

Novel Hybrid Electricity Generation Technique using Solar and TEG by Waste Heat Recovery

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ABSTRACT: All of us are aware that in future there is a scarcity of energy. Already many countries in the world are facing the energy crisis. Increase in population is increasing the power demand. Over the years many technologies were developed for power generation. In those Technologies solar energy technology (PV Panels) in renewable energy sector and Thermo-Electric Generator (TEG) in waste heat recovery sector has made their own mark in market because of their simplicity and technology. This TEG can generate electricity when there is a temperature difference at its surfaces, so this TEG can be used anywhere where there is use of heat.

The technology of TEG has attracted the power generation sector much. Although we have many green energy technologies in power generation either they are costly or else they are not efficient in all the times. In the present work the TEG's are installed on the surface of any surface where there is heat application and temperature difference is maintained in it so that whatever the energy generated is sent to charge controller and the charge controller controls and refines the energy pulses generated and stores it in battery. Battery further can be used for useful work and this system will be further integrated with solar panels so that continuous power generation can be done when there is no waste heat is available.

1. PV panels cannot harness waste heat and this can be harvested by TEG's.
2. PV panels require large area for installation but when integrated with TEG then the system requires unused surface which is exposed to hot surfaces.
3. In waste heat recovery systems Organic Rankine Cycle can also be used but the technology is only applied for large scale industries but TEG technology proposed in this project can be used anywhere.

For example, we all use heat for cooking food. But while cooking large amount of heat is wasted in stove and oven walls as the heat is absorbed by the walls of stoves and ovens. When we use TEG on such surfaces significant amount of energy can be trapped easily and solar PV Panels can be used anywhere in the world where we get solar radiation throughout the year as in the countries like India.

Benchmarking

1. Requires less area for installation. Preferably the hot surface which is exposed high heat.
2. Installation area to power generation ratio is higher.
3. Compared to Organic Rankine Cycle TEG's have less cost and integration of it with PV panels makes the system efficient and reliable.
4. Waste heat is converted into useful energy.
5. Meets energy demand at very less investments.

Technical Description

The present project involves making the TEG technology with PV panels, feasible for power generation process by waste heat recovery from hot surfaces and also from solar radiation.

The methodology includes,

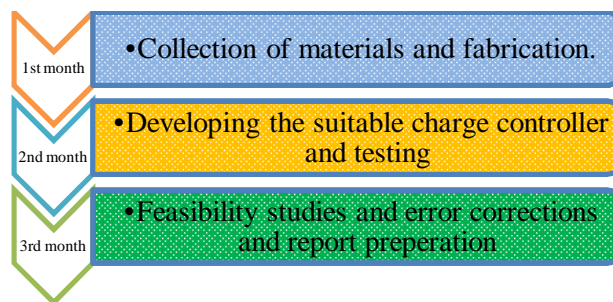
The TEG's are fitted onto the surfaces of the hot walls which are preferably exposed heat and PV Panels on the roof top. When the TEG's are fitted in series and parallel they have a tendency to produce significant amount of electricity.

One surface of TEG is exposed to hot surface and other surface is cooled by the use of heat sink in which water will be flowing. The electricity generated from the TEG's and PV panels will be sent to charge controller from which the battery is charged.

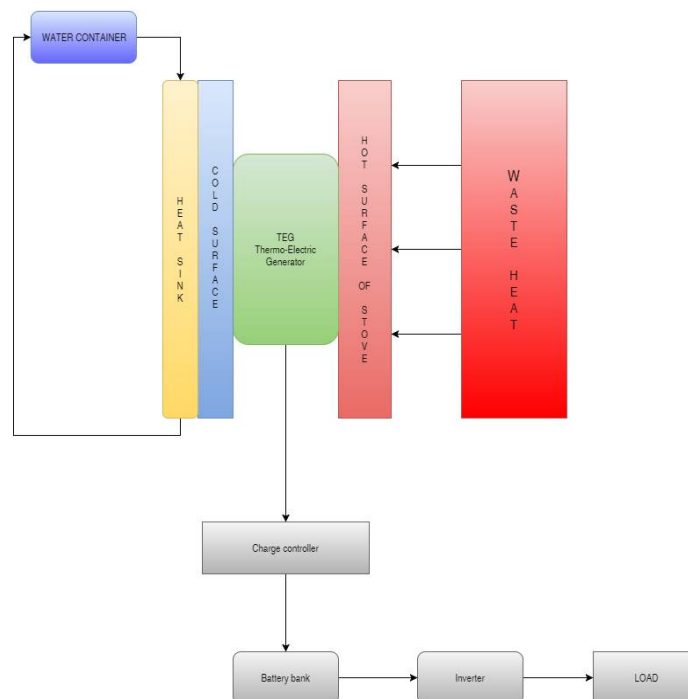
Materials required.

1. Thermo-Electric Generators.
2. PV Panels.
3. Charge controller.
4. Battery bank.
5. Heat sink.
6. Water pump.

Time line



Concept



I. INTRODUCTION

All of us are aware that in future there is a scarcity of energy. Already many countries in the world are facing the energy crisis. Increase in population is increasing the power demand. Over the years many technologies were developed for power generation. In those Technologies Thermo-Electric Generator (TEG) has made its own mark in market because of its simplicity and technology. This TEG can generate electricity when there is a temperature difference at its surfaces, so this TEG can be used anywhere where there is use of heat.

For example, we all use heat for cooking food. But while cooking large amount of heat is wasted in stove and oven walls as the heat is absorbed by the walls of stoves and ovens. When we use TEG on such surfaces significant amount of energy can be trapped easily.

