OPTIMIZATION OF SMALL SCALE AXIAL AIR TURBINE USING ANSYS CFX

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Abstract- Efficient small scale axial air turbine is one of the proposed solutions for improving the overall efficiency of energy recovery cycles based on renewable energy sources. Turbine design requires an intensive CFD simulation and design optimization to identify optimal blade profile for maximum efficiency. Axial turbine rotor optimization was carried out usingdifferent optimization techniques available in ANSYS CFX. The highest rotor efficiency was accomplished using Multiobjective optimization algorithm (MOGA) with highest turbine efficiency of87.78% was achieved.

Keywords- Axial Turbine, Optimization, CFX, Efficiency

I. INTRODUCTION

Axial turbine aerodynamic design has been developed using analytical methods which include: similarity analysis, meanline modelling, and 2D / 3D blade designMoustapha, Zelesky et al. 2003). Meanline design approach is the common method in turbine preliminary sizing and turbine efficiency can be estimated using one of the published correlations. These correlations include: (Ainley and Mathieson 1951), (Trauple 1958), (Balje and Binsley 1968),(Craig and Cox 1970),(Smith 1965), and (Kacker and Okapuu 1982). Meanline approach and performance prediction methods are based on simplified assumptions and some results of blade tests of typical gas turbine engines. According to (Craig and Cox 1970), and (Dunham and Came 1970) the use of traditional performance estimation methods (e.g. Ainely, Traupel, Smith Chart, and Soderberg) in steam turbine design leads to unsuccessful results and significant improvements are required. As a result there is no an optimum turbine profile shape due to internal flow complication and the judgment of the best blade profile or optimum design is left to the designer. Thus, all recent work is attempting to improve the turbine loss prediction correlations in order to maximize turbine efficiency by varying all independent blade geometry parameters for on and off design conditions and applying optimization method on meanline design (Wakeley 1997) Balje and Binsley (1968) applied a numerical optimization technique for simplified loss prediction correlations integrated with meanline approach. This approach aimed to maximize turbine efficiency by varying blade profile geometry parameters and an increase of 5% in turbine efficiency was achieved. Rao and Gupta 1980applyied multi-objective optimization (maximizing efficiency and minimizing turbine mass) and turbine efficiency was increased by 2.48% with a considerable reduction in turbine mass.

Nowadays, there is a rapid increase in computing resources and there are many numerical optimization methods developed for turbine design optimization. These optimization techniques can be also integrated with CFD solver to achieve detailed design. (Massardo and Statt 1990) developed an optimization code integrated with meanline design approach. This code was based on multi-objective algorithm for ranges of blade geometry parameters and an increase of 1.7% in turbine efficiency was reported. (Moroz, Govoruschenko et al. 2004) provided a detailed process of axial turbine flow path optimization based on DOE and FEA package. This work proved the capability of commercialCFD in turbine optimization through 3D simulation. (Mohamed and Shaaban 2013) applied automated optimization algorithm to optimize Wells turbine pitch angles for maximum turbine efficiency using standard aerofoil geometries NACA0012 and NACA0021 and increases of turbine efficiency by 2.3% (NACA0012) and 6.3 % (NACA0021) were achieved. (Yang and Xiao 2014) conducted an optimization design of a pump-turbine impeller by performing CFD simulation and response surface method (RSM) was used to select an optimum design point. The comparison of simulation results with conducted tests showed that multi-objective optimization based on CFD and RSM are good optimization strategy in turbine and pump designs.

This work presents the optimization of small axial turbine rotor blade geometry through ANSYS CFX workbench using different optimization techniques. The main goal of this optimization is finding an optimal blade shape that gives highest efficiency with minimum loss for certain operating conditions.

II. OPTIMIZATION TECHNIQUES IN ANSYS CFX

Recently, CFD has become a reliable computing tool with high accuracy and as a result aerodynamic blade optimization through CFD simulation can reduce the time and the cost of turbine design process(Sasaki, Obayashi et al. 2001),(Janjua, Khalil et al. 2013).

Turbine design optimization can be created in ANSYS CFX explorer which offers a set of optimization techniques that can be used to reach optimum turbine geometry. The optimum blade profile should satisfy the objective function (max or min) for certain constrains. These optimization techniques include:

- Screening optimization: This optimization approach is suitable tool to generate design space for discrete and continuous defined parameters in preliminary design stage and for more advanced design MOGA is recommended.
- Multiobjective Genetic Algorithm (MOGA): this technique is normal genetic algorithms (Gas) with more than one objective function (min/max) subjected to a set ofindependent variables. MOGA is well known approach in turbomachinery design optimization.
- Mixed-Integer Sequential Quadratic programing (MISQP): It is mathematical optimization tool that can be applied for continues and discrete parameters in both response surface and direct optimization for only one objective function.

