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Electrical Generation from Thermal Solar Energy using a Turbocharger with the Brayton Thermodynamic Cycle

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Abstract

This paper addresses the use of Solar Thermal Energy to continuously generate electrical energy with a commercially available Turbo-Charger driving an Electrical Generator. The system is based on Brayton´s thermodynamic cycle and the energy is provided by a thermal accumulator. We propose that using air as the working media, the compressor element is capable of producing sufficient boost to achieve a useful level of efficiency for the cycle at the operating speed range claimed by the factory. The design or selection of the other important components of the system, such as the electrical generator, the starting motor, the electrical drive, the rectifying and inverting of the current is discussed. A parametric analysis that proves the theoretical feasibility of this model is included.

Keywords: Brayton; Thermal; Solar; Energy; Turbo-Charger; Pressure Ratio; Electrical Generator; Simulation.

Introduction:

There have been several successful applications where Solar Thermal Energy has been used to generate Electrical Power, but they have been mostly in higher production levels than what we propose here, also they tend to be too complicated, since normally the Turbine, the Compressor and the Generator are always designed specifically for each project, resulting in an expensive and complicated unit, this becomes even worse when combinations of more than one Turbine or Compressor are used. The purpose of this investigation is to prove if a single commercially available industrial engine Turbo-Charger can implement a Brayton-cycle based engine capable of driving an Electrical Generator to produce at least one Kilowatt, providing an option for domestic scale distributed generation. The most important questions to answer are: will the compressor be able to produce a Pressure Ratio, required by a Brayton cycle engine as it is, or does it have to be modified? Will the hot compressed air drive the Turbine to the required RPMs to produce the work required by both, the Compressor (back-work) and the Generator (net-work output)? How will the required heat be conveyed to the compressed air? Will the system setup be intrinsically safe? (to operate unattended on a household´s roof).

Nomenclature:

$\eta_{Br.}$	Brayton cycle´s overall efficiency.
$\frac{P_2}{P_1}$	Ratio between the highest and the lowest pressures in the cycle.
k	Thermodynamic capacity of the media employed
A/R	relation between cross-section area and the radius of the centroid for a Volute [20]
Trim	area of the compressor's inducer to area of exducer (ratio), and inversely for the turbine

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The Brayton Cycle

With the *Brayton cycle*, as with all other thermodynamic cycles, it is necessary to distinguish the cycle its self from the technological applications. Brayton cycle engines have been quite varied, and will resemble modern reciprocating engines, but the most important are those with a continuous flow of a thermodynamic fluid. It is the working principle for the gas turbine.

The development of the gas turbine occurs basically in the early 20th century, and comes as a result of the settlement of the problematic main technique associated with the Brayton cycle, i.e. the compression stage. The compression of a compressible fluid is not simple: piston engines solved the problem confining the gas in a closed Chamber - cylinder-, and by reducing the volume with a piston, thus increasing the pressure; however, this requires heavy and large engines for big powers, and calls for a high mechanical inertia in order to guarantee its continuous operation. [2]

The gas turbine uses a compressor, consisting of one or more steps of rotating blades that transmit a kinetic energy to the gas by accelerating it and then, through some fixed blades or diverting passages that slow it down to convert the added energy into pressure. It was also the advance of technology, the development of new materials and getting a better understanding of fluid mechanics for men to produce the first truly effective compressors, and with that, the first gas turbines.

On these devices, after compression followed the addition of fuel in a rudimentary combustion chamber where it burned, and then expansion was set in a turbine, producing mechanical work, part of which is used to drive its compressor, and the remaining power can drive any mechanical device such as a generator. Also a Brayton Turbine can have external combustion with the hot compressed gases entering the turbine and converting its energy by expanding and making it turn.

The application of a gas turbine based on the Brayton cycle to airplane propulsion is due to the English engineer Frank Whittle, who in 1927 patented the idea and proposed it to the British air force. The gas turbine would only power the compressor, and propulsion would come from the high speed of gases at the output of the turbine, forming a propulsive jet which would generate a thrust force. The idea of Whittle was also raised at about the same time by the German Hans von Ohain. During World War II a frenetic race between the two sides towards the development of the first Jet engines. Since then, based on the Brayton cycle, the gas turbine would dominate as aircraft propulsion system. At the same time it continued being implemented within the generation industry.

To use air as a thermodynamic fluid, the Brayton cycle requires high temperatures to achieve reasonable performance levels.

Variations on the basic cycle, like multiple stages in compression or in expansion, or the combination with a Rankine cycle machine in what is called the “Combined cycle”.

The Brayton cycle can be open or closed. In an open-cycle, ambient air is compressed in iso-entropic form with a rotary axial or centrifugal compressor, then it enters a combustion chamber where fuel is injected burning the fuel at constant pressure, the product of this combustion then expands in a turbine, down to its output pressure which, once again is the environment pressure. Real gas turbines have open cycles, where air enters continuously.

The thermal efficiency of the Brayton cycle depends mainly on the relationship of pressures, inlet gas temperature to the turbine (TIT) and parasitic losses (especially the efficiencies of the compressor and the turbine).

$$\eta_{Br.} = 1 - \frac{1}{\left[\frac{P_2}{P_1}\right]^{\frac{(k-1)}{k}}} \qquad (1)$$

The real cycle differs from the ideal cycle due to the properties of real air (k, C_p) that are not constant over the whole range of temperatures, and as far as the internal losses, these become significant beyond 1367^0K and even useless beyond 1922^0K. [1,4].

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