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A survey on waste heat recovery: Electric power generation and potential prospects within Pakistan

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ABSTRACT

Waste heat recovery system plays a pivotal role for heat extractions in every energy consuming sector. Thermo-Electric Module converts this waste heat into useful work done as “electric energy”. Electric energy thus produced possesses many promissory benefits, such as: (a) energy storage in DC batteries, (b) running various loads in residential, commercial and industrial sector, (c) exporting power to grid, thus earning valuable revenues, (d) maintain economic growth of plant, and (e) environment friendly system. Recently, among various renewable energy technologies, Waste Heat Recovery (WHR) is paid much consideration in commercial, residential, and industrial sectors. In past decade, a number of WHR technologies are developed and improved. In this paper, relevant research works are reviewed regarding existing technologies of WHR. Thermoelectric Generator (TEG) is one of extensively emerging WHR technique among existing technologies. TEG with promising features, such as: simpler structure, vast scalability, solid state operation, the absence of toxic residuals, a long life span of reliable operation, no noise or vibration, and lack of chemical reaction or moving parts. Basic principle of TEG with its series and parallel arrangement for voltage and current enhancement is also reviewed. Our work described a standalone thermoelectric module generate 1–125 W whose modular arrangement produces ~5 kW and the wattage improvement is defendant on array size. The potential application of TEG in various applications are comprehensively discussed and described. A detailed description to Pakistan energy status and WHR potential especially in Cement Industry is assessed in this survey. Finally, the TEGs model in Matlab/SimScape for direct heat energy harvesting with DC/DC converter is simulated, as a case study of “Officer Colony, Abbottabad, Pakistan”.

1. Introduction

The exploration for more sustainable and cleaner energy is an ever-growing worldwide interest due to global warming and increasing cost associated with the conventional fossil fuel sources [1–5]. The energy resources of the earth are finite. The confirmed energy resources include: (a) petroleum, (b) uranium, (c) coal, and (d) natural gas are depleting day-by-day and will exhaust within fifty years (Japan Energy Conservation Center, 1994/5) [6]. The conventional energy sources possesses an adverse impact of climate change and carbon dioxide (CO_2) emissions. Industrial Revolution and increase usage of fossil fuels upsurges CO_2 level by 30% worldwide [7]. The excessive CO_2 emission has direct consequences of global warming. The hostile effects of global warming are: (a) rise of sea level, (b) high surface temperature, (c) production of dislocation in agriculture, and (c) northern hemisphere snow shrinkage. The problem of green gas emission is 22% per decade increase, with increase of CO_2. The depletion problem of conventional energy sources is resolved by exploiting renewable sources i.e. Wind, Solar, Hydro, Tidal, Biogas, Wave, Geothermal, and Waste Heat Recovery (WHR) [7–9].

Pakistan is facing severe energy crises problem since past decade. To meet the increasing demand of electricity and energy shortfall of Pakistan, renewable energy sources must be developed and utilized as alternative source of non-renewables. Since they are non-polluting and enduring [10–12]. One of the renewable technologies is Waste Heat Recovery System (WHRS). A tremendous amount of waste heat is produced as a bi-product in various sectors namely: (a) residential, (b) commercial, and (c) industrial [13]. Massive amount of heat is produced from cooking gas stoves, gas heaters, automobile, hotels, restaurants, nuclear power and thermal power plants, cement industry, and glass industry. Additionally, heat sources under 100 °C (low-grade) are available from nature, namely: (a) solar energy and (b) geothermal

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reservoirs. Utilizing this heat for electricity generation will save a significant amount of money generate, lower fuel cost, and will be beneficial to the environment [14]. The fraction of heat which is converted to electricity defends on intake and exhaust temperature of generation and combustion processes. The utilization of available heat in environment and technology system for electricity harvesting is the focal motive for researchers [15].

Waste heat energy discharged into atmosphere is one of the largest sources of clean, fuel-free, and inexpensive energy available [16]. Currently, in literature a large number of WHR methods are available. One of such method is Brayton Cycle (BC) based on thermodynamic cycle that describes working of constant pressure heat engine. The BC requires three components namely: (a) compressor, (b) mixing chamber, and (c) expander [17–19]. The BC are extensively employed in airplanes and gas power plant due to low maintenance cost [20]. Alternative method is Sterling Engine (SE) that cyclically compresses and expands working fluid at different operating temperatures [21,22]. The SE is highly efficient, less polluted, silent operation, simple configuration, reliable, and multi-fuel capability [23,24]. Other technologies includes: Kalina Cycles (KC) [25–28], carbon dioxide transcritical cycles [29–31], Organic Rankine Cycle (ORC) [32–37], Steam Rankine Cycle (SRC) [38–41], piezoelectric energy harnessing [42–47], thermo-photovoltaic (thermo-PV) devices [48–50], Thermionic [51–53], and Thermoelectric or Thermoelectric Generator (TEG) [54–58].

