Thermal Analysis of HAWT-Nacelle operating in Hot Climate Regions using CFD code TransAT

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***Abstract*—Wind turbines installed in hot climate regions operate often under severe weather conditions. Particularly, the electric/electronic components located within the nacelle may be subjected to extremely high temperature environment. To maintain acceptable temperature levels inside the nacelle and manage efficiently the thermal effect, cooling systems should be used properly. For this purpose, a commercial CFD code TransAT© has been adopted. The simulations have been performed through a typical horizontal axis wind turbine (HAWT). Preliminary results including temperature fields within the nacelle have been obtained and showed quite reasonable behaviour.**

***Keywords*— Nacelle, HAWT, Thermal analysis, Numerical Simulation, TransAT**

I. Introduction

Wind turbines that would be installed in hot climate regions should operate under severe weather conditions and fluctuating temperature during the day and seasons. Particularly, the electric/electronic components located within the nacelle may be subjected to extremely high temperature variations, thus leading to inconsistent design stresses. In order to maintain acceptable temperature levels inside the nacelle and to manage efficiently the thermal effect, the heat released by the electrical and mechanical components as results of various power dissipations (due to Joule effect, friction losses; e.g. electrical generator, gearbox, bearings…) should be rejected to the atmosphere, and the heat exchange between the air inside the nacelle and the surrounding air should be controlled properly. Therefore, cooling systems must be employed to ensure safe operation and to prevent failure of the turbine, especially under high ambient temperature conditions (e.g. Saharan climate). However, while the turbine benefits high cooling efficiency, it also suffers lower reliability and higher cost for adding such a complex cooling system. The main challenge for electronic equipments in a wind turbine nacelle is that they must withstand a wide range of ambient temperature, usually from -40°C to +55°C.

Previously Smaïli et al. ([1], [2]) proposed and used an in house CFD code to assess the effect of temperature environment on wind turbines-nacelle operating in Canadian Nordic climate as well as in Algerian Saharan climate. In this paper, a CFD commercial code TransAT© [3] has been adopted to investigate the nacelle thermal behaviour operating under extreme Saharan hot weather conditions.

II. Mathematical Model

For steady flow conditions, the time averaged continuity, Navier-Stokes and energy equations written in Cartesian tensor form are

$$\frac{\partial(\rho u_i)}{\partial xi} = 0 \qquad (1)$$

$$\rho u_j \frac{\partial u_i}{\partial xj} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu_e\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \qquad (2)$$

$$\rho u_j \frac{\partial(c_p T)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(k_e \frac{\partial T}{\partial x_i}\right) + \mu_e\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j} \qquad (3)$$

where, u_i is the i^{th} flow velocity component, T is the air temperature, p is the air pressure, ρ and c_p are respectively density and heat capacity of the air. To take into account the temperature dependence of the air density, the ideal gas law has been used:

$$\frac{p}{\rho} = R_{air} T \qquad (4)$$

with R_{air} is the specific air constant.

Where, μ_e $(=\mu + \mu_t)$ and ke $(=k+k_t)$ refer respectively to effective viscosity and effective thermal conductivity; in which, μ *is* the molecular viscosity and μ_t is turbulent viscosity, and k is the molecular thermal conductivity and k_t is

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turbulent thermal conductivity. The turbulent properties (μ_t and k_t) can be estimated from an appropriate turbulent model.

III. Commercial CFD code TransAT ©

The CFD code TransAT © developed at ASCOMP is a multi-physics, finite-volume code based on solving multi-fluid Navier-Stokes equations. The code uses structured meshes, though allowing for multiple blocks to be set together. MPI parallel based algorithm is used in connection with multi-blocking. The grid arrangement is collocated and can thus handle more easily curvilinear skewed grids. The solver is pressure based (Projection Type), corrected using the Karki and Patankar technique [4] for low-Mach number compressible flows (<2). High-order time marching and convection schemes can be employed up to third order Monotone schemes in space (Quick scheme of Leonard), 3rd to 5th order Runge-Kutta schemes for time marching. Turbulent flows can be tackled using (i) interface tracking techniques for both laminar and turbulent flows (level set, VOF with CVTNA interface reconstruction, and Phase Field), (ii) phase-averaged homogeneous mixture model (Algebraic Slip), and (iii) Lagrangian particle tracking (one-to-four way coupling, including with heat transfer).

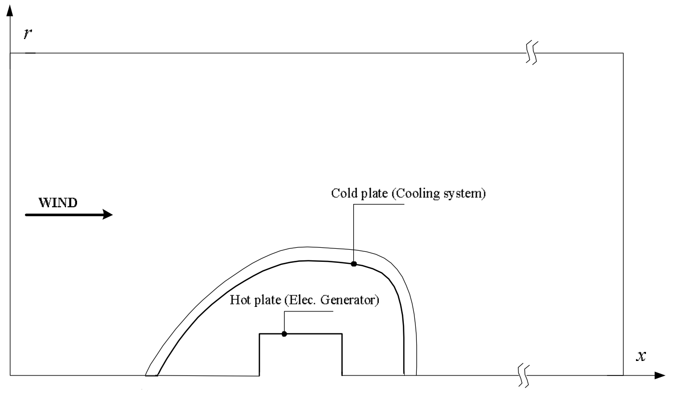

Fig. 1 Computational domain

IV. Results and discussions

The thermal behaviour of electrical components located within the nacelle of wind turbine operating under extremely weather conditions has been investigated through a typical 750 kW commercial HAWT. For this purpose, the temperature level inside the nacelle (given by the average temperature inside the nacelle T_{av}) has been determined as function of cooling system load. Similarly to the recent work [2], the flow field in the vicinity of the turbine and nacelle (i.e. ignoring the effects of the tower and the ground) immersed in a uniform incoming flow parallel to the turbine's axis of rotation is assumed to be axisymmetric. Furthermore, the following considerations and simplifying assumptions have been adopted.

