Development of an efficient Boundary layer Turbine electrical generation system for HRSG applications

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Abstract—The boundary layer turbine, also known as the Tesla turbine, was invented and patented in 1913 by Nikola Tesla and has remained one of today's most underutilised designs. It is the purpose of this paper to present the development of such a system which can be used in modern heat recovery steam generator systems replacing or complimenting axial turbine designs used for electrical generation plants. Historical research has shown isentropic efficiencies of single stage units of up to 55% with a conversion efficiency of up to 95%.These figures are extraordinary when comparing them to the complexity of modern multi stage reaction turbo generators versus the simplicity in construction of the Tesla turbine. Based on experimental observation, this study will attempt to identify the requirements which could make such a system an industrial candidate in areas such as power utility plants, geo thermal plants and other areas where the working fluids can vary vastly.

***Index Terms*—Boiler, Boundary layer turbine, Medupi, SCPC, Tesla**

1 INTRODUCTION

The modern era in steam turbine power generation has utilised many of the same concepts invented by Sir Charles Parsons in 1884. Most of the world's power generation needs are served by steam turbines such as these [1].The use of turbo machinery such as this have many advantages as is obvious by their widespread use. The question then is why would there be a need to consider using anything other than what is seemingly a very efficient and established prime mover.

To gain insight into understanding the answer to this, it is important to review the peripheral support infrastructure required to run these systems, such as is currently being built and installed at one of South Africa's latest super critical pulverized coal fired power stations, Medupi. Fig. 1 represents the basic building blocks of one of the six units at Medupi power station.

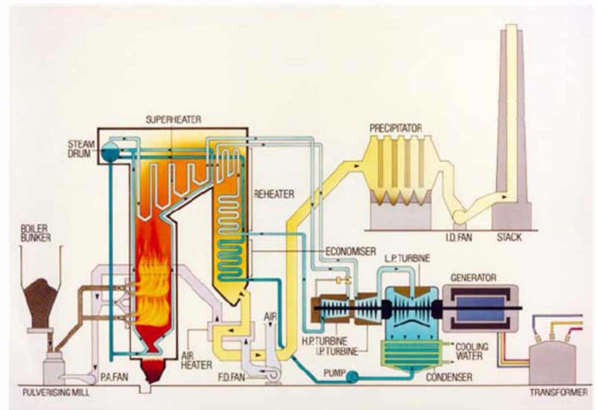

Fig.1. Typical layout of a super critical pulverized coal fired power station.

The full description of the components making up the SCPC system is outside the scope of this document and focus will be placed on the steam turbine and how the boundary layer turbine compares.

2 THE PRIME MOVER

The Medupi power station makes use of 6 Alstom STF100 steam turbines. These units are certainly impressive and each will provide enough motive power to generate 794 MW. Fig. 2 shows a section view of this turbine.

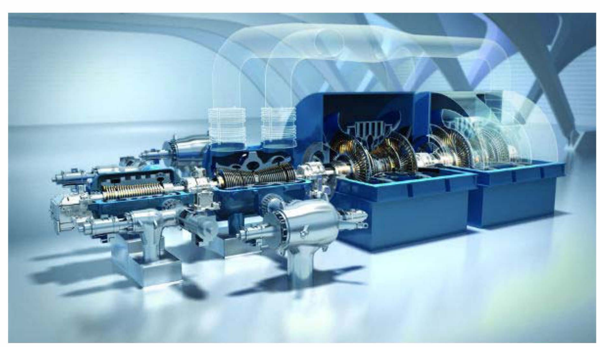

Fig.2. Section view of an Alstom STF100 steam turbine

It can be seen that the complexity of these systems tend to increase as efficiency figures increase. This can be linked to material development versus steam cycles. Fig. 3 shows the progression from the early 1900's to what may be achievable in the near future. Fig. 3 also illustrates where in this progression the Medupi power plant features.

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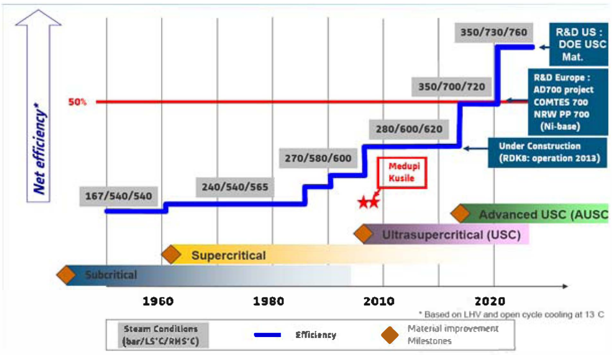

Fig. 3. Steam cycles vs efficiency, courtesy of Alstom

The boundary layer turbine (BLT) by comparison seems extraordinary simple. The departure from classical design has led to its misunderstanding especially when efficiency figures are considered. The BLT was a design which was ahead of its time for the same reason the efficiencies of its axial counterpart was lagging and that is material technology. The stresses imposed on the BLT rotor discs caused them to warp at the higher RPM's. Modern metallurgy has changed dramatically since then, allowing such challenges to be easily overcome.

