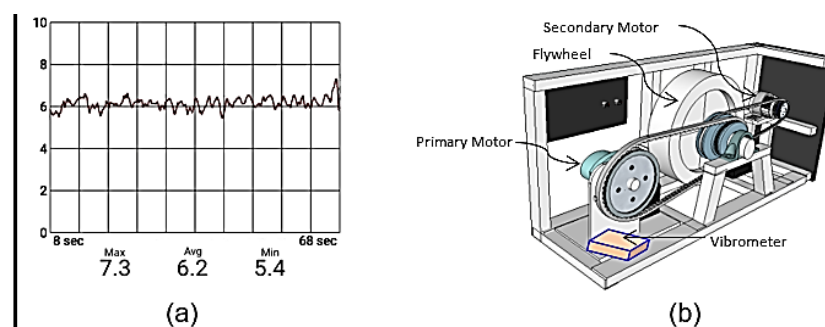*Figure 2. Dimension of the machine.*

Figure 3. Sample of vibration testing: (a) Result and (b) placement of the vibration meter.

The noise level of the developed self-sustaining electric generator is also tested as shown in Fig. 3. The noise meter is placed near the secondary motor, which results in an average of 68 dB, near the primary motor, which results in an average of 69 dB, and with enclosure, it resulted in an average of 79 dB (Fig. 4). The noise level of 79 dB on average passed the Class 1 noise level standard of the Philippines. Unfortunately, it does not pass the ambient noise levels of 55 dB of Class A of general areas of the NPCC Memorandum Circular No. 002, Series of 1980.
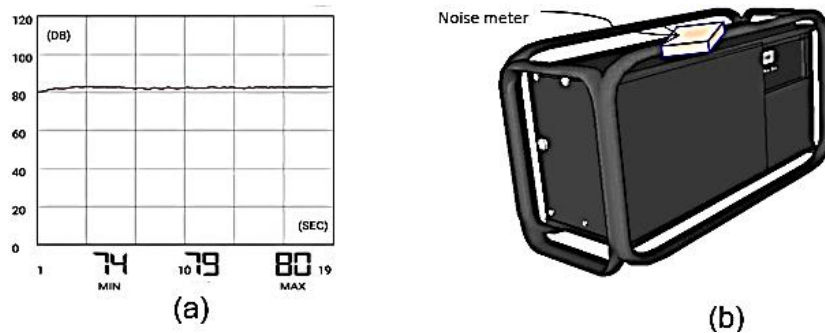

Figure 4. Sample of noise testing: (a) Result and (b) placement of the noise meter.

The temperature rise of the motors of the developed self-sustaining electric generator is tested using a thermal gun. The primary motor reaches up to 50.5 °C in 20 minutes while the second motor reaches 35.9 °C in 20 minutes. Both motors started at 27.1 °C temperature.

Table 1. Temperature rises in motors.

Time (min)	Primary Motor Temperature (°C)	Secondary Motor Temperature (°C)
0	27.1	27.1
2	29.3	28.8
4	31.2	30.2
6	35.5	32.1
8	37.1	33.9
10	41.4	35.1
12	44.8	35.1
14	47.3	35.4
16	50.1	35.7
18	50.3	35.7
20	50.5	35.9

The developed prototype has an input of 174 W of power to start the primary motor which started the whole system. The output power was 121.03 W which is from the consolidated power produced by the secondary motor (self-sustaining electric generator - SSEG), thermoelectric system (TEG), Piezo electric system (PES), and solar panel. The ratio of the power output and the power input yielded a 69.55 percent efficiency of the developed self-sustaining electric generator with a control system.

Table 2. Temperature rises in motors.

Parameters	SSEG	TEG	PES	Solar Panel
Current input (Amps)	14.5	0.4	0.0025	5.56
Voltage input (Volts)	12	12	12	18
Power (Watts)	174	4.8	0.03	100
Total Power (Watts)			278.83	

Joule thief circuit in the patent of Miller [13] is used in boosting the output of the piezo-electric system and thermoelectric system. In the piezo-electric system, the circuit does not do much of the boosting since according to the observation of the piezo technology, there is a gap in producing electricity. In the TEG system, the circuit was a good help in boosting the voltage. The circuit boosted up to 81.86% efficiency.
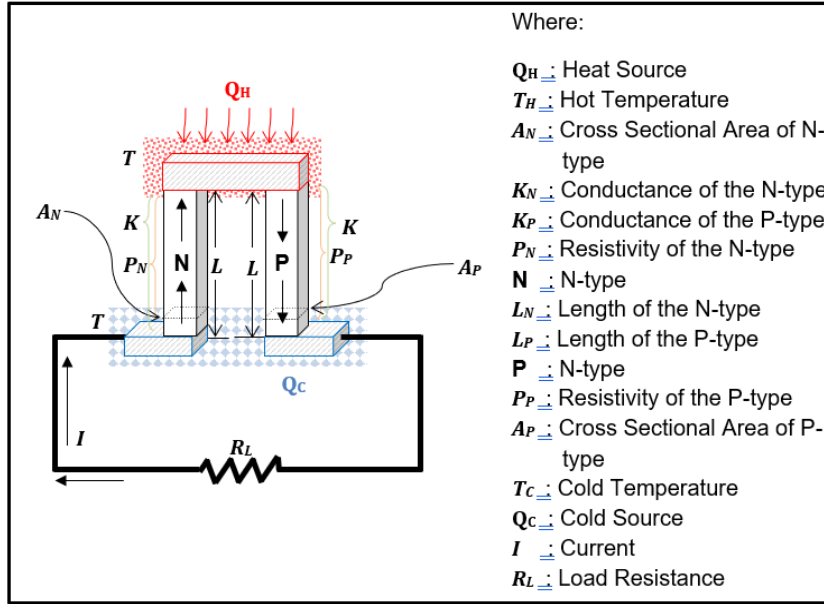
Figure 5. Schematic diagram of single N-type and P-type thermocouples.