- The nacelle is considered to be air-tight.
- The effect of gravity is neglected.
- The air is assumed to remain stationary within the nacelle.
- The heat transfer by radiation is neglected.
- The heat generation (considered to result mainly from electrical generator) is idealised as an isothermal condition, represented by a hot plate (i.e. generator wall) at temperature T_H in the computational domain.
- The cooling system is idealised as an isothermal condition, represented by a cold plate (i.e. nacelle internal wall) at temperature T_C in the computational domain.
- The effect of the rotating blades has been neglected.

Fig. 1 shows a (x, r) section of the computational domain, which consists of a cylinder including the axisymmetric nacelle.

Fig. 2 shows the temperature fields obtained for a fixed temperature of the hot plate, T_H = 373 K (being limited temperature for safe operation of electronic equipment), and for the following cold plate temperatures T_C = 268 K and 288 K. As it can be seen, the behaviour of these simulation results seems to be quite reasonable, hence confirming qualitatively the validity of the numerical solutions obtained by TransAT.

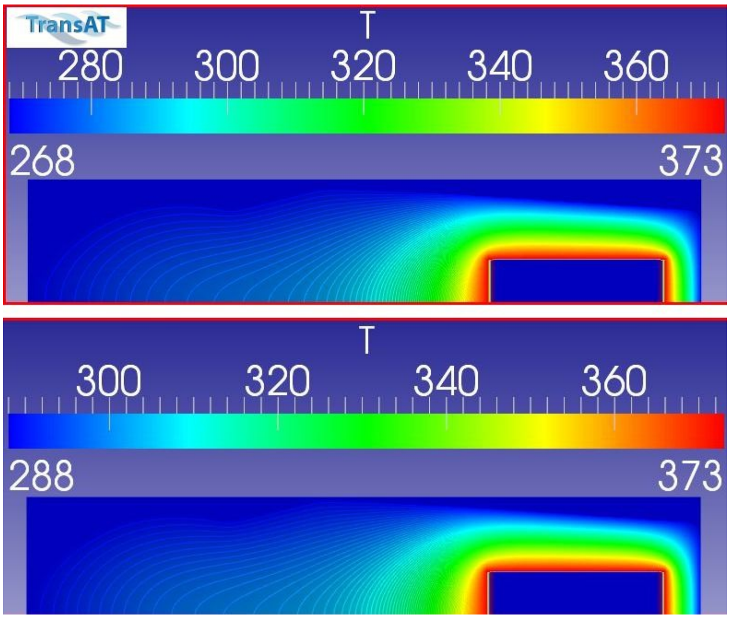

Fig. 2 Temperature field in and around the nacelle; obtained at cold-plate temperature T_C = 268 K, and 288 K

From the resulting temperature fields, the average temperature, T_{av}, inside the nacelle given by the relationship

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$$T_{av} = \frac{1}{\forall}\int_{\forall} T(x,r,\theta)\,d\forall \qquad (5)$$

where, $\forall$ is the inside nacelle volume.

T_{av} can be thus determined as function of cold plate temperature. Fig. 3 shows the results. As expected, the curve T_{av} versus T_C exhibits a roughly linear variation trend; also good agreements with the previous results obtained with the in house code NS2D [2] can be noted. Thus confirming again the validity of the numerical predictions due to TransAT.

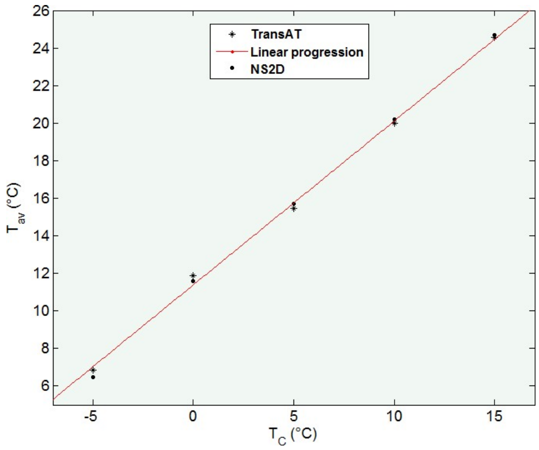

Fig. 3 Evolution of the average air temperature inside the nacelle as a function of the cold-plat temperature

V. Conclusion

A CFD commercial code TransAT has been used to investigate the thermal behaviour of HAWT-nacelle operating under typical high temperature conditions. The preliminary results have showed the code ability to predict consistent temperature fields within the nacelle.

Future works will be mainly focused on the development of more detailed numerical method that takes into account most of practical and nacelle thermal design considerations; such as the effects of gravity, radiation heat exchange, unsteady three-dimensional flowfields around wind turbine.

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