III. TURBINE BLADE PARAMETRIZATION

Well known method of aerofoil cross section parameters definition is published by (Pritchard 1985), which can be described as clear example of blade cross section creation. In this method, blade profile is defined by eleven parameters (flow angles, axial blade chord, turning angle, Leading edge radius, trailing edge thickness, etc.) or by using control points (x, y) of Bezier curves to define presser and suction surfaces of blade (Moustapha, Zelesky et al. 2003). Figure (1) shows turbine blade profile geometrical parameters and figure(2) shows Bezier curve control points. ANSYS CFX explorer allows the designer to parametrize all geometrical blade variables and CAD parameters are supported by ANSYS CFX explorer.

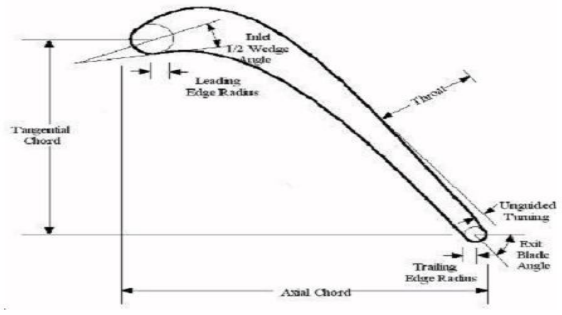


Fig.(1): Blade Geometry Parameters [15].

In the present study, eight blade geometry parameters were chosen as input variables. These variables include: stagger angel (λ), number of blades (N), leading edge major radius (r_{LM}),leading edge minor radius (r_{Lm}),trailing edge major radius (r_{TM}), trailing edge major radius (r_{LM}),wedge angle (ω), and throat (d_h). Also, the blade profile is parametrized through control points of Bezier curve and blade profile can be optimized for the best thickness distribution.

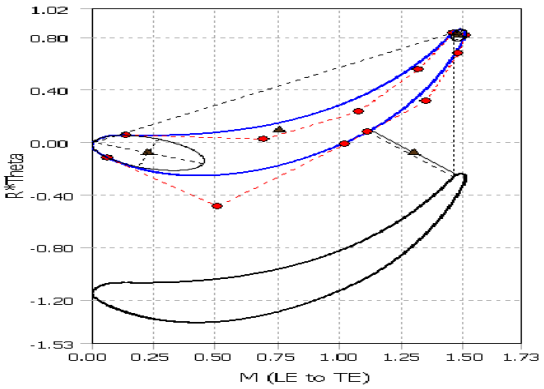


Fig. (2): Blade Bezier Curve control Points.

IV. CFD SIMULATION AND OPTIMIZATION

A 3D steady flow simulation using ANSYS CFX15 was created for axial turbine rotor optimization. ANSYS CFX design explorer can use design of experiments (DoE) which divides design space into candidate points based on number of input and output parameters and lower and upper bounds of these parameters. Also, the design explorer response surface method (RSM) to identify the influence of input parameters variation on output performance parameters. Once that the design candidates are generated by running of DoE, the blade geometry optimization can be performed using CFX solver which is capable to define the objective functions and optimization constrains. The general optimizations strategy using ANSYS CFX is described by a flowchart shown in Figure (3). Direct optimization also can be conducted without using DoE and RSM but response surface optimization tool is an efficient optimization strategy leads quickly to optimal blade profile.

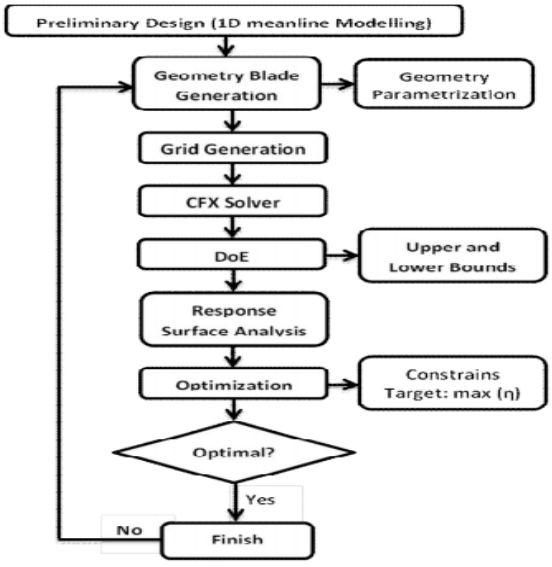
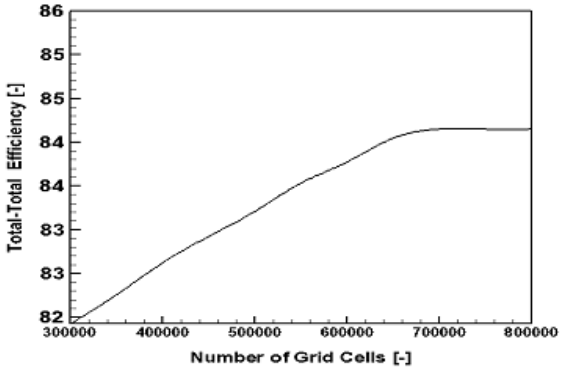


