
“A COMPRENSHIVE REVIVEW ON CFD SIMULATION OF A RADIAL FLOW GAS TURBINE ROTOR USING GENETIC ALGORITHMS”

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ABSTRACT

As radial turbines can effectively transform fluid energy into mechanical energy, they are extensively used for power production in emergency situations, as mini-power plants, and transportable plants. They are most helpful in remote locations, conflict zones, and natural disasters where cost-effectiveness, portability, and rapid deployment are essential. In difficult situations, these turbines power vital services like communication systems, medical units, and water purifying. Radial turbines must be made smaller and less expensive to become more feasible. Turbines can be distributed more quickly in environments with limited resources. More compact form of a turbine helps to reduce costs and improves portability enabling simple distribution and transportation in remote locations. Since its high cost necessitates optimization to reduce material usage and rotor size, Titanium alloy is selected for its exceptional thermal and mechanical qualities, with a balance between performance, cost-effectiveness, and mobility Various algorithms have been developed to tackle design optimization problems, including Particle Swarm Optimization (PSO), Simulated Annealing (SA), Differential Evolution (DE), and more. However, Genetic Algorithm (GA) and Ant Colony Optimization Algorithm (ACO) are chosen for this study due to their distinct advantages. GA, inspired by natural selection and genetics, excels in exploring a wide range

of design possibilities and finding near-optimal solutions in large, complex search spaces. ACO, stimulated by the foraging actions of ants, is particularly efficient in refining solutions and searching for the global optimum, making it highly effective in complex, multidimensional optimization problems. The combination of these two algorithms leverages their strengths, providing a robust approach to identifying and fine-tuning optimal designs for radial flow gas turbine rotors. In order to achieve an ideal design that optimizes structural integrity and aerodynamic performance while minimizing weight and manufacturing costs, this thesis works on GA and ACO. To meet design specifications, structural and thermal stresses were performed for mechanical consideration. The correctness and dependability of this optimization strategy are confirmed by the combination of finite element analysis and computational fluid dynamics, which is verified by ANSYS and CFD simulations.

KEYWORD'S: Swarm Optimization (PSO), Simulated Annealing (SA), Differential Evolution (DE), Genetic Algorithm (GA), Ant Colony Optimization Algorithm (ACO), ANSYS, CFD.

INTRODUCTION

The idea of gas turbine is oldest one which was used several centuries back. It is an improved version of windmill and water wheels which operated on the principle of converting kinetic energy into mechanical energy. Gas turbines are the principal components of many power plants like gas turbine power plant which is used for generation of electric power, to drive turbo jet and turbo propeller engines, super charger fitted in aviation gasoline engine, in heavy duty diesel engines and used in marine engines also. The design improvements focused on ensuring durability and minimizing energy losses, especially in high-temperature environments. In a gas turbine the working substance is generally air, which is obtained from the atmosphere. A compressor is used to compress this air. Later, the compressed air is sent to the heat exchanger where it gets heated. Hot air flows over the turbine blades causing them to rotate and transfer the motion to the rotor blades. In the moving blades the air expands to a lower pressure. Major part of the power produced is utilized to drive the compressor which is used to compress the air and remaining is used to do some external work. Inefficient pressure ratio must be provided in order to develop an expansion of air through gas turbine, for this, compressing the working fluid is essential. After compression the fluid expands directly in the turbine without any losses in the compressor or the turbine, the power developed by the turbine is exactly equal to the work required to operate the compressor. Thus, if they are

