DESIGN AND ANALYSIS OF WIND TURBINE BLADES USING BLADE ELEMENT MOMENTUM THEORY

SRINIVAS BOGA
BTech student Dept. of ME, Sreenidhi Institute of Science and Technology, T.S,
Srinivaschinna323@gmail.com

Mr. KOKKU SOHAN
BTech student, Dept. of ME, Sreenidhi Institute of Science and Technology, T.S,
sohan.k007@yahoo.com

Mr.LALITH KUMAR NALLAVELLI
BTech student, Dept. of ME, Sreenidhi Institute of Science and Technology, T.S,
n.lalithkumaaar@gmail.com

Dr.GONDI KONDA REDDY
Associate Professor, Dept.of ME, Sreenidhi Institute of Science and Technology, T.S,
kondareddyg@sreenidhi.edu.in

Abstract: *In this project, a code dynamic stall handle mechanism is strongly increased for a 5MW wind turbine. The dynamic loads for MW scale horizontal axis wind turbines are measured and examined. The developed design was based on BEM (Blade Element Momentum) theory, and this design has operated ten various cross-sections of S809 Airfoil. The generated code is examined on linearly growing wind speed and varying wind speeds involving sinusoidal waves. The study results show that the given dynamic stall design is compatible with automated wind turbine power generation. The presented study method of aerodynamic loads and power generation is well advanced for future purposes and analyses. In addition, combining manufacturing design knowledge into optimization decreases the design space and, consequently, the time taken by the optimization algorithm. While the proposed method herein is defined for a standalone aerodynamic optimization, it can also use it for aerostructure optimizations.*

Keywords: *Wind blade, manufacturing, Blade Element Momentum, aerodynamic design.*

I. INTRODUCTION

Hundreds of wind turbine blades vary widely in pitch and yaw pitch, tower shadow, atmospheric turbulence, wind shear, tower, blade vibration, and blade head losses during each overturn. The difference in these blade loads has a severe impact on power fabrication. At low wind speeds, the presence of these factors will not allow overcoming the static friction between the rotor and the turbine blade. Excessive wind speed damages the device due to lifestyle stress and overheating due to Coulomb friction. Unique control mechanisms have been developed to reduce these problems.

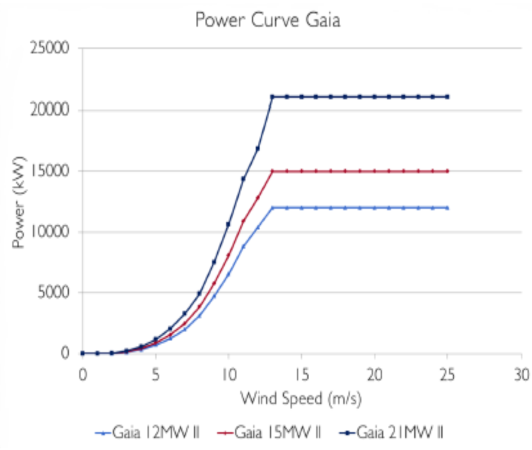

Fig.1 Power Production of Different MW Scale Wind Turbines

Figure 1 illustrates this difference between electro synthesis and tone processing mechanism scale. The most appropriate wind speed is taken 12 m / s, also known as the nominal rate, to increase the working life of a wind turbine. The handling mechanism is interrupted, and the rotor speed is slowed down mainly by changing the attack perspective and thus the drag and lift coefficients to obtain better wind speeds, and secondly, the use of the brake device. In general, the reduced velocity is limited to 25 m/s. After this device, the wind speed stops and is disrupted. Failure to do so may also cause the alternator to explode or damage the equipment. Therefore, it is necessary to calculate the pulling and pulling forces to improve this mechanism. Lower wind speeds should maximize the power output, and high wind speeds should be maintained below the control level with the help of reducing the attack potential, which increases drag pressure. In this factor, our reason is to increase the control mechanism to account for power output, aerodynamic loads, and output torque and still produce less power than handling for excessive wind speeds. The code will be developed for the 30m wind turbine blade and 5MW wind turbine.