TEG:

A thermoelectric generator (TEG), also called a Seebeck generator, is a solid state device that converts heat flux (temperature differences) directly into electrical energy through a phenomenon called the Seebeck effect (a form of thermoelectric effect). Thermoelectric generators function like heat engines, but are less bulky and have no moving parts. However, TEGs are typically more expensive and less efficient.[1]

Thermoelectric generators could be used in power plants in order to convert waste heat into additional electrical power and in automobiles as automotive thermoelectric generators (ATGs) to increase fuel efficiency. Another application is radioisotope thermoelectric generators which are used in space probes, which has the same mechanism but use radioisotopes to generate the required heat difference.[1]

In 1821, Thomas Johann Seebeck discovered that a thermal gradient formed between two dissimilar conductors can produce electricity.[2] At the heart of the thermoelectric effect is the fact that a temperature gradient in a conducting material results in heat flow; this results in the diffusion of charge carriers. The flow of charge carriers between the hot and cold regions in turn creates a voltage difference. In 1834, Jean Charles Athanase Peltier discovered the reverse effect that running an electric current through the junction of two dissimilar conductors could, depending on the direction of the current, cause it to act as a heater or cooler.[3]

Thermoelectric power generators consist of three major components: thermoelectric materials, thermoelectric modules and thermoelectric systems that interface with the heat source.[4]

Thermoelectric materials

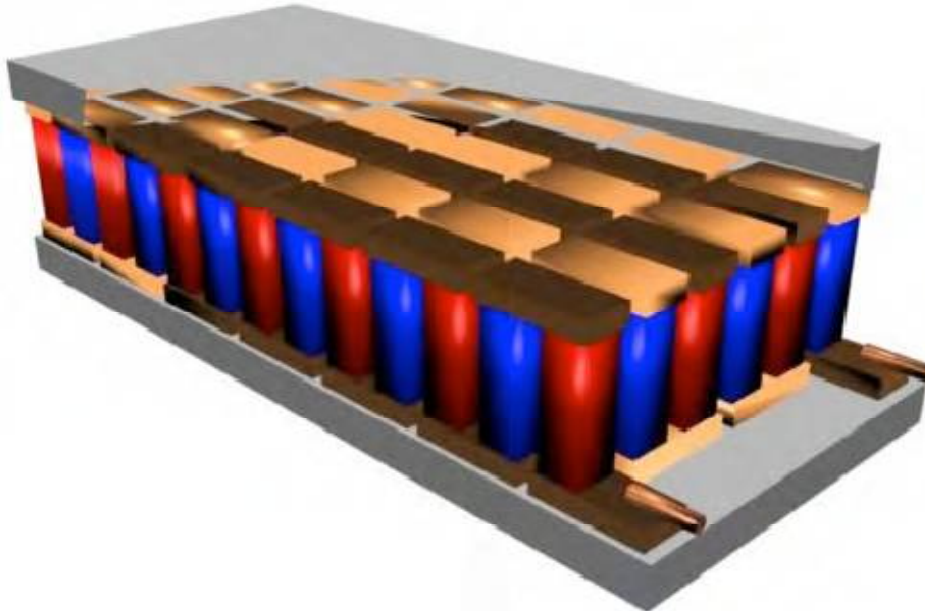
Thermoelectric materials generate power directly from heat by converting temperature differences into electric voltage. These materials must have both high electrical conductivity (σ) and low thermal conductivity (κ) to be good thermoelectric materials. Having low thermal conductivity ensures that when one side is made hot, the other side stays cold, which helps to generate a large voltage while in a temperature gradient. The measure of the magnitude of electrons flow in response to a temperature difference across that material is given by the Seebeck coefficient (S). The efficiency of a given material to produce a thermoelectric power is governed by its "figure of merit" $zT = S^2\sigma T/\kappa$.

For many years, the main three semiconductors known to have both low thermal conductivity and high power factor were bismuth telluride (Bi_2Te_3), lead telluride (PbTe), and silicon germanium (SiGe). These materials have very rare elements which make them very expensive compounds.

Today, the thermal conductivity of semiconductors can be lowered without affecting their high electrical properties using nanotechnology. This can be achieved by creating nanoscale features such as particles, wires or interfaces in bulk semiconductor materials. However, the manufacturing processes of nano-materials is still challenging.

Thermoelectric module

A thermoelectric module is a circuit containing thermoelectric materials that generate electricity from heat directly. A thermoelectric module consists of two dissimilar thermoelectric materials joining in their ends: an n-type (negatively charged); and a p-type (positively charged) semiconductors. A direct electric current will flow in the circuit when there is a temperature difference between the two materials. Generally, the current magnitude has a proportional relationship with the temperature difference. (i.e., the more the temperature difference, the higher the current.)



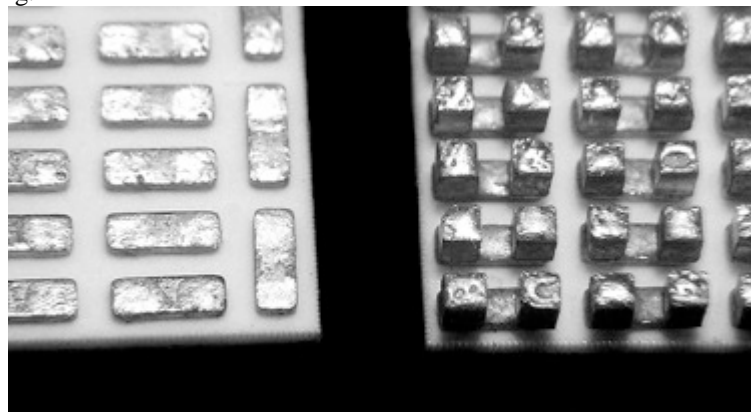
Thermo Electric Modules

In application, thermoelectric modules in power generation work in very tough mechanical and thermal conditions. Because they operate in very high temperature gradient, the modules are subject to large thermally induced stresses and strains for long periods of time. They also are subject to mechanical fatigue caused by large number of thermal cycles.

Thus, the junctions and materials must be selected so that they survive these tough mechanical and thermal conditions. Also, the module must be designed such that the two thermoelectric materials are thermally in parallel, but electrically in series. The efficiency of thermoelectric modules are greatly affected by its geometrical design.