coupled together nothing would be done not more than turn itself round. Therefore, there is a need to enhance the power generated by the turbine. This can be done by summation of some extra energy i.e., by raising the temperature of the working substance before penetrating into turbine blades. For an open cycle gas turbine, a combustion chamber is used for applications such as aircraft aviation, whereas a heat exchanger is used in stationary power plants the turbines are classified depending upon the path of the working substances as closed cycle gas turbines, open cycle gas turbines and semi closed gas turbines. In the closed cycle gas turbine, the air path is confined within the plant and works on the Joule's or Brayton's cycle. In the open cycle gas turbine, the air is taken from the atmosphere and exhausted to atmosphere. In some turbines part of working fluid is confined to plant and remaining from the atmosphere. These are known as semi closed gas turbines. In regard to functional mechanism gas turbines are classified into radial flow and axial flow type. The fluid enters in the radial direction that is either inward to outward or outward to inward to the rotor in radial flow. When the fluid flows from inside outward it is called Outward Flow Radial (OFR) and when the fluid flows from outward in it is called as an Inward flow radial (IFR). The flow is in axial direction to the rotor in axial flow type. The rotor is impacted by the air flow but for a radial turbine the flow is smooth and oriented at 90° by the compressor towards the combustion chamber in axial flow turbine. Inward Flow Radial turbines are commonly used in applications where high efficiency and compact size are required. There is an increasing need for portability, cost effectiveness, and rapid deployment of such turbines. Inward flow Radial turbines are generally more compact than axial flow turbines. However, further reducing size and weight while maintaining performance is difficult. Portable turbines must tolerate difficult conditions such as high temperatures, vibration, and corrosion. Any technology that is widely adopted must be cost effective. This is especially significant in areas like renewable energy like small-scale wind turbines and emergency power applications, where budgets are sometimes limited. But because of the complex geometries and the accuracy needed to manufacture radial flow turbines, advanced composites and high-performance materials should be used which are more expensive. Demanding applications such as mini power plants or turbochargers in automotive field require turbines to be long-lasting, which can increase costs if improperly constructed. Rapid deployment of inward flow radial turbines is crucial in scenarios such as military operations, disaster relief, and off-grid power generation for quick production of electricity. Because of reduced setup times, rapid deployment is possible along with quick power generation. Inward flow radial turbines, which are utilized in high-performance or specialized applications need complicated

installation procedures. It can take longer time to deploy some turbines since they need a lot of infrastructure like fuel, cooling systems, etc. Deployment time is greatly shortened by exporting turbines partially or completely builds. By reducing manual intervention and improvements in automation, rapid and more effective deployment can be achieved. To produce portable, more affordable, quickly deployable Radial flow turbines, it is required to overcome major engineering and material obstacles. Radial flow turbines are noted for their performance and dependability, which may be met by concentrating on lightweight materials, modular designs, creative manufacturing processes, and integrated systems. The ultimate objective is to develop flexible, reasonably priced, and readily deployable turbines that may be used for a range of purposes, from portable applications, energy generation in defence areas and in remote areas. The main advantage of inward flow radial turbines is their small size, which makes them comfortable for high power density. and mainly used in devices like turbochargers, jet engines, and micro turbines. Nevertheless, there are intrinsic design trade-offs associated with compactness. Due to weight and space restrictions smaller turbines are preferable. But the increased pressure losses, flow imbalances, and possibility of substandard aerodynamic performance can all lead to a decrease in efficiency. Achieving high pressure ratios in a compact design means increased pressure losses in the flow route. The physical size of the turbine must be balanced with the required power output and efficiency, which is a crucial factor for applications in aerospace and the automotive sectors.

LITERATURE REVIEW

Angelo Leto [1] Introduced a model for the preliminary optimized design of a radial turbine along with an analysis of key relevant loss models for efficiency prediction using MAT lab. The loss models were examined and developed to provide useful thermodynamic and geometrical information, which are required for an optimization CFD simulation.

Chao Zhang and Matthew Janeway [2] Optimized turbine blade designs using artificial neural networks with high fidelity CFD to improve efficiency and power. This approach was applied to an idealized turbine CFD problem as a proof-of concept but not suitable for production-level gas turbine designs, where more and more detailed constraints on the geometry or loading curve need to be incorporated to achieve more realistic optimization results.

Waqar Muhammad Ashraf et al.[3] Have modeled turbine heat rate of gas turbine system installed in 1180 MW combined cycle gas power plant by DINN (Data Information Integrated Neural Network) algorithm and thermal efficiency, power. The DINN-based

process models are trained with more than 95% predictive accuracy and are embedded in the multi-objective optimization problem was solved and the robust optimal solution was identified.