The multi-objective improvements have made a significant contribution to improving the overall performance of wind turbines [1]. For example, discounting the price of blades by reducing materials, even while maintaining high hardness, is a significant improvement problem for wind turbine design. In addition, proactive optimization algorithms involving a set of genetic or colony bases of ants are commonly used and reduce the computational time required to discover the most specific solutions [2]. At the same time, due to the wide use of optimization techniques, the durability and accuracy of wind turbine shapes have also been greatly improved [3]. In particular, the evaluation of the aerodynamic structure has become the norm. However, the coupling of the pneumatic structure dramatically increases the length of the optimization problem. For example, optimizing the internal design of the blades is itself a time-consuming optimization process. As a result, wind turbine optimization technologies fall into two categories.

The first category refers to the improvements that are included in today's wind turbine modelling tools. While this method guarantees optimization of the latest design multidisciplinary, the optimization algorithms are computationally demanding. This means that the characteristic of aerodynamic, structural evaluation, and the considerable length of the design area cause time-consuming optimization. The second category refers to improvements that divide wind turbine design into sub-problems. Although the final design is probably not the most secure in this case, the optimization algorithms are significantly faster than those in the first category.

Moreover, the latest wind turbine designs obtained with the help of the optimal combination of each sub-problem are, most likely, the closest solutions to the most effective ones. Therefore, it is essential to make appropriate assumptions or simplifications while performing subdivisions. For example, an independent aerodynamic design will likely fail without considering structural constraints in structural analysis. The first reason is to impose the rule of optimizing the specific speed with the help of reducing the design space and time spent on the fitness evaluation function to simplify two functions [4]. The second reason for simplification is manufacturing limitations while researching a design. This document proposes implementing manufacturing design knowledge as part of a set of improvement rules. Thus, the best response obtained in this way is ready for manufacture. In addition, incorporating the understanding of production design into optimization reduces the design space and thus the time taken by the optimization algorithm. Production limitations examined during the duration of this investigation are the linearity of the chain and airfoil mixing.

II. REVIEW OF LITERATURE

Mohamed et al. [2012] the ultimate goal of the article is to increase the reliability of wind turbine blades by optimizing the aerodynamic surface structure to calculate the most crucial blade shape for the way development begins with the selection of aerodynamic surface properties. Next, the initial design of the wind blade is determined using the blade detail engine. The blade plays a crucial role because it is the essential part of the force-absorbing system. Practical designs of horizontal axis wind turbines (HAWTs) use aerodynamic profiles to convert the kinetic Electricity of the wind into helpful power. Therefore, they must be carefully designed to allow for more efficient energy harvesting. There are many elements to select a profile. The problem with good size is the chord span and torsion angle, which depend on different values during the blade. In these panels, the air sections used in the horizontal axis wind turbine (HAWT) are S818; S825 and S826 aerodynamic profiles used in Part 2 and Section III NREL wind turbines. They have many advantages in installing wind generators' intrinsic requirements in terms of design factor, off-design skills, and structural housing. Information on lift and drag coefficients is available for these airfoil sections, and Matlab code was used to obtain wind turbine blade coordinates. Aerodynamic and static structural analyzes are shown. The commercially available FLUENT software is used to calculate the Navier Stokes-averaged (RANS) drift area on the k-omega shear stress transport (SST) side, based on the finite-element method (FEM). Both the network and time step are optimized for independent responses. Gift paints form the basis for developing an exact copy of the 3D Horizontal Axis Wind Turbine (HAWT) and can aid in wind tunnel experiments [5].

Elfarra et al.[2011] The primary purpose of this observation is to design and improve the dynamic wing, rotation direction distribution, and slope perspective of a wind turbine blade using CFDs to produce more electricity. The Numeca Fine/Turbo RANS solver was tested using two test cases, NREL II and NREL VI papers. Effects showed significant normalization with the measurements for both cases. Two specific preconditions for a low Mach band wave were implemented. The fallout showed the Merkle pre-conditioner outperforming Hakimi, and Merkle switched to the selector for further simulations. Furthermore, the characteristic perturbation patterns were compared, and Launder-Sharma showed high-quality agreement with the measurements Wash: Sharma has become the preferred choice for subsequent simulations and the design process. Before starting the design and optimization, the exclusive configurations of the wing were studied. Fins pointing to the suction side of the blade produced higher power output. The genetic algorithm and artificial neural network were implemented in the form of design and optimization. The improved fin showed an electrification growth of approximately 9.5%, with a 4% increase in torque. The regulated code was then converted into a degree regulated code to produce the additional power output. The final design was produced using a combination of improved fins, improved cornering, and a Class 1 positioning for each wind speed. The latter design showed an increase in power output of about 38% [6].

