DESIGN A SOLAR-PIEZOELECTRIC HYBRID STREET LIGHTING SYSTEM

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INTRODUCTION

With the development of the road system in the country, a considerable amount of power is consumed by street lights, which ultimately consumes national energy while increasing the peak demand of the country. Therefore, the national grid supply for street lights should be replaced with renewable energy sources. This will help to decrease grid power demand in peak times. The reliability of the street lighting system is also a problem since there is no backup power source when there is a power outage in the grid. The new energy source for street lights should be capable of increasing the reliability of the system.

There are several alternative renewable energy sources identified for street lighting. Solar-powered Street light systems are the most common solution where hybrid street lighting is a new trend.[1]

At present, the roads are full of vehicles and due to developed conditions of roads, the speeds of the vehicles are also high. When a vehicle moves, there is considerable relative wind energy generated. This wind energy can be used to generate electricity for street lights. To prevent glare from the incoming vehicles plants, walls or boards are installed in the middle of the roads. These conventional side dividers can be replaced with a setup that can absorb the relative wind energy and convert it to electricity.

In this research study, the design of a solar-piezoelectric hybrid street lighting system is introduced. A mechanism consists of oscillators that can convert this wind energy into vibration. Piezoelectric crystals are a better solution to gain electricity from these vibrations ([2] and [3]). A prototype of the complete system was implemented and tested at different wind speeds.

METHODOLOGY

Figure 1 shows the complete block diagram of the proposed hybrid street lighting system. Relative wind energy is absorbed by a vertical axis wind turbine. The rotary motion of the wind turbine is used to create oscillations to generate vibration of piezoelectric plates [4]. An oscillation mechanism using permanent magnets is used to create a piezoelectric generator.

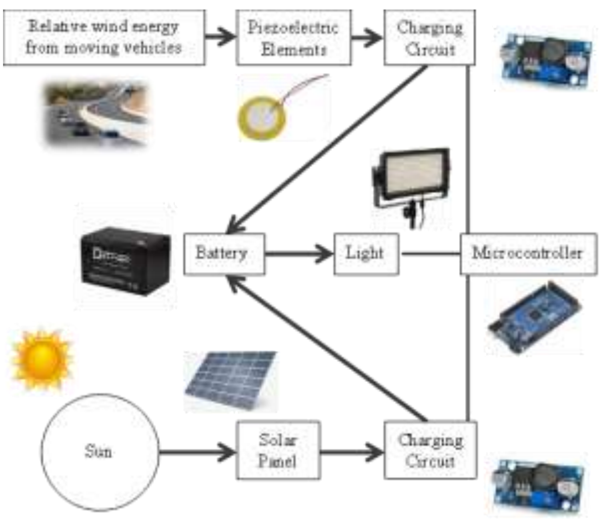

Figure 1: Block diagram of the proposed system

A rectifier circuit is used to convert the AC output of piezoelectric plates to a DC output. A capacitor is connected to the DC output bus and it performs as a smoothing capacitor and as a temporary energy storing device. As the power output of piezoelectric plates is low, power is harvested and accumulated in a capacitor. This is used as the battery charging circuit by the piezoelectric generator. The microcontroller measures the output voltage of the capacitor. The microcontroller switches the battery to charger when capacitor voltage is up to required charging voltage limit ([5] to [9]).

Solar power is converted into electricity by a solar panel and the output voltage of the solar panel is stepped down to the required charging voltage of the battery and it charges the battery when solar power is available. The lighting load is connected via a microcontroller and it switches lights.

Figure 2 represents the flow diagram for the above-proposed system. A battery with a different voltage is used in the prototype. Because in this system a number of wind turbines are to be connected to the system to get the required power output. Only one wind turbine is designed for the prototype and a low voltage battery (4V) is used instead of a 12V battery.