PanelBiaoLietal.[4] Optimized the geometric parameters, kinetic parameters and thermodynamic parameters by applying the mean-line design method and the PSO (Particle Swarm Optimization) algorithm. Then they analyzed the influence of parameters on turbine performance.

Om Prakash Shukla et al. [5] discussed various optimization techniques with primary focus on Genetic Algorithm (GA). They evaluated by selecting the initial population of individuals and evaluating the fitness of each individual in that population, This process was repeated on this generation until termination criteria were met (time limit, sufficient fitness achieved, etc.). The best-fit individuals were chosen for reproduction and new individuals were generated through crossover and mutation operations to create offspring. The fitness of new individuals was then evaluated and replaced least-fit population with new individuals.

Chang Qiu-xiang [6] Developed two enhanced genetic algorithms: an adaptive genetic algorithm and simulating annealing algorithm based on niche and the genetic algorithm combining between improved genetic algorithm based on schema theorem with an adaptive genetic algorithm.

Lukas Benjamin et al. [7] Designed and optimized a Mach 2 supersonic axial inlet and radial outflow turbine for a specified inlet diameter, which relies on the upstream combustor and/or nozzle. They employed a genetic multi-objective optimization procedure along with twelve design parameters to define the blade surface, hub, and shroud.

Chen et al. [8] Introduced a process to optimize the imbalance of a multi-stage rotor during assembly using a genetic algorithm. For the first time, considering the screw holes of adjacent rotors, they developed an assembly error propagation model for the multi-stage rotor.

Lalit Kumar Behera and Aparna Sasidharan [9] proposed the idea of hazard navigation and a swarm robotics surveillance system deployment over the target using an approach based on the behavior model. It has been inspired from ant colony models that led to the heuristic target localisation technique with decentralised swarm dispersal. Target localization is found on the combination of the dynamic ant colony approach along with a random walk method.

R. Sagayam et al. [10] have developed a set of classification rules and comparisons for the identification of spam hosts by using the ant and bee colony optimization technique. The

optimum weight calculation technique for spam host detection is compared with the ant and bee

Fate et al. [11] used a genetic algorithm and an ant colony optimization method to route moving robots in dynamic situations of varying complexity. Because environments were dynamic and distinct pathways varied in length, a variable-length chromosomal structure was used. The performance of both algorithms concerning the execution speed and number of occurrences for the determination of an ideal path under dynamic situations is tested using MATLAB simulation methods.

Sai Teja et al.[12] Using graphite, titanium and zirconium alloys. A model was developed to compute stress and strain and also to study the effects of displacements. The numerical analysis results showed that Titanium alloy has less displacement, strain and stress distributions, and thermal conductivity compared to graphite and zirconium materials. They also proved Titanium alloy is the best suited material for the gas turbine blade compared to graphite and zirconium alloys.

Geetika K. Salwan et al. [13] Focusing on the material properties required for industrial gas turbine blades in order to select the right material based on casting techniques. Various super alloys with typical compositions are investigated for their tensile properties at different temperatures, as well as their chemical makeup. This study on mechanical properties of materials at various temperatures and chemical compositions paved the way to suitable material creation for future generations' gas turbine blades.

Swati Biswas et al. [14] discussed about various alloys used for turbine units, Materials for accessory Systems and their merits and demerits. Composites, intermetallic and several new material systems are explored and some of them are successfully inducted into the applications.

Chakraborty et al.[15] Compared the effectiveness of two optimization techniques, namely the genetic algorithm and particle swarm optimization, for the structural optimization of a gas turbine blade. They used FEA to simulate the stress 34 distribution of the blade and optimized the blade shape to minimize the maximum stress. The results showed that both optimization techniques were able to reduce the maximum stress of the blade, but the genetic algorithm was found to be more effective in finding the optimal design.