Fig. (3): Optimization Strategy Description.

V. CFD ANALYSIS AND OPTIMIZATION RESULTS

For CFD simulation, the grid sensitivity analysis was carried out based on turbine total efficiency as shown in Figure (4). It is clear from this figure that with number of grid cells higher than 650000, the turbine total efficiency remains constant indicating that the solution is not affected by the number of grid cells. The CFD results of velocity vectors and blade loading are shown in figures (6, 7).



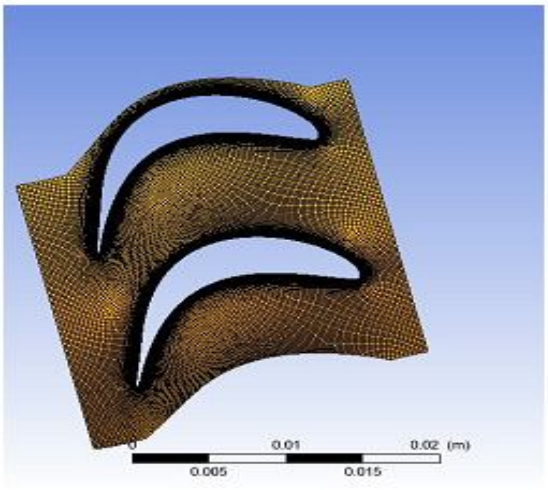


Fig (5): Mesh Generation (Fine 650,000 cells)

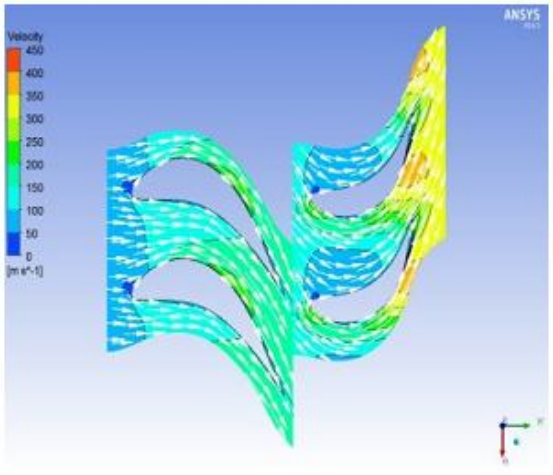


Fig.6: Velocity vectors for Axial Air Turbine

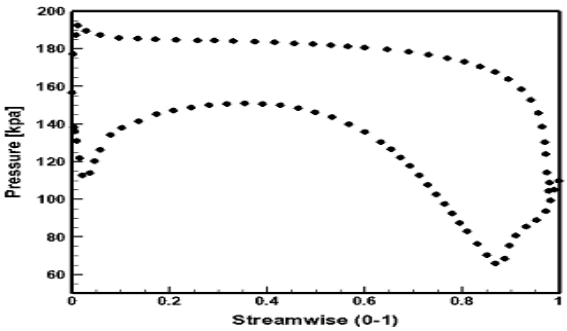
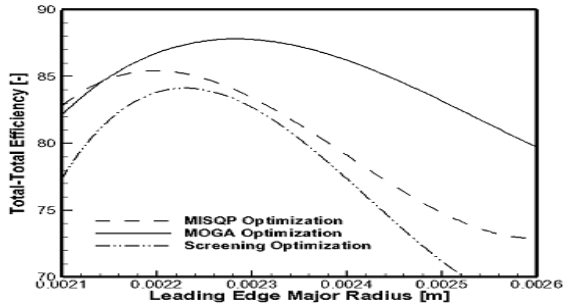
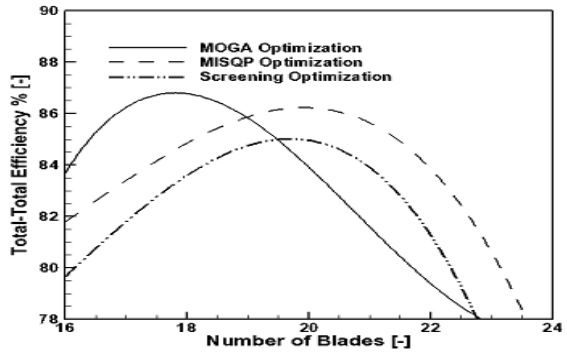
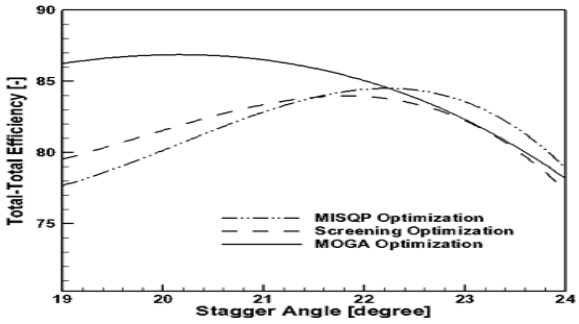