Different equations are considered from the analysis of the different principles. The mathematical equation to formulate using those principles is the hot junction (Q_H) and the cold junction (Q_C) according to the TEG model shown in Fig. 5. In balancing energy produces in the (Q_H) and (Q_C) the following mathematical equations are derived:

$$Q_H = T_H - T_C \left[\frac{K_P A_P}{L_P} + \frac{K_N A_N}{L_N} \right] + \alpha_{PN} I T_H - \frac{1}{2} I^2 \left[\frac{P_P L_P}{A_P} + \frac{P_N L_N}{A_N} \right] \tag{1}$$

$$Q_C = T_H - T_C \left[\frac{K_P A_P}{L_P} + \frac{K_N A_N}{L_N} \right] + \alpha_{PN} I T_C + \frac{1}{2} I^2 \left[\frac{P_P L_P}{A_P} + \frac{P_N L_N}{A_N} \right] \tag{2}$$

The electrical power (EP_L) mathematical equation is given by,

$$EP_L = V_L I = Q_H - Q_C = I^2 R_L \tag{3}$$

Substituting and manipulating the mathematical equations lead to the electrical power (EP_L) mathematical equation that is equated to the direct proportionality to the temperature difference.

$$EP_L = \left[\frac{\alpha_{PN} \Delta T}{\left[\frac{P_P L_P}{A_P} + \frac{P_N L_N}{A_N} \right] + R_L} \right]^2 R_L \tag{4}$$

The mathematical model shows the relationship of electrical power (EP_L) in the Thermoelectric generator system that is directly proportional to the temperature difference (ΔT) of the hot and cold side, moreover, validating the Seebeck effect theory (Fig. 6).
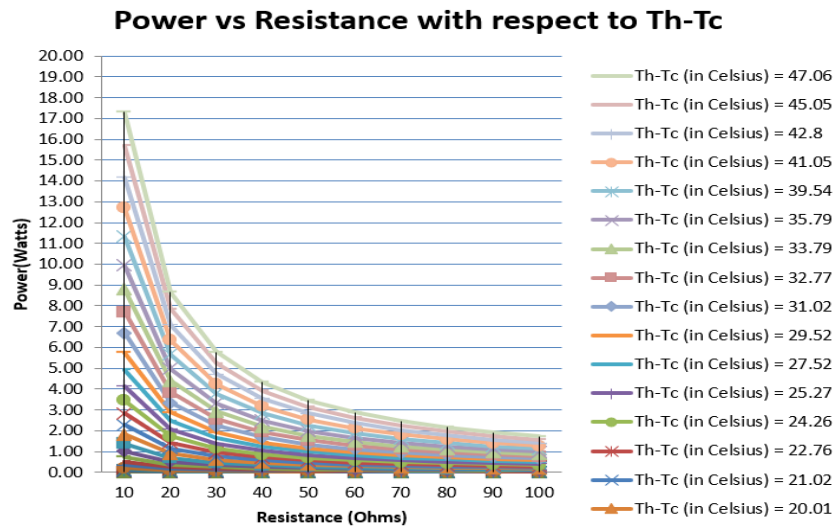
Figure 6. Resistance and Power relationship with respect to each Temperature Difference

As shown in Fig. 6, power of the system substantially decays with the load resistance. Note also that the larger T_h-T_c differences yield to higher power output.

4. CONCLUSION

The developed self-sustaining electric generator is acceptable for households use. The noise level of the project passed the Class 1 noise level standard of the Philippines stated in NPCC Memorandum Circular No. 002, Series of 1980, vibration level is concluded to be better with enclosure, and the temperature rise is of normal temperature. The developed self-sustaining electric generator is functional and usable. The consolidated power from the solar panel, electric generator motor, thermoelectric system, and piezoelectric system yields an above-average efficiency.

The application of the Joule thief circuit is valid and usable in the thermoelectric generator system but not in the piezo-electric system of the self-sustaining electric generator due to discontinuity of the production of electricity in the process. The produced mathematical model validates the Seebeck effect theory given in Eq. 4, which shows the proportional relationship between power and the temperature difference. The principles of Joule heating, conduction heat, the Peltier effect, and the Seebeck effect contributes mainly to the mathematical model. Application of Joule thief circuit on higher current/voltage boosting application for better improvement of the circuit. PES needs a further study to make a continuous production of electricity. Application of the mathematical model in any Seebeck effect application for further improvement of the model.

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