Thermoelectric system

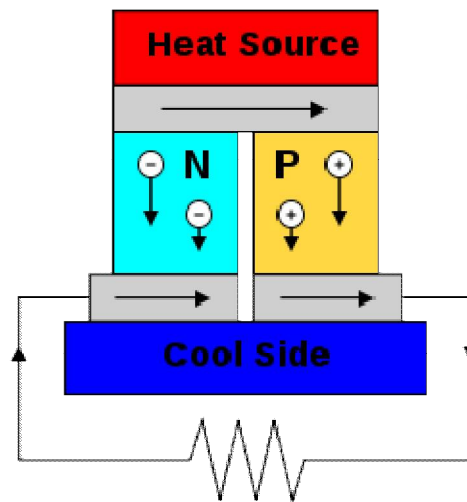
Using thermoelectric modules, a thermoelectric system generates power by taking in heat from a source such as a hot exhaust flue. In order to do that, the system needs a large temperature gradient, which is not easy in real-world applications. The cold side must be cooled by air or water. Heat exchangers are used on both sides of the modules to supply this heating and cooling.



Inside TEG

There are many challenges in designing a reliable TEG system that operates at high temperatures. Achieving high efficiency in the system requires extensive engineering design in order to balance between the heat flow through the modules and maximizing the temperature gradient across them. To do this, designing heat exchanger technologies in the system is one of the most important aspects of TEG engineering. In addition, the system requires minimizing the thermal losses due to the interfaces between materials at several places. Another challenging constraint is avoiding large pressure drops between the heating and cooling sources.

After the DC power from the TE modules passes through an inverter, the TEG produces AC power, which in turn, requires an integrated power electronics system to deliver it to the customer.



SEEBECK EFFECT

Materials for TEG

Only a few known materials to date are identified as thermoelectric materials. Most thermoelectric materials today have a ZT, the figure of merit, value of around unity, such as in Bismuth Telluride (Bi₂Te₃) at room temperature and lead telluride (PbTe) at 500-700K. However, in order to be competitive with other power generation systems, TEG materials should have zT of 2-3 range. Most research in thermoelectric materials has focused on increasing the Seebeck coefficient (S) and reducing the thermal conductivity, especially by manipulating the nanostructure of the thermoelectric materials. Because the thermal and electrical conductivity correlate with the charge carriers, new means must be introduced in order to conciliate the contradiction between high electrical conductivity and low thermal conductivity as indicated.[5]

When selecting materials for thermoelectric generation, a number of other factors need to be considered. During operation, ideally the thermoelectric generator has a large temperature gradient across it. Thermal expansion will then introduce stress in the device which may cause fracture of the thermoelectric legs, or separation from the coupling material. The mechanical properties of the materials must be considered and the coefficient of thermal expansion of the n and p-type material must be matched reasonably well. In segmented thermoelectric generators, the material's compatibility must also be considered. A material's compatibility factor is defined as $s = \left(\frac{\sqrt{1-zT}-1}{ST} \right)$. [6] When the compatibility factor from one segment to the next differs by more than a factor of about two, the device will not operate efficiently. The material parameters determining s (as well as zT) are temperature dependent, so the compatibility factor may change from the hot side to the cold side of the device, even in one segment. This behavior is referred to as self-compatibility and may become important in devices design for low temperature operation.

In general, thermoelectric materials can be categorized into conventional and new materials:

Conventional materials:

There are many TEG materials that are employed in commercial applications today. These materials can be divided into three groups based on the temperature range of operation:

1. Low temperature materials (up to around 450K): Alloys based on Bismuth (Bi) in combinations with Antimony (Sb), Tellurium (Te) or Selenium (Se).
2. Intermediate temperature (up to 850K): such as materials based on alloys of Lead (Pb)
3. Highest temperatures material (up to 1300K): materials fabricated from silicon germanium (SiGe) alloys.

Although these materials still remain the cornerstone for commercial and practical applications in thermoelectric power generation, significant advances have been made in synthesizing new materials and fabricating material structures with improved thermoelectric performance. Recent research have focused on improving the material's figure-of-merit (zT), and hence the conversion efficiency, by reducing the lattice thermal conductivity.[5]

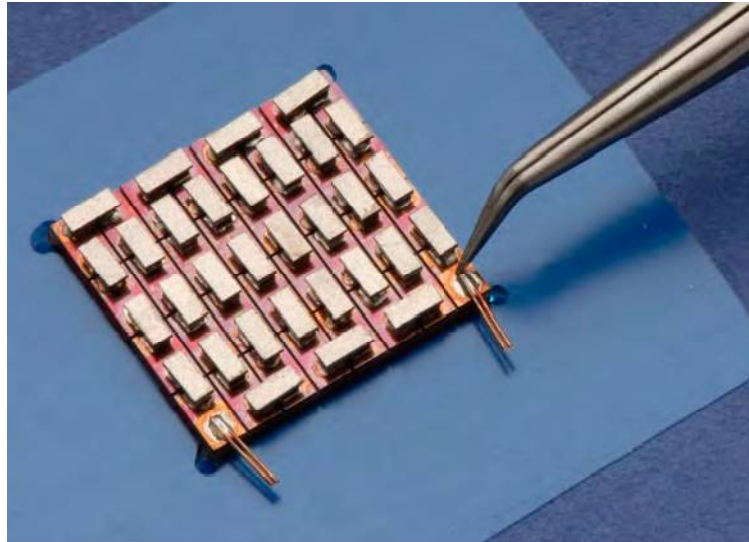
New materials:

Researchers are trying to develop new thermoelectric materials for power generation by improving the figure-of-merit zT . One example of these materials is the semiconductor compound β -Zn₄Sb₃, which possesses an exceptionally low thermal conductivity and exhibits a maximum zT of 1.3 at a temperature of 670K. This material is also relatively inexpensive and stable up to this temperature in a vacuum, and can be a good alternative in the temperature range between materials based on Bi₂Te₃ and PbTe.[5]