McNamara et al. [2014] The wind turbine's rotating blade, primarily based on the US National Renewable Energy Laboratory (NREL) 5 MW reference turbine, has been optimized for a minimal energy value through simultaneous attention to aerodynamics and torsional elastic coupling. Eighty-three design variables are considered, including airfoil shapes, chord and roll distributions, and the degree of torsion and elastic coupling in the blade. An advanced approach is used these days that requires much less computation than evaluating the finite details of planning and predicting rotor bending behaviour and torsional coupling. Airfoil performance is calculated using XFOIL, even when wind turbine masses and overall performance are calculated using the NREL FAST code. An objective feature is the annual cost of electricity (COE), whereby reductions in bending blocks by fins and blade surface location are assumed to reduce rotor price by reducing fabric needs. Advanced improvement initiatives have reduced hundreds of blades while maintaining the overall performance of the wind turbine [7].

Maalawi et al. [2003] the primary objective of this document is to classify practical families of horizontal axis wind turbine rotors, which can be optimized to provide the highest possible power output. The straight blade geometry is obtained from a first-order approximation of the best theoretical chord and torsion distributions calculated from the rotary blade. The mathematical formula mainly relies on dimensionless quantities to make the aerodynamic analysis valid for any arbitrary turbine model that has unique rotor volumes and works with distinct wind systems. The specified design parameters consist of blade range, aerodynamic phase-type, and blade root displacement from the center of the axle. The consequences of wind shear and tower shadow are also tested. A computer program has been developed to automate general analysis methods. Several numerical examples illustrate the version of the power and thrust coefficients with the design tip velocity ratio for various rotor configurations [8].

Jackson et al.[2005]The Blade System Design Study (BSDS) aimed to investigate and evaluate wind turbine blade design and production problems in the 1-10 megawatt size range. A set of analysis commitments has been completed to aid in the design effort. We started with a parametric scale to assess the shape of the paper in modern-day uses. This was accompanied by an economic look at the cost of manufacturing, transporting, and installing large shovels. We subsequently outlined several recent design procedures that emphasized the ability to overcome essential body and production limitations. The final stage of work was used to expand on several initial designs of 50-

meter blades. The main design effects identified in this study are 1) blade slope sections, 2) chance materials, three) IEC design coolness, and four) root stabilization. The consequences show that thicker blade cross-sections can provide a significant reduction in blade weight, even while maintaining high overall aerodynamic performance. Increasing blade thickness for internal sections is a crucial way to improve structural performance and reduce blade weight. Hybrid carbon/glass blades have been found to deliver the best improvements in blade weight, stiffness, and yaw when used within core blade structural parameters. Adding carbon led to modest price increases and provided significant benefits, primarily in skew recognition. The exchange of design loads between IEC classes is huge. Papers optimized for all the classes of IEC design must be designed. Much of the blade's weight is related to the mounting base and steel hardware of traditional root lock designs. The results showed that increasing the number of blade holders has a high-quality effect on the total weight because it reduces the thickness required for root plates [9].

III. DESIGN OPTIMIZATION TOOL

Rotary blade optimization is critical because previous studies show that for correct design and correct optimization, electricity production for wind turbines can be accelerated by up to 38% for a low-flow variety of Mach. The BEM concept, entirely based on the Glauert propeller concept, is one of the most popular methods for analysing wind turbines that divide the turbine blades into unique sections. Over the years, this mathematical technique has been developed through unique modifications. The above trends and modifications suggest that impressive wind speeds have evolved. BEM theories have the same mentality with empirical influences. For the accuracy of the boom for the calculations of the downward force of the BEM principle, the dynamic stall is taken into account. Various semi-experimental versions of the DS are provided for dynamic loss assessment, along with models from Boeing Verto, ONERTA, Oye, and B-L. In nearly every BEM theory, taps and load elements are connected to an element that is an axial induction problem.

The results of the overall manufacturing-based optimization are compared with the conventional optimization to examine the overall performance of the proposed technology. Each simplification is compared independently. Since evaluating traditional techniques and more straightforward offerings requires optimizing one design variable, optimization is used for mismatched goals. Among the potential Meta heuristic optimization strategies, a genetic algorithm (GA) was developed for this research. Since the optimization problem is to optimize a single target with a small search area, GAs are convenient and easy to implement.