This major drawback of the BLT in the early 1900's resulted in the parsons style turbine such as the Alstom STF100 mentioned in this paper, which is the forerunner of today's conventional turbine becoming one the industry standards.

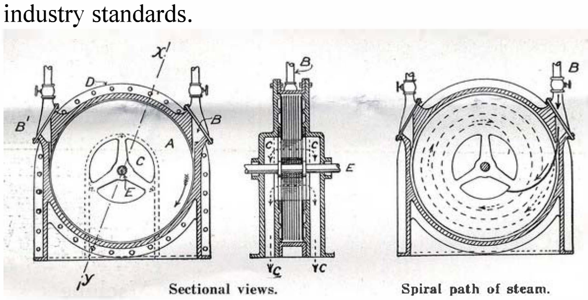

Fig. 4. Sectional views of Nikola Tesla's boundary layer turbine. [2]

In 1911 a Tesla turbine was tested at the Edison Waterside Station in New York. Fig. 5 shows this Tesla turbine with the top half of the casings removed, showing two rotors. Each rotor consists of 25 disks 9.5 mm thick by 457 mm in diameter. The steam enters at the periphery, and flows in spiral paths to exhaust at the center of the disks. The driving turbine is to the left, the brake turbine to the right. Between them is a torsion spring. The steam inlets are on opposite sides on the two rotors; the driving rotor moving clockwise. The torsion of the spring is automatically shown by beams of light and mirrors and the horse-power is read off a scale. At 9,000 revolutions per minute, with 125 pounds at the throttle and free exhaust, this turbine develops 200 horse-power or approximately 149 kW. It weighs 900grams per horse-power [3].

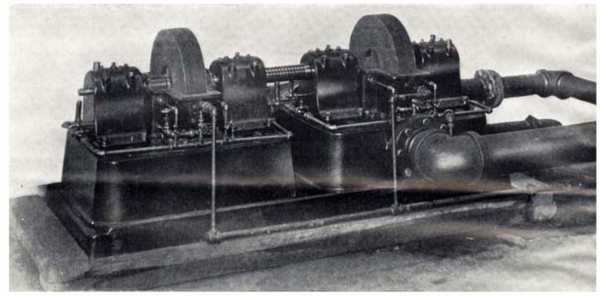

Fig. 5.The Tesla turbine testing plant at the Edison Waterside Station, New York in 1911.

3 OPERATING PRINCIPLES

Since the conventional turbine has been used over many years, its operation has become well understood and only a short summary will be devoted to this.

In conventional turbines, rotational energy is transferred to a rotor shaft by means of either reaction or impulse methods or both, due to an incoming stream of expanding high pressure super-heated steam as shown in Fig. 6

This is usually achieved by means of multiple rotary blades and stator sections along the length of the turbine.

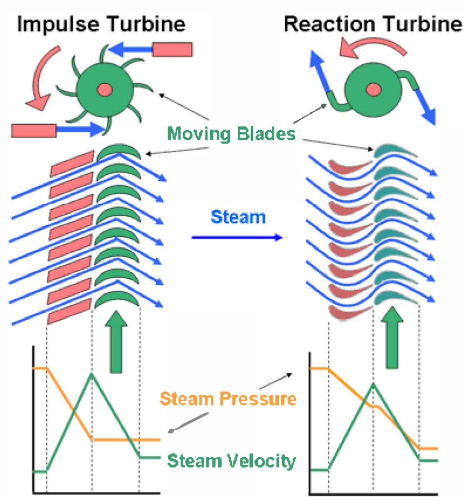

Fig. 6 Conventional turbine operating principles

The boundary turbine differs considerably in its operation as the working fluid does not impinge any surface to produce and impulse or reaction. The blades or discs inside the turbine are completely smooth and rely on the properties of viscosity and adhesion of the working fluid. The working fluid enters the turbine casing at the periphery and through an appropriate nozzle, is directed tangentially between the discs.