Besides improving the figure-of-merit, there is increasing focus to develop new materials by increasing the electrical power output, decreasing cost and developing environmentally friendly materials. For example, when the fuel cost is low or almost free, such as in waste heat recovery, then the cost per watt is only determined by the power per unit area and the operating period. As a result, it has initiated a search for materials with high power output rather than conversion efficiency. For example, the rare earth compounds YbAl₃ has a low figure-of-merit, but it has a power output of at least double that of any other material, and can operate over the temperature range of a waste heat source.[5]

Novel Processing

In order to increase the figure of merit (zT), a material's thermal conductivity should be minimized while its electrical conductivity and Seebeck coefficient is maximized. In most cases, methods to increase or decrease one property result in the same effect on other properties due to their interdependence.[7] A novel processing technique exploits the scattering of different phonon frequencies to selectively reduce lattice thermal conductivity without the typical negative effects on electrical conductivity from the simultaneous increased scattering of electrons. In a bismuth antimony tellurium ternary system, liquid-phase sintering is used to produce low-energy semicoherent grain boundaries, which do not have a significant scattering effect on electrons.[8] The breakthrough is then applying a pressure to the liquid in the sintering process, which creates a transient flow of the Te rich liquid and facilitates the formation of dislocations that greatly reduce the lattice conductivity.[8] The ability to selectively decrease the lattice conductivity results in reported zT values of $1.86 \pm .15$ which are a significant improvement over current commercial thermoelectric generators which have typical figures of merit closer to .3-.6.[9] These improvements highlight the fact that in addition to development of novel materials for thermoelectric applications, using different processing techniques to design microstructure is a viable and worthwhile effort. In fact, it often makes sense to work to optimize both composition and microstructure.[10]



Manufacturing of TEG

Efficiency

The typical efficiency of TEGs is around 5–8%. Older devices used bimetallic junctions and were bulky. More recent devices use highly doped semiconductors made from bismuth telluride (Bi_2Te_3), lead telluride (PbTe), [11] calcium manganese oxide ($\text{Ca}_2\text{Mn}_3\text{O}_8$), [12][13] or combinations thereof, [14] depending on temperature. These are solid-state devices and unlike dynamos have no moving parts, with the occasional exception of a fan or pump. For a discussion of the factors determining and limiting efficiency, and ongoing efforts to improve the efficiency, see the article Thermoelectric materials - Device efficiency.

Uses

Thermoelectric generators have a variety of applications. Frequently, thermoelectric generators are used for low power remote applications or where bulkier but more efficient heat engines such as Stirling engines would not be possible. Unlike heat engines, the solid state electrical components typically used to perform thermal to electric energy conversion have no moving parts. The thermal to electric energy conversion can be performed using components that require no maintenance, have inherently high reliability, and can be used to construct generators with long service-free lifetimes. This makes thermoelectric generators well suited for equipment with low to modest power needs in remote uninhabited or inaccessible locations such as mountaintops, the vacuum of space, or the deep ocean.

- Common application is the use of thermoelectric generators on gas pipelines. For example, for cathodic protection, radio communication, and other telemetry. On gas pipelines for power consumption of up to 5 kW thermal generators are preferable to other power sources. The manufacturers of generators for gas pipelines are Gentherm Global Power Technologies (Formerly Global Thermoelectric), (Calgary, Canada) and TELGEN (Russia).
- Thermoelectric Generators are primarily used as remote and off-grid power generators for unmanned sites. They are the most reliable power generator in such situations as they do not have moving parts (thus virtually maintenance free), work day and night, perform under all weather conditions, and can work without battery backup. Although Solar Photovoltaic systems are also implemented in remote sites, Solar PV may not be a suitable solution where solar radiation is low, i.e. areas at higher latitudes with snow or no sunshine, areas with lots of cloud or tree canopy cover, dusty deserts, forests, etc.
- Gentherm Global Power Technologies (GPT) formerly known as Global Thermoelectric (Canada) has Hybrid Solar-TEG solutions where the Thermoelectric Generator backs up the Solar-PV, such that if the Solar panel is down and the backup battery backup goes into deep discharge then a sensor

starts the TEG as a backup power source until the Solar is up again. The TEG heat can be produced by a low pressure flame fueled by Propane or Natural Gas.

- Many space probes, including the Mars Curiosity rover, generate electricity using a radioisotope thermoelectric generator whose heat source is a radioactive element.
- Cars and other automobiles produce waste heat (in the exhaust and in the cooling agents). Harvesting that heat energy, using a thermoelectric generator, can increase the fuel efficiency of the car. For more details, see the article: Automotive Thermoelectric Generators.
- In addition to automobiles, waste heat is also generated in many other places, such as in industrial processes and in heating (wood stoves, outdoor boilers, cooking, oil and gas fields, pipelines, and remote communication towers).
- Microprocessors generate waste heat. Researchers have considered whether some of that energy could be recycled.[15] (However, see below for problems that can arise.)
- Solar cells use only the high frequency part of the radiation, while the low frequency heat energy is wasted. Several patents about the use of thermoelectric devices in tandem with solar cells have been filed.[16] The idea is to increase the efficiency of the combined solar/thermoelectric system to convert the solar radiation into useful electricity.
- The Maritime Applied Physics Corporation in Baltimore, Maryland [17] is developing a thermoelectric generator to produce electric power on the deep-ocean offshore seabed using the temperature difference between cold seawater and hot fluids released by hydrothermal vents, hot seeps, or from drilled geothermal wells. A high reliability source of seafloor electric power is needed for ocean observatories and sensors used in the geological, environmental, and ocean sciences, by seafloor mineral and energy resource developers, and by the military.
- Ann Makosinski from British Columbia, Canada has developed several devices using Peltier tiles to harvest heat (from a human hand,[18] the forehead, and hot beverage[19]) that claims to generate enough electricity to power an LED light or charge a mobile device, although the inventor admits that the brightness of the LED light is not competitive with those on the market.[20]

Practical limitations

Besides low efficiency and relatively high cost, practical problems exist in using thermoelectric devices in certain types of applications resulting from a relatively high electrical output resistance, which increases self-heating, and a relatively low thermal conductivity, which makes them unsuitable for applications where heat removal is critical, as with heat removal from an electrical device such as microprocessors.