Fig.7: Rotor Blade Loading for Axial Air Turbine

The influences of geometry parameters variation on turbine performanceare shown in figures (8-10) and it is obvious that the turbine performance is sensitive to blade profile geometry and any variation in each parameters generate a considerable change in turbine efficiency due to the impacts on flow characteristics and loss development and there is an optimum value for each independent parameter to gain high efficiency with minimum loss. The turbine sensitivity to blade shape can be seen clearly from figure 7 where the change in number of blades lead to a great reduction in turbine efficiency and there is an optimum blade number value of 18 that provides high efficiency with good flow guidance.







A comparison between optimization techniques using ANSYS CFX explorer is shown in figure(11). Table (1) summarizes the optimization results with different techniques compared with basic CFX results. The best candidate for each optimization approach is presented. The MOGA optimization technique gave the highest efficiency value of87.67%. The CDF results of turbine blade geometry optimization show clearly that the overall turbine performance is controlled by blade profile which actually defines the flow passage based on blade thickness distribution.

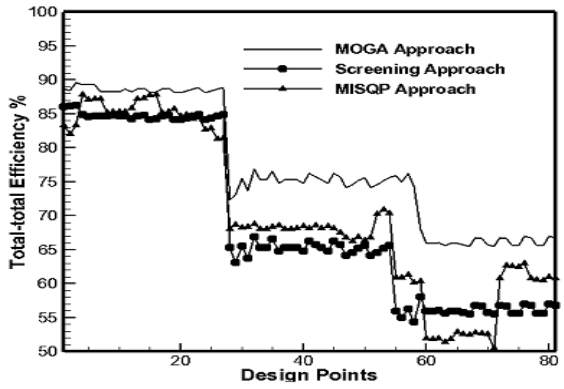


Table (1): CFD Optimization Results:

MAXIMIZE: EFFICIENCY	GOAL, MAXIMIZE EFFICIENCY: (DEFAULT IMPORTANCE); STRICT CONSTRAINT			
OPTIMIZATION METHOD	SCREENING – MOGA- MISQP			
CONFIGURATION	GENERATE 150 SAMPLES INITIALLY, 100 SAMPLES PER ITERATION AND FIND 5 CANDIDATES IN A MAXIMUM OF 100 ITERATIONS.			
BEST CANDIDATE POINTS				
	BASIC CFX	SCREENING	MOGA	MISQP
STAGER. ANGLE (DEGREE)	20.05	22.0287645	20.48560	23.38522
NUMBER. BLADES	18	20	18	20
LEAD. MAJOR RADUIS (M)	0.00227	0.00225	0.002286	0.002177
LEAD. MINOR RADUIS (M)	0.00127425	0.00125451	0.00123327	0.00130721
TRAILING. MAJOR RADUIS (M)	0.005	0.00545	0.005	0.005
TRAILING. MINOR RADUIS (M)	0.003	0.003323	0.0031	0.0027
LEADING WEDGE ANGLE (DEGREE)	18	17.13	18.22	19.07
THROAT(M)	0.003477	0.0028776	0.0035628	0.003004
EFFS OUT	83.65224	84.15823	87.7861	86.08616
OUTPUT POWER (W)	5663.227	5987.407	6176.467	6426.467

CONCLUSION

Axial turbine optimization was carried out based on ANSYS CFX explorer by using different optimization techniques. The turbine blade geometry variation affects significantly turbine overall performance. The highest rotor efficiency was accomplished using Multiobjective optimization algorithm (MOGA) for an optimal aerodynamic profile with an efficiency of 87.78%.

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