Flow diagram

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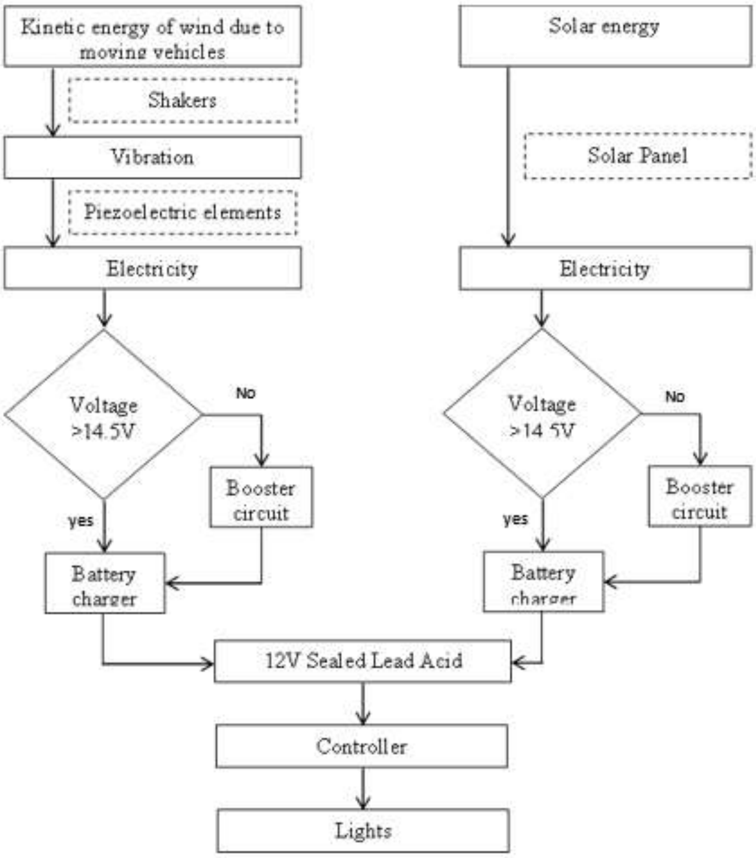

Figure 2: Flow chart of the proposed system

Design of hardware and software

Figure 3 represents the schematic of the total assembly of the whole unit including the structure, wind turbine, piezoelectric generator, rectifier controller unit, battery, lamps, and PV panel. Figure 4 shows the actual constructed prototype with specified components.

As this is a prototype, size of 30 cm diameter and 60 cm height vertical axis wind turbine was designed and the structure was designed to accommodate the size of the wind turbine. The structure is designed to absorb as much as wind energy without blocking the wind flow. This is easy to mobilize and is stable for high wind flows. When considering the effective horizontal wind flow in the center of the road it changes the direction from 0 to 360 degrees. That was the most important factor to be identified when designing the most effective wind energy absorbing method. A vertical axis wind turbine is the most suitable method to absorb that type of wind energy and it is suitable to place in the center of highways as it requires little space.

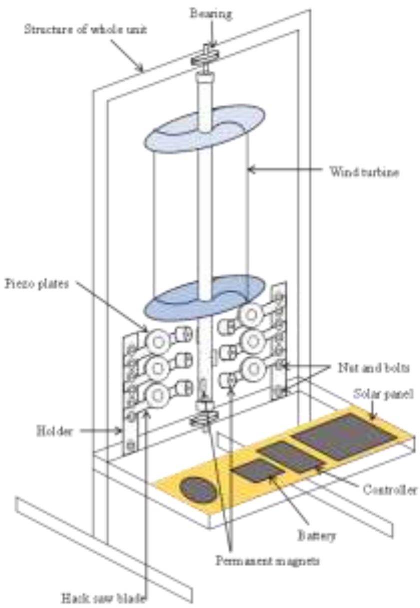

Figure 3: Assembly of whole unit

Figure 4: Complete prototype

In the design of the prototype, a vertical axis turbine with a diameter 30 cm was designed. The energy absorbed by the wind turbine is converted into electricity by this generator unit. There are many design limitations due to the inability of customising the parts of the generator. Piezoelectric plates are still manufactured in small sizes for specific applications. In this design, the spring blade is used to generate oscillations that is due to the magnetic force between rotor magnets and magnets attached to the end of the spring blades. These magnets that are attached to the free end of the spring blade work both as tip mass and force transmitter to generate oscillations. There are three oscillators mounted to one holder and two holders are going to be placed in the opposite directions of the turbine shaft. IN4007 diodes are used to form the full wave bridge rectifier and two outputs of piezoelectric plates are fed to one rectifier block. For the 12 oscillators 6 bridge rectifiers are installed and a 25V, 2500µF capacitor is used for storing smoothing energy. As the energy generation of the prototype is in micro range generated current is about 1 mA. The energy accumulated in the capacitor is to be sent to the battery as the capacitor voltage increase with the energy harvesting. To prevent the battery overcharging and exposure to higher voltages, the microcontroller measures the voltage and controls the charging input to the battery. Solar energy is also fed via a buck converter and load lights are connected to the battery through a microcontroller-controlled relay block [10,11].