- **High generator output resistance:** In order to get voltage output levels in the range required by digital electrical devices, a common approach is to place many thermoelectric elements in series within a generator module. The element's voltages add, but so do their individual output resistance. The maximum power transfer theorem dictates that maximum power is delivered to a load when the source and load resistances are identically matched. For low impedance loads near zero ohms, as the generator resistance rises the power delivered to the load decreases. To lower the output resistance, some commercial devices place more individual elements in parallel and fewer in series and employ a boost regulator to raise the voltage to the voltage needed by the load.
- **Low thermal conductivity:** Because a very high thermal conductivity is required to transport thermal energy away from a heat source such as a digital microprocessor, the low thermal conductivity of thermoelectric generators makes them unsuitable to recover the heat.
- **Cold-side heat removal with air:** In air-cooled thermoelectric applications, such as when harvesting thermal energy from a motor vehicle's crankcase, the large amount of thermal energy that must be dissipated into ambient air presents a significant challenge. As a thermoelectric generator's cool side temperature rises, the device's differential working temperature decreases. As the temperature rises, the device's electrical resistance increases causing greater parasitic generator self-heating. In motor vehicle applications a supplementary radiator is sometimes used for improved heat removal, though the use of an electric water pump to circulate a coolant adds an additional parasitic loss to total generator output power. Water cooling the thermoelectric generator's cold side, as when generating

thermoelectric power from the hot crank case of an inboard boat motor, would not suffer from this disadvantage. Water is a far easier coolant to use effectively in contrast to air.

II. LITERATURE SURVEY

Fabrication and performance of flat plate solar thermoelectric Generator for near-earth orbits

Auxiliary power is one of the most difficult requirements to satisfy in space. For near-earth orbital trajectories, direct solid-state energy conversion from solar radiation is one of the most advantageous techniques at power levels below 1 kW.

A unique feature of this historical work is the application of the unit couple concept in the design of solar thermoelectric flat plates. Due to this feature, the solar energy conversion panels to be fabricated by series combinations of couples. Each unit couple is soldered to the adjacent couples and mounted on a ridged lightweight aluminium radiator plate [10].

The construction of a unit couple consist the aluminium absorber and radiator plates, 0.5-mil-thick nickel disks, which are soldered to the aluminium at the thermoelectric leg locations and the four thermoelectric legs (a series connection of a pair of n- and p-type legs). The absorber and radiator plates are made from aluminium alloy 1100 foil of thickness 0.0002 inch (rolled to provide a mirror finish which reduces the internal emissivity of the plates to 0.03) formed into mechanical ridged members by special jigs. A group of unit couple types is required to form 3-by 3-inch panels of nine 1- by 1-inch unit cells connected in series which are mounted on a lightweight aluminium radiator plate.

After fabrication process, the ac resistance of the unit couple is measured at ambient temperature. Now by using the apparatus the unit couple is placed on the calibrated thermoelectric module, which in turn, rests on a thermoelectric temperature-controlling module. The control module is used to maintain the bottom of the calibrated module at a fixed temperature.

After testing of a generator, the calibrated module current is recorded for a predetermined temperature difference across the module. The tests are carried out in a vacuum of 10-4torr or much better. A 150-watt, focused projection lamp is used for the radiant heat source purpose.

These performance investigations have concluded that flat plate solar thermoelectric generator panels can be fabricated to give 3 to 3.3 watts with $A_r/A_a = 1$, and 30 watts/pound at the unit couple (or cell) stage and 15 watts/pound at the panel stage [11].

These panels are capable of producing 3 watts/ft² and 15 watts/ pound when operating in a near-earth orbit, The Potential advantages of these solar energy converters over photovoltaic cells are discussed and include higher radiation resistance, improved watts/pound, and lower cost on a per watt basis.

High efficiency Thermo-Electric power generator

Thermoelectric material properties and the power generator architecture play a fundamental role in the achievement of high energy conversion efficiencies.

The research focuses on the TE module architecture design, assembly and the subcomponents manufacturing. Commercial Bismuth Telluride cells were used to fabricate TE materials. The TE generator taken into account for energy conversion efficiency calculation which is characterized by a series of TE elements placed in a counter-current heat exchanger of the hot and cold gaseous streams. A catalytic combustion chamber were designed and manufactured (SiC monolith heat exchangers, catalysts and supports for the combustion chamber, system housing) to ignite an air/fuel mixture. Pd/NiCrO₄ and Pt/Al₂O₃ catalysts were investigated to ignite H₂, CH₄ and H₂/ CH₄ mixtures, at different gas flow rates and fuel concentrations. This air/fuel mixture at room temperature T_{in} is fed to the generator flows in the cold channel where it warms up absorbing heat from the cold side of the TE element enters the combustion chamber with the regeneration temperature TR, and here it burns reaching the temperature TH. The flue gases from the combustion chamber pass through the hot channel, in counter-current with respect to the inlet air/fuel stream. The flue gases cool down, transferring heat to the hot side of TE elements, and leave the system at relatively low-temperature T_{out} . Such generator can be called "U-shape" TE generator. The results led to the design of a TE generator architecture providing flexible electrical loads through a modular assembly, with an improved thermal management which enhanced the energy conversion efficiency [12].

The "U-shape" TE module was finally assembled and tested, in different operating conditions. The achieved efficiency was around 1.7% with an external oven providing the desired temperature at the TE module hot side, while a lower efficiency of 1.3% was achieved with the embedded combustion chamber. CFD simulations, which provided excellent fitting with the experimental data, predicted a maximum efficiency of 1.85% at higher gas velocities.