Among various sustainable WHR technologies, TEG is gaining much attention due to the solid state devices that transform heat energy from various sources i.e. factories, power plants, computers, electric vehicles, stoves, and even human bodies into electrical energy utilizing Seebeck Effect (SE) [59–63]. The promising features of TEG are: (a) vast scalability, (b) solid state operation, (c) the absence of toxic residuals, (d) long life span of reliable operation, and (e) lack of chemical reaction or moving parts [64–67]. However, Thermo- Electric (TE) devices are also used to convert electrical energy into heat energy for heating (cooling) based on Peltier Effect (PE). In Comparison with conventional refrigeration and heating process, TE devices are simple, possesses no vibration, and free greenhouse gases over life time [68]. Fig. 1, describes retrieval of electrical energy from waste heat using various sources [69].

Low efficiency of TE materials effect commercialization of TEG on large scale. The present TEG materials need advancement to compete with the existing refrigeration and power generation technologies [70]. Advances in TEG materials progressing day by day. Table 1 critically analyzed various existing surveys in comparison with our work.

The remaining of the paper is structured as follows: Section 2 describes an overview of global energy demand. The energy status of Pakistan is presented in Section 3. Section 4 demonstrates existing technologies of waste heat recovery. Thermoelectric generators are elaborated in Section 5. Economic, environment and commercialization of TEG are discussed in Section 6. The application of thermoelectric generators is explained in Section 7. Waste Heat Recovery prospective in Pakistan is described in Section 8. Section 9 described SimScape implementation of TEG as Case study of “Officer Colony Abbottabad”. Section 10 concludes the survey with a brief summary and proposal for future work.

2. An overview of global energy demand

Energy is an integral part of our everyday life. Energy is directly and indirectly used in residential, commercial, and industrial sectors. One of the most fundamental needs of the universe is energy that makes life easier. The demand for reliable and affordable energy is an evergreen domain. The world energy demand is fulfilled through long period planning, monitored over years of work, and huge investment paid for reliable and effective infrastructure of generating. In last 150 years, global energy demand has increased unprecedentedly, due to the rapid growth of population and industrial development. Table 2 describes the prediction of continuously increasing energy demand [94].

3. Energy status of Pakistan

The demand for electricity in Pakistan is rapidly growing at 11–13% per year (energy rate). In 2006, the requirement of energy in Pakistan was 57.9 million Tons of Oil Equivalent (TOEs) and is predicted to cross 179 million TOEs in 2020. The short fall of Pakistan electricity is 8500 MW in 2012 and entire country suffered from continuous load shedding persisting over 14–20 h per day. The shortfall on the contrary effected on economic growth [95]. In 1996, Pakistan imported 1400 million US dollars crude oil that badly affected on economic development. Twenty percent of foreign exchange expenditures were spent on importing fossil fuels [96], whereas approximately 14.5 billion US dollars for non-renewable energy resources was equivalent to 40% of total import of Pakistan [97]. Energy demand is far higher than production and is anticipated to be almost three time more by 2050 [98,99]. Currently Pakistan is dependent on non-renewable energies, such as: hydro, thermal, nuclear, diesel, and gas to fulfill its energy demands as presented in Fig. 2.

In last decade, Pakistan is suffering from energy spell. Consequently, to overcome energy crises and to improve economic growth, it is mandatory to explore and utilize renewable (alternative green energies) in combination with non-renewable resources [100]. Pakistan is naturally enriched with potential of green energy sources

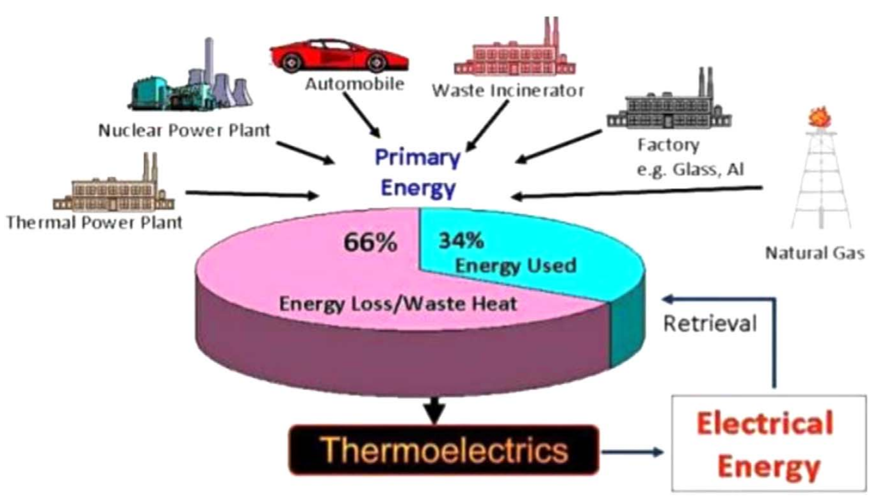

Fig. 1. Energy Statistics: Thermoelectric Generators.