Average strength (P_{av}) is defined as the health characteristic that should maximize. The roulette wheel selection method and the elite renewal step avoid early convergence and maintain high diversity during optimization. The optimization problem is defined in the form of constrained maximization as follows.

$$\text{Max } P_{av}(x), \ x \in \mathrm{R}^n$$

$$\text{Subject to } P(v) \leq P_{rated}$$

A. CHORD LINEARIZATION

In BEMT, blades are considered as a separate set of segments, as shown in Figure 1. As a result, the proposed maximum aerodynamic optimization for the blade also considers each blade as separate segments. The variable design of the variants has lengths similar to the number of segments (i.e., Nsec). However, the final sheet design completed in this way may need further alteration to accommodate production limitations. For example, the blades should have a simple geometry along the span across the airfoil, pre-torsion, and tendon distributions [10]. Since wind turbine blades are expensive and difficult to manufacture, the linearity of the radial chord profile (c) is one of the most common simplifications used by producers to reduce charges and simplify the blade structure as shown in Figure 2

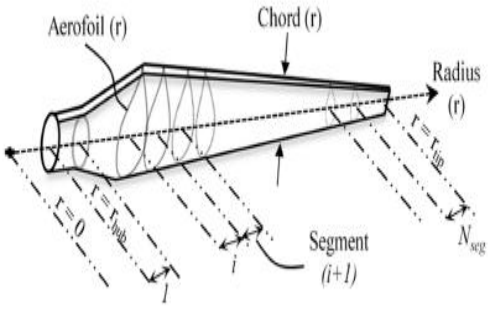

Fig.2 Wind turbine blades decomposed into independent segments

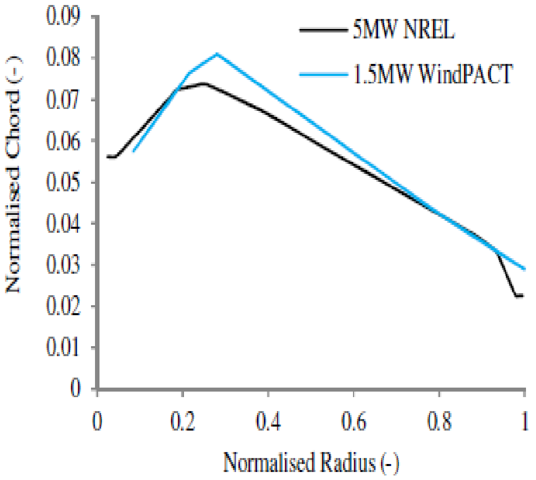

Fig.3. Wind turbines normalized chord distribution.

B. AEROFOIL BLENDING

The mixing or interpolation in Aerofoil is the second manufacturing-based limitation built into the optimization. Air distribution along the blade.

The extension is essential for both the aerodynamic design and the chassis. Aerodynamics is responsible for generating the aerodynamic forces that lead to squeezing electricity and blade loads. Regarding chord, the classical optimization approach to dynamic profile distribution uses the number of segments as variables. However, the final aerodynamic design of the blade should have a smoothly varied external geometry. If two different aerodynamic segments are used in two adjacent segments, it is necessary to perform an internal completion along the blade, as shown in Figure 4. So the wing interpolation is an intrinsic part of

Wind turbine blade design. Moreover, assuming an abrupt change in the aerodynamic profile from one part to another can also lead to inaccuracies in all calculations of the overall aerodynamic performance of a wind turbine.

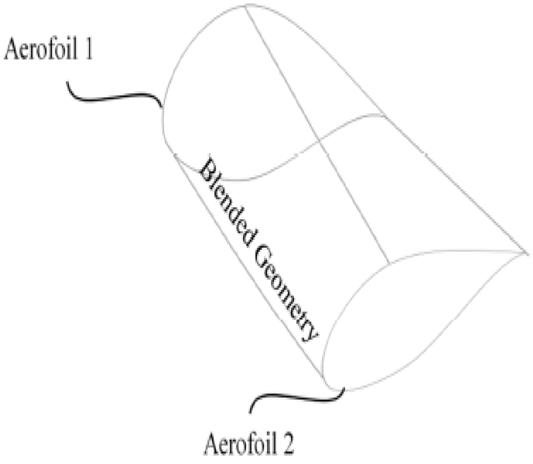

Fig. 4 Scheme illustrating the blending of aerofoils

All-aerodynamic optimization without structural design issues will result in low airfoil distribution across the entire blade extension. However, the airfoil thickness should be increased so that you can direct the second to increase the flex near the root of the blade. In addition to mixing the airfoil, it is necessary to ensure that the thickness distribution along the blade is monotonously reduced from root to tip.