Parametrical analysis of the design and performance of a solar heat pipe thermoelectric generator unit

This paper describes a solar heat pipe thermoelectric generator (SHP-TEG) unit comprising a TEG module, a finned heat pipe and an evacuated double-skin glass tube. To meet the TEG operating requirement, the system takes the advantage of heat pipe to convert the absorbed solar irradiation to a high heat flux. An analytical model of the SHP-TEG unit is presented for the condition of constant solar radiation, which may lead to different performance characteristics and optimal design parameters compared with the condition of constant temperature difference usually dealt with in other studies. This analytical model presents the complex influence of basic parameters such as solar irradiation, thermo element length, number of thermo elements cooling water temperature, and cross section area etc. on the maximum power output and conversion efficiency of the SHP-TEG. Mathematical simulation based on the analytical model has been carried out to study the performance and design optimization of the SHP-TEG [13].

Analysis of the internal heat losses in a thermoelectric generator

A 3D thermoelectric numerical model is used to investigate different internal heat loss mechanisms for a thermoelectric generator with bismuth telluride p- and n-legs. This model considers all thermoelectric effects, temperature dependent material parameters and simultaneous conductive, convective and radiative heat losses including surface to surface radiation. It is shown for radiative heat losses that surface to ambient radiation is a good approximation of the heat loss for the temperatures considered.

For conductive heat transfer the module efficiency is shown to be comparable to the case of radiative losses. The combined case of radiative and conductive heat transfer resulted in the lowest efficiency. For increased heat loss, the optimized load resistance is found to decrease. The leg dimensions are varied for all heat losses cases and it is shown that the ideal way to construct a TEG module with minimal heat losses and maximum efficiency is to either use a good insulating material between the legs or evacuate the module completely and use small and wide legs closely spaced [14].

Geometric effect on cooling power and performance of an integrated thermoelectric generation-cooling system

Geometric design of an integrated thermoelectric generation-cooling system is performed numerically using a finite element method. In the system, a thermoelectric cooler (TEC) is powered directly by a thermoelectric generator (TEG). Two different boundary conditions in association with the effects of contact resistance and heat convection on system performance are taken into account. These outputs suggest that the characteristics of system performance under varying TEG length are significantly different from those under altering TEC length. If the TEG length is changed, the entire behaviour of system performance depends highly on the boundary conditions. Other hand, the maximum distributions of cooling power and coefficient of performance (COP) are exhibited when the TEC length is altered, if the hot surface of TEG is given by a fixed temperature or heat transfer rate. Performance of the system will be reduced once the contact resistance and heat convection are considered. Whether the lengths of TEG and TEC vary, maximum reduction percentages of system performance are 12.45% and 18.67%, respectively. The numerical predictions have provided a useful insight into the design of integrated TEG-TEC systems [15].

Electric power generation from solar pond using combination of thermosyphon and thermoelectric modules

Salinity-gradient solar pond is one type of solar collector with the ability to store thermal energy for long period of time and lower cost of construction compared with the other type of solar collector. This collector can collect and store solar heat at temperatures up to 80°C. A system in which heat from the lower zone is transferred to the hot surface of the thermoelectric modules using gravity assisted heat pipes as thermosyphons has been investigated experimentally. Temperature difference between the lower convective zone and the upper convective zone is applied across the hot and cold side of the thermoelectric modules surface [16].

The results have been found by using water as working fluid in experiment, the temperature of the solar pond in lower convective zone is at 50°C. This is clear that the thermoelectric generator is able to generate electricity at 36.25 mV [16].

In another place an experimental rig was developed to generate electricity from salinity gradient solar pond with 16 TEGs connected in series. The TEGs are each arranged in a tablet with 8 TEGs in each tablet unit. The tablets are made of aluminium plates with 1mm thickness to achieve good heat transfer across the TEGs surface. The two tablets are arranged such that the hot water goes through the central channel and the cold water will be channelled to the outer cold channels.

It shows that the TEGs are capable of producing power using the heat from salinity gradient solar pond and the amount of power produced is linear to the temperature difference across the TEG. This designed experimental rig was able to provide maximum power of 5.30 W which was obtained at 13.4 V and 0.24 A when the temperature difference of 75^oC was maintained across 16 thermoelectric cells. In this case, the open-circuit voltage and the short circuit current values of 26 V and 0.4 A respectively were obtained [17].

Waste heat recovery using a thermoelectric power generation system in a biomass gasifier

The aim of this study is to investigate the use of waste heat that is recovered from a biomass gasifier. In the gasification process, the low heating value of biomass can be transferred to a high heating value for combustible gaseous fuel, a form that is widely used in industry and power plants. Conventionally, some of cleaning processes need to be conducted under higher operating temperatures than the low temperatures typically used to burn biomass. Therefore, the catalytic reactor was designed before installation the scrubber in the downdraft gasifier system to make effective use of the waste heat. The experimental result shows that the temperature of the gasifier outlet is about 623–773K; dolomite is used for tar removal in the catalytic reactor. To further improve the use of waste heat, a thermoelectric generator is added to provide for the recovery of waste heat. The thermoelectric generator system is manufactured using a Bi₂Te₃ based material and is composed of eight thermoelectric modules on the surface of catalytic reactor. The measured surface temperature of the catalytic reactor is 473–633K that is the correct temperature for Bi₂Te₃ as thermoelectric generator [18]. The result shows that the maximum power output of the thermoelectric generator system is improved to 6.1W and thermoelectric generator power density is approximately 193.1 W/m².

Experimental analysis of Thermoelectric Generator using Solar Energy

The performance of a 4x4 cm² Bismuth Telluride based thermoelectric generator with 126 thermocouples connected in series is analysed experimentally along with heat dissipater at the cold side is fixed on a stand. The terminals of the cold side are connected to multi meter and 3.3Ω load. The hot and cold junction temperatures were measured with thermometer and the corresponding voltage and current were measured with a multi meter and the power is calculated the hot junction of the thermoelectric generator is exposed to solar and candle heat and the cold side is exposed to atmosphere. With the hot junction temperature of 530C and cold junction temperature of 320C, the output power, current and voltage are measured as 0.014W, 0.042A and 0.35V respectively.