The main difference between the conventional turbine and the boundary layer turbine is the torque curve. Conventional turbines deliver very low torque until they spool up to operating speed. The boundary layer turbine exhibits almost no torque until it reaches about 50% of its rated speed as shown in Fig. 7, at which point the value suddenly spikes to 100% and then gradually decreases as the rotor speed reaches maximum velocity [4]. Fig. 8 shows the ideal case conversion efficiency [4]. Extensive testing was done in 1960 in this area by Rice[6] and Breiter et al.[7]. Fig. 9 shows this observed relationship. Here it can be seen that usable horse power can only be extracted after we cross the 50% rated speed threshold

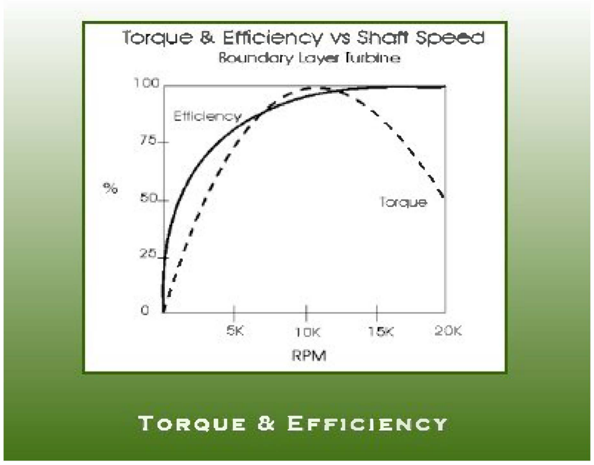

Fig.7.Boundary layer turbine torque and efficiency curves.

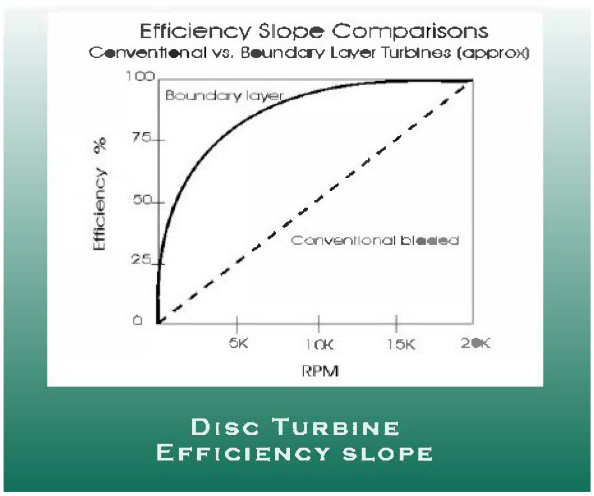

Fig.8.Comparison of the efficiency curves of a conventional turbine vs a boundary layer turbine.

Both pistons and conventional turbines exhibit what we can be referred to as analog torque and power curves—where torque and horsepower increase steadily. This is analogous to a common analogue power amplifier.

On the other hand, the disc turbine (like a parallel wound electric motor) exhibits a torque response similar to a digital gate—in which there is a rapid change in power from zero to maximum in one fast step.

The boundary layer turbine, therefore, must toggle between idle and maximum loaded power in one quick step [4].

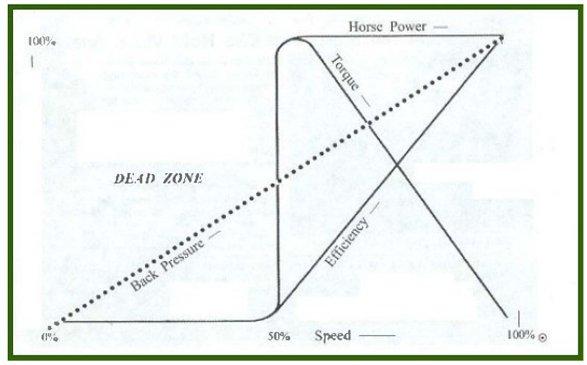

Fig. 9. Torque vs horse power curve of the boundary layer turbine.

4 TURBINE OPERATING CRITERIA

The following table compares the operating regions of the boundary layer turbine and the reaction/impulse or conventional turbine.

Table I. Use of various working fluids show that the boundary layer turbine operates over a broader spectrum of conditions

Type of Working Fluid	Boundary Layer System	Conventional System
Clean Dry Steam	Yes	Yes
Wet Steam	Yes	No
Low Temperature, high pressure fluids	Yes	No
Fluids containing a high degree of particles	Yes	Yes, however extremely high maintenance is required due to erosion of the turbine blades
High pressure gases	Yes	No
High pressure Liquids	Yes	No
High pressure liquids with entrained gasses	Yes	No

5 DEVELOPMENT OF A TEST PLATFORM

Now that the basic operation and differences between the conventional and boundary layer turbine have been considered it allows the development of a scaled test bench.

It is proposed that the test platform contain the following components as indicated in Fig. 10, to fully evaluate the extent to which the boundary layer turbine could be utilized to extract waste or excess heat.

The test method is modelled around the Rankine cycle. The BLT is evaluated in this manner to determine its isentropic efficiencies over various working fluid parameters.