RESULTS AND DISCUSSION

Testing of the prototype

The prototype was fabricated to install 12 piezoelectric plates. But it was very difficult to purchase piezoelectric plates. And results can be evaluated correctly if the same type of piezoelectric plates were used. During testing a few piezo plates were damaged and only 6 remained. Therefore, the testing was done with 4 piezoelectric plates.

3.2 Capacitor voltage (V)

Capacitor voltage was recorded every 20 seconds for each number of piezoelectric plates connected. Wind velocity was set to 3m/s. Figure 5 shows the graph for capacitor voltage.

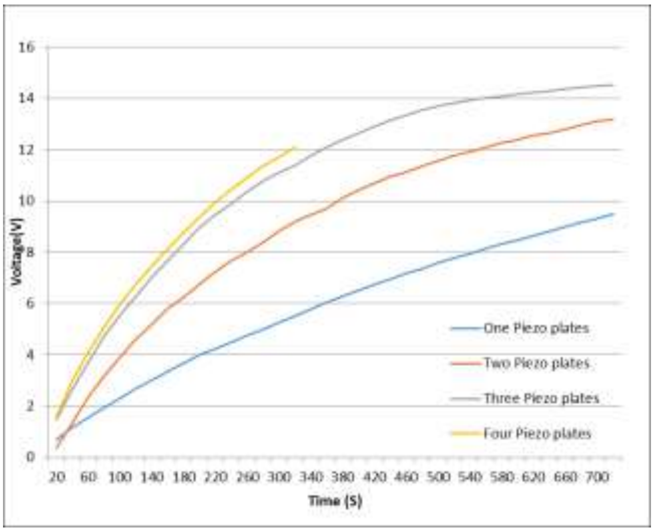

Figure 5: Capacitor Voltage (V)

According to the figure 5, capacitor voltage is increased when more piezoelectric plates are connected to the wind turbine generator.

3.3 Power (µW) of a piezoelectric generator

First wind speed of 3m/s was tested and repeated the measurements for 2m/s and 4m/s speeds. The following test was done while maintaining the wind velocity at 3m/s. The number of piezoelectric plates connected to the rectifier is increased one by one. Voltage, energy, and power of the generator for four piezoelectric plates supply are shown in figure 6. Figure 7 represents the generated power for all four scenarios.

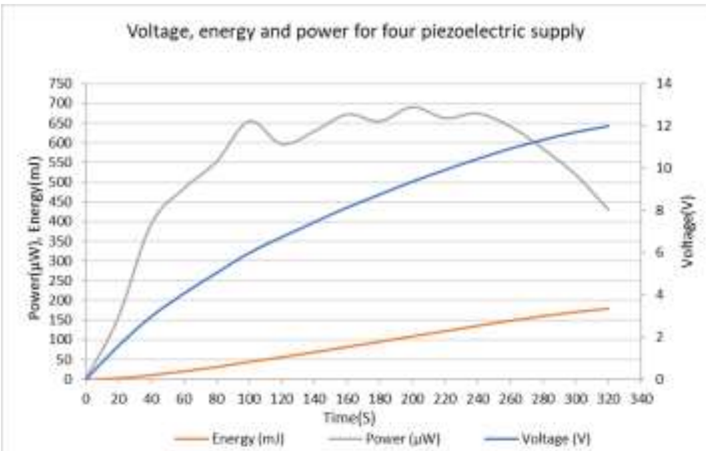

Figure 6: Voltage, energy, and power for four piezoelectric plates

Figure 7: Generated power for each piezoelectric plate configuration

Power generation of piezoelectric generator is calculated using the energy storage of the capacitor. For each test done with single to multiple piezoelectric plates, results were observed. The maximum wattage of the system varies with the voltage of the capacitor. Energy storage and wattage of the generation at each voltage can be observed from the graph. From figure 7, it can be seen that with 4 piezoelectric plates the energy stored in capacitor is higher and the rate of increment is also high with lower time.