Now the hot junction of the thermoelectric generator is exposed to solar concentrator heat and the cold side is exposed to ice. If the hot junction temperature of 100.2^oC and cold junction temperature of 2.9^oC, the output power, current and voltage are measured as 0.319W, 0.1083A and 2.96V respectively. This power output is increased by 30.5%. The power density is 2.11μ Wcm⁻²°C⁻²[19].

It shows performance of Bismuth Telluride based TEG. With the solar and candle heat the average power output is 0.0273W. With solar concentrator the average power output is 0.134W. The power output increases with the increase of temperature gradient and the increase in temperature at the hot side. The power output can be increased further by developing vacuum at the hot and cold junction and by external cooling of the cold side.

Thermoelectric bond development for the Flat plate solar thermoelectric generator

The flat plate solar thermoelectric generator is a device that has been developed specifically to utilize direct nonconcentrated sunlight for power generation. Since the generator under consideration is designed for orbital applications, criteria applicable to other orbital power systems must be considered as well as the conventional criteria for thermoelectric systems [20]. An analysis has shown that the desirable characteristics of the optimum systems are high specific power, good radiation resistance, and small size coupled with ease of manufacture, high reliability, and low cost. In the flat plate thermoelectric solar generator module, these criteria dictate minimum element volume, lightweight shoes, and minimum radiator and absorber thicknesses. The successful thermoelectric bond:

- a. Must be chemically stable under operating conditions.
- b. Must not produce a zone of charge carrier depletion in the element.

- c. Must be sufficiently strong or thermally compensated to be able to withstand shear stresses generated by thermal expansion of bond and element materials.
- d. Must not serve as a source of any agent that may diffuse into the element and produce poisoning or cross-doping.

In addition to these general criteria, the specific design imposed the following conditions and restraints on the bonds:

- a. Hot junction temperature: 520⁰K.
- b. Cold junction temperature: 350⁰K.
- c. Useful lifetime: 2000 to 7000 hours (to 25% degradation of electrical performance).
- d. Initial electrical resistance of both bonds: less than 5% of element resistance.

Effect of various leg geometries on thermo-mechanical and powergeneration performance of thermoelectric devices

This study aims to investigate possible effect of various thermoelectric leg geometries on thermo mechanical and power generation performances of thermoelectric devices. Hence for this purpose, thermoelectric modules with various leg geometries were modelled and finite-element analyses for two different temperature gradients were carried out using ANSYS. Power outputs, Temperature distributions, thermal stresses in the legs, conversion efficiencies were evaluated for each model. Due to changing leg geometries the differences in magnitudes and distributions of the thermal stresses in the legs are occurred significantly. Thermal stresses in the rectangular prism and the cylindrical legs were 49.9 MPa and 43.3 MPa respectively for the temperature gradient of 100⁰C [21].

III. BACKGROUND AND INNOVATION

Innovation

The technology of TEG has attracted the power generation sector much. Although we have many green energy technologies in power generation either they are costly or else they are not efficient in all the times.

In the present work the TEG's are installed on the surface of any surface where there is heat application and temperature difference is maintained in it so that whatever the energy generated is sent to charge controller and the charge controller controls and refines the energy pulses generated and stores it in battery. Battery further can be used for useful work and this system will be further integrated with solar panels so that continuous power generation can be done when there is no waste heat is available.

1. PV panels cannot harness waste heat and this can be harvested by TEG's.
2. PV panels require large area for installation but when integrated with TEG then the system requires unused surface which is exposed to hot surfaces.
3. In waste heat recovery systems Organic Rankine Cycle can also be used but the technology is only applied for large scale industries but TEG technology proposed in this project can be used anywhere.

Benchmarking

1. Requires less area for installation. Preferably the hot surface which is exposed high heat.
2. Installation area to power generation ratio is higher.
3. Compared to Organic Rankine Cycle TEG's have less cost and integration of it with PV panels makes the system efficient and reliable.
4. Waste heat is converted into useful energy.
5. Meets energy demand at very less investments.

IV. OBJECTIVES

From the literature survey it is clearly understood that there is lot of potential in power generation using TEG, and it also attracts the engineers as it is the only one device which converts waste heat into electricity at solid state as there is no liquid medium is involved in the process.

So according to the necessity and the requirement for the development of the country and to bring out this technology as an alternate to the power generation the following objectives are set,

1. To provide power generation technology at less cost compared to PV panels
2. To convert waste heat from the kitchen into useful energy
3. To have a green technology using TEG
4. To make system simple and reliable for rural people to operate.
5. To provide mobile charging unit from the developed system for the remote areas.

V. PROJECT METHODOLOGY

Technical Description

The present project involves making the TEG technology with PV panels, feasible for power generation process by waste heat recovery from hot surfaces and also from solar radiation.

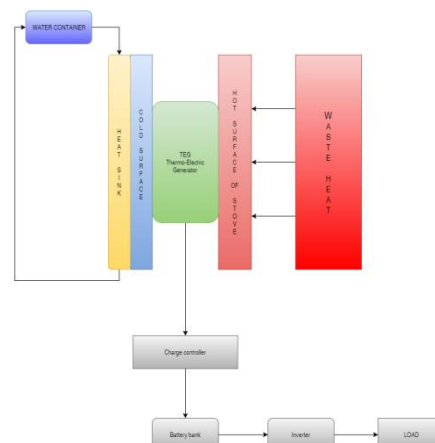
The methodology includes,

The TEG's are fitted onto the surface s of the hot walls which are preferably exposed heat and PV Panels on the roof top. When the TEG's are fitted in series and parallel they have a tendency to produce significant amount of electricity. One surface of TEG is exposed to hot surface and other surface is cooled by the use of heat sink in which water will be flowing. The electricity generated from the TEG's and PV panels will be sent to charge controller from which the battery is charged.

Materials required.