Zhang et al.[16] Proposed an optimization methodology to improve the aerodynamic performance and structural strength of gas turbine blades. The authors used computational fluid dynamics (CFD) and finite element analysis (FEA) to simulate the flow field and structural behavior of the blade, respectively. The optimization objectives were to maximize

the efficiency and minimize the deformation and stress of the blade. The results showed that the optimal blade design had a higher efficiency and lower deformation, and stress compared to the original design.

Amir Karimi Noughabi and Shervin Sammak [17] Presented the full design of a radial-inflow turbine, including volute, nozzle blade row and rotor blade row and explained preliminary and detailed aerodynamic design approaches for a radial inflow turbine. ANSYS CFX is used to perform unsteady 3D simulations of the designed RI turbine at design and off-design conditions to predict the aerodynamic performance of the turbine for future optimization.

Li et al. [18] Used multi objective optimization to optimize the design of a turbine blade using a response surface methodology. They developed a three dimensional blade model and finite element analysis to simulate the structural behavior of the blade. The objectives of the optimization were to minimize the blade weight and maximize the blade natural frequency while considering fuzzy parameters in the design. The optimization was carried out using a genetic algorithm.

P. Sai Teja et al. [19] summarized the numerical analysis of the vertical axis gas turbine rotor blade components with different traditional and advance materials. CATIA V5 and ANSYS 11.0 are used for the design of model and optimization analysis for structural, thermal and modal of gas turbine rotor blade components. In optimization analysis of the turbine rotor blade components, they used both ways of static and dynamic conditions for better understanding of the behavior of rotor blade materials. Titanium, graphite and zirconium were the rotor blade materials used for the optimization analysis.

Chauhan et al. [20] used ceramic cores to increase the turbine entry temperature and to reduce the weight of individual blades. Blades were produced by investment casting to generate complex internal cooling passages. an attempt is made to quantify the shrinkage and war page during injection molding. The flow process during filling, packing and cooling stages and the effect of injection molding parameters such as holding time, injection pressure (packing pressure) and flow rate on shrinkage, warpage and Von-Mises stresses on green core is studied using Moldex3D and CFD analysis.

Bhupesh Sonkar et al. [21] used computer-aided design (CAD) and finite element analysis (FEA) techniques to optimize the design of turbine blades. They presented a comprehensive review of the recent advancements in CAD-based design optimization and FEA techniques for improving the performance of turbine blades. They also covered various aspects of

turbine blade optimization, including aerodynamic performance, structural strength, and vibration characteristics. They discussed the challenges and limitations of the current optimization techniques.

Research Gaps

- Derive aerodynamic equations (Mach number, velocity, Bernoulli's, etc.) and set design constraints (geometric, operational, and material limits).
- Apply Genetic Algorithm (GA) to optimize rotor dimensions (blade length, diameter, etc.), balancing efficiency and structural integrity.
- Calculate and analyse velocity triangles based on optimized rotor dimensions.
- Use Ant Colony Optimization (ACO) to further optimize rotor dimensions, addressing multi-objective challenges.
- Update velocity triangles with refined dimensions from ACO.
- Validate optimized designs through ANSYS (structural) and CFD (aerodynamic) simulations.
- Test three different materials for the rotor to identify the most suitable based on performance and durability.

OBJECTIVES

• Miniaturization of Radial Turbines

- i) Reduce size and weight of the turbine rotor for portability in emergency, remote, and off-grid applications.
- ii) Employ Genetic Algorithm (GA) and Ant Colony Optimization (ACO) for solving complex design challenges.

• Performance Optimization

- i) Optimize aerodynamic and mechanical components.
- ii) Balance size reduction with sufficient power output to meet specified design conditions.

• Cost-Effective Design

- i) Utilize durable yet affordable materials to minimize production costs.
- ii) Focus on Titanium alloy for its performance-cost balance, while evaluating alternatives like Inconel 718 and Aluminium alloys.

• **Validation through Simulation**

- i) Use FEA and CFD simulations to validate structural integrity, thermal behaviour, and overall performance.
- ii) Conduct structural and thermal stress analyses to ensure design reliability.

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