Power Supplied by solar panel

For the design, a 10W solar panel is used. The output voltage was tested throughout a sunny day and 18V output was observed for about 6 hours. A Buck converter is used to maintain the required voltage for charging the battery via solar panel. As the voltage of the rechargeable battery is 2.4 V solar panel output voltage is set to 2.8V for battery charging.

As solar panel output power is very high compared to the piezoelectric generator output of the prototype, it was much more difficult to use both sources at once to charge the battery. Rechargeable battery specifications were selected to make it possible to monitor the charging by the piezoelectric generator. When the battery is connected to a solar energy source it charges the battery very fast compared to piezoelectricity generator.

DISCUSSION

Power generation of piezo elements is very small compared to conventional electricity generating methods. Piezo materials are customized according to the applications and power generation via piezoelectricity is still at the research level. So, available piezo materials are not capable of generating high power. Hence the number of piezo materials needs in the design is high and with increasing the number of elements the design is more complex. Handling of piezo materials needs much care as the ceramic layer is very fragile. Over bending (over stress stroke) case in easily cracking the ceramic layer which decreases the capacity of power generation.

As this is a prototype for piezoelectric generation generated power is very low. By increasing the number of piezoelectric plates and by using multiple wind turbines piezoelectric power output can be increased. As solar panels are commercially developed, it is possible to use panels of desired capacity, therefore power output of the solar panel is not tabulated under results.

CONCLUSION

Piezoelectricity is still at research level for use to generate power. A common application is the signal generation and power generation for sensors which consumes nano to micropower. This research focuses on a hybrid street lighting system where power generation uses solar panels and piezoelectric elements. The purpose of using hybrid power in this research is to make it much more reliable and generate more power using relative wind energy in roads.

The design of the parts of the prototype played an important role in this research. Energy absorption from relative wind energy that is bidirectional and converting the kinetic energy of wind into vibration is the main mechanical design in the project. Also, the way of transmitting that vibration to piezoelectric plates was a challenge.

By considering the results the energy output of piezoelectric plates is very low. Energy absorbed by the wind turbine as per the calculation was 2.62 W. But the conversion of kinetic energy into electric energy by piezoelectricity gives 674 μW. That power was observed for only 4 piezoelectric plates. As the design was made for 12 total plates, the total energy that can be observed under this prototype unit is about 2000 μW. That is 2mW. Conversion efficiency is low which is about 0.1%.

Solar panels are available at the commercial level and it is well developed technology. Panels can be customized and are readily available in required capacities. As two energy sources are used during the daytime solar panels can contribute to charging the battery.

RECOMMENDATIONS AND FUTURE WORK

Future developments can be classified into three stages mainly design, fabrication, and testing. The major concern to be addressed in the design stage is to design the mechanism to absorb more energy from the relative wind, then convert that kinetic energy into vibration.

To develop the power output number of piezoelectric plates used must be increased. When designing the piezoelectric generator more oscillators should be included. By increasing the rotor shaft height more rotor magnets can be installed around the shaft hence the number of oscillators can be increased. Oscillator holders can be installed around the rotor shaft more than 2 (as per the prototype) therefore more power can be generated.

At the fabrication stage, a vertical axis wind turbine can be made without friction losses. By increasing the mass of the turbine almost constant speed and smooth rotation can be achieved in the turbine.

When selecting the spring blade for generating oscillations the hardness is the main factor to be concerned with. Compared to the piezoelectric plates, hardness of hacksaw blades is very high. Using spring blades with low hardness can increase the number of oscillators that can be connected to the wind turbine. By using high-power permanent magnets much stress can be applied to oscillators and it will increase the stress applied to piezoelectric plates resulting in more power output. As these vertical axes wind turbines are planned to be installed in the center region of highways a number of turbines can be installed along the road. The use of high-quality piezoelectric plates with customized sizes and shapes with proper fixing methods can directly improve power generation. During the testing stage, a wind energy source needs to be selected to make a wind flow covering the whole wind turbine. If not only a part of the turbine experiences the power of the wind. Energy harvesting circuits should be at a microwatt level to increase the efficiency of the system.

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