1. Thermo-Electric Generators.
2. PV Panels.
3. Charge controller.
4. Battery bank.
5. Heat sink.
6. Volt amp meter
7. Load

CONCEPT



To meet the requirements of the undertaken work it was necessary to have the below mentioned materials

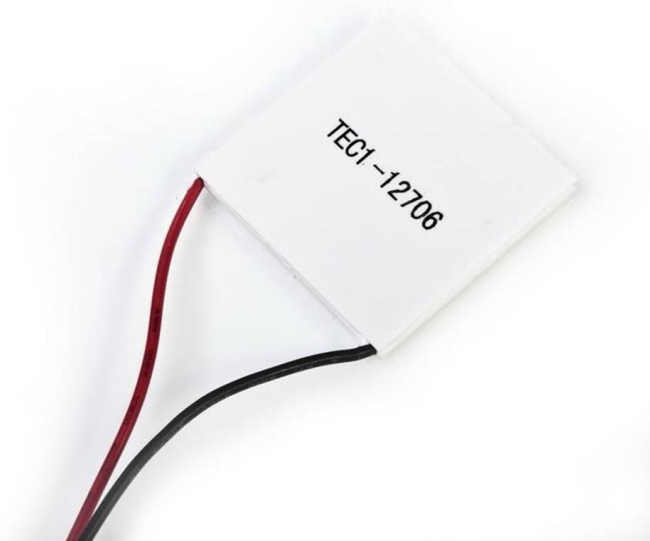
1. Thermo-Electric Generators
2. PV panels
3. Charge controller.
4. Battery bank.
5. Heat sink.
6. Volt amp meter
7. Load

System development

1. Thermo electric Generators

In the present work TEG's work as a heart of the system as they are concentrated more in the present work. So to meet the objectives set it was necessary to have an efficient TEG and at the same time which should be cheaper also. So the following TEG's performance was studied thoroughly and the results obtained were satisfying the requirement.

When the temperature at the hot surface is maintained at 150⁰C and the temperature at the cold surface maintained at 28⁰ C by making the water to flow over the TEG's surface. At this time the total temperature difference between the both surfaces was about 122⁰C. at this temperature difference TEG was producing about 2.3 Volts. So finally it was decided to have 10 TEG's, which will produce totally 23 volts at that temperature difference at also this voltage will be enough to charge the battery and also to run the DC water pump for heat exchanger.



Product	TEC1-12706
Operational voltage	12V DC
Current max	6 Amp
Voltage max	15.4 V
Power max	92.4
Power nominal	60
Couples	127
Dimensions	40 x 40 x 3.5 mm

TEC specifications

2. PV panel

Specification

Voltage: 12 Volts

Power: 15 Watts

3. Charge controller.

For the output given by the 10 TEG's the suitable charge controller was manufactured. The charge controller was able to charge the battery, charge the mobile and it also has the provision to connect it to the LED lightings for the usage at night time.

4. Heat Sink

The heat sink was necessary to cool the cold surface of the TEG, so to make the heat sink it was initially tested with forced convection type heat exchanger which used air as the cooling medium.

Material : Aluminium

Size :40x 40x 15 mm

Finally when the performance of TEG setup was tested with water heat exchanger the power developed was found to be almost double that of air cooled heat sink.

5. Power Measuring Devices



Specifications

- Make : Tanotis measuring instruments
- Size: 48mm x 29mm x 21mm.
- Display color: Red & Blue LED (dual display).
- Display: 0.28" LED digital.
- Operating voltage: DC 4.5 ~ 30V.
- Measure voltage: DC 0 ~ 100V.
- Minimum resolution (V): 0.1V.
- Refresh rate: ≥ 500 ms / times.
- Measure accuracy: 1% (± 1 digit).
- Minimum resolution (A): 0.01A.
- Operating Current: <20mA.

- Measure current: 10A (direct measurement, built-in shunt).
- Operating temperature: -10 to 65°C.
- Operating Humidity: 10 to 80% (non-condensing).
- Mounting cutout: 45.5mm x 26.5mm.

6. Battery

Specifications

Voltage : 6 Volts

Capacity : 4.5 Ah

VI. RESULT ANALYSIS

System was built using TEG modules and tested by applying heat from a electric heating element. To measure the voltage and the current produced by the system Multimeter was used and to measure the temperature of both surfaces digital thermometer was used.

The power of the developed system could reach about 500 W (predicted using experimental data) with a temperature difference of about 200°C between hot and cold sides. An output power of over 160 W has been generated under a temperature difference of 80 (hot side temperature was about 110°C and the cold side was 30°C). The instantaneous efficiency of the TEG system reached 4.5% at average temperatures of about 95°C on the hot side and a temperature of 30°C on the cold side. This efficiency increases exponentially with the inlet temperature.

VII. CONCLUSION

Present method for electricity generation is converting thermal energy into Electrical energy. Burning of these fuels causes environmental problem like radio activity pollution, global warming. Hence (coal, oil, gas) are the limiting resources resulting new technology is needed. The project paper is tested and implemented. The system gives the best economical pollution free, required energy solution to the people.

Two power generators have been built using TEG modules and tested. The power of the first one could reach about 500 W with a temperature difference of about 200°C between hot and cold sides. This work can be used for many applications in urban and rural areas where power availability is less or totally absence. By making this system generates 12 Volts and can be used for any application between 4-6-1 Volts as the charge controller is flexible for the purpose and charge 12v which is capable to recharge a mobile. it avoiding dependency of grid supply. This is a Promising technology for solving power crisis to an affordable extent

ADVANTAGES

- Clean, Noise less , Cost is less
- This is a Non-conventional system , No fuel is required
- Easy maintenance Charging time is less (at maximum temp)
- Promising technology for solving power crisis to an affordable extent.
- Simple in construction.
- Pollution free.
- Reduces transmission losses.
- Wide areas of application
- Required less space.
- It can be use at any time when it necessary.
- Less number of parts required.
- we can charge any electronic devices
- Electricity can used for many.

SCOPE OF THE FUTURE WORK

- By addition of the more TEG in SERIES is to increase the voltage.

- Feasibility studies are to be undertaken for successful implementation.

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