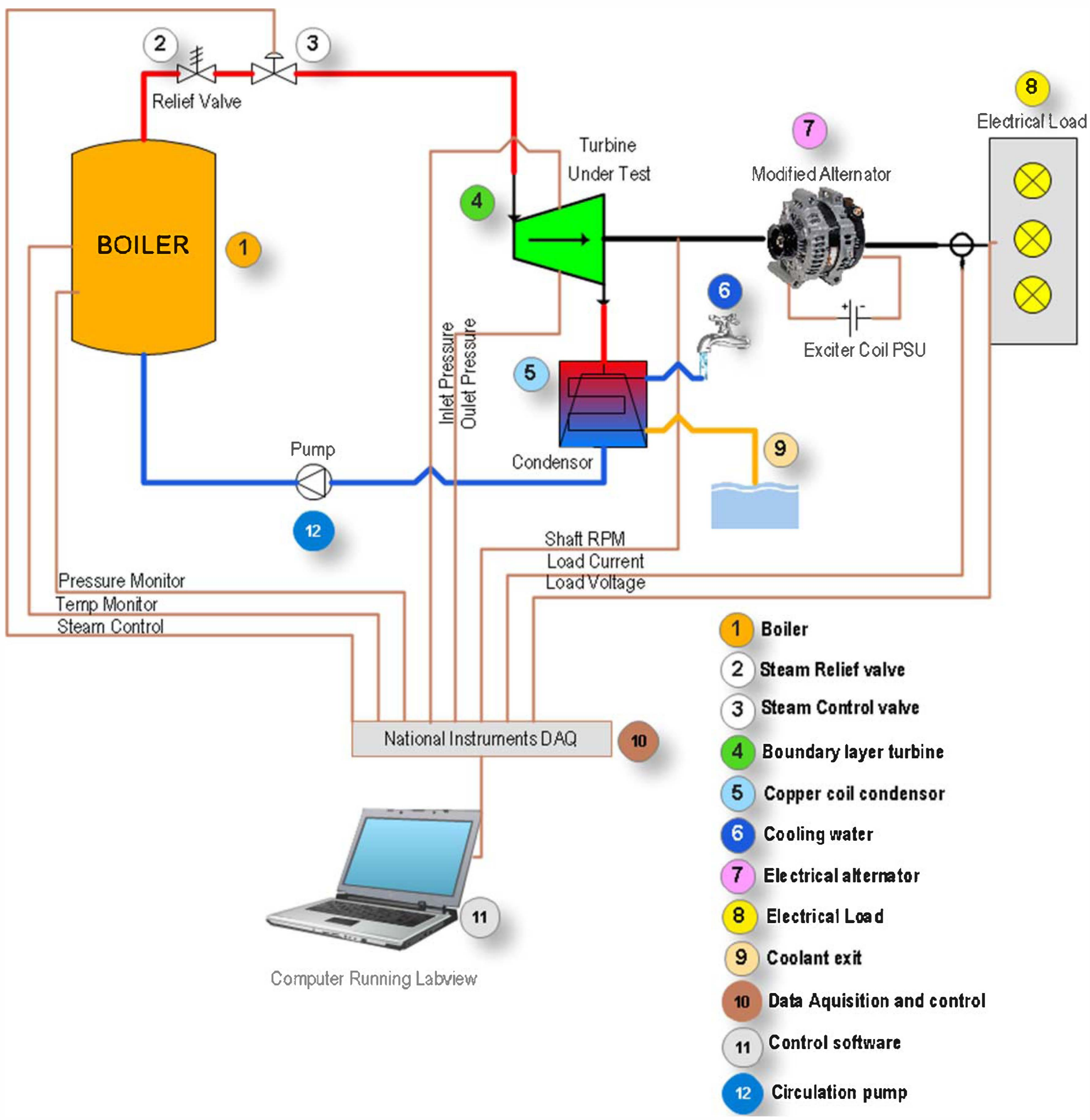

Fig. 10. The boundary turbine layer development test bench to test efficiency of heat recovery.

6 CONCLUSION

Given the main differences of the boundary layer turbine versus the conventional turbine, it shows promise for the following reasons:

- Potentially much lower total cost of manufacture
- Improved reliability, resistance to erosion due to cavitation when steam quality is poor.
- When power to weight ratio or power to size ratio is compared, the boundary layer turbine shows a clear benefit.
- As a geothermal turbine, because of its resilience to impurities it can be built almost directly above the well head rather than piping and then purifying the steam to be used downstream.
- It is reversible.
- It can operate in all 5 liquid/vapour phases, namely, sub cooled liquid, saturated liquid, phase region, saturated vapour and superheated vapour [5].

This study successfully identifies the requirements and design criteria for an efficient Boundary layer Turbine electrical generation system for HRSG applications which would make such a system an industrial candidate in areas such as power utility plants, geo thermal plants and other areas where the working fluids can vary vastly .

7 REFERENCES

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8 AUTHORS

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