IV. RESUTLS AND DISCUSSION

The NREL 5MW variable wind turbine design is used to control pitch and pitch, as the case examined during this investigation. The chord distribution and the aerodynamic profile of the original blade design are used as design variables to validate the proposed optimization. The following optimization results were obtained for a population of 50 people and 50 generations. The probability of crossover and mutation were set, respectively, at 60% and 5%.

Results for Chord Linearization

String optimization results for linear and non-linear techniques are compared with unique design statistics in Figure eight. As shown in Figure 5(a), each design strategy finds a chord very close to the original leaf chord. Moreover, it can be seen that both force (Fig. 5 (b)) and thrust (Fig. 5(c)) of each design constitute the original blade design. The affinity of the GA and Pareto frontal one explored during research in Figs was also tested. Nine and 10. Because the regeneration and selection methods used for each technique are the same, similar patterns of convergence, have been found. It can also be found that the improvement covers a large proportion of the Pareto front.

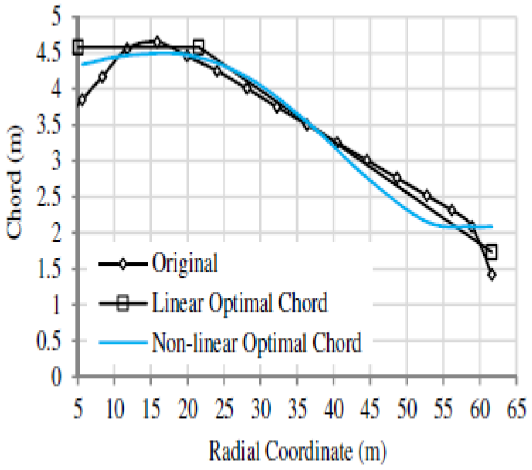

Fig.5 (a) Chord

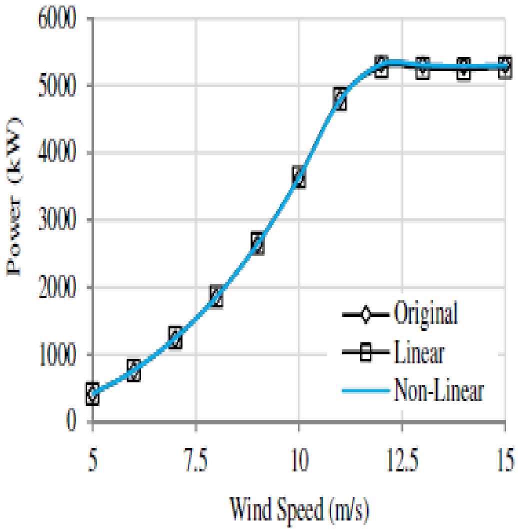

Fig.5 (b) power

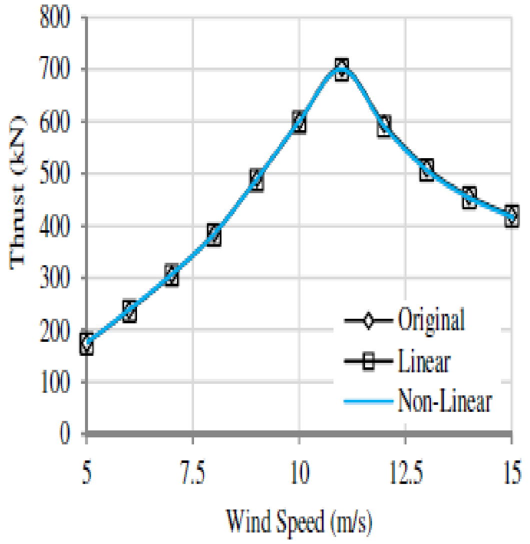

Fig.5 (c) thrust optimisation results.

Results for Aerofoil Blending

The era of aerodynamic coefficients for mixed aerodynamic profiles requires that the corresponding Reynolds numbers be calculated with code extension. Figure 6 indicates the differences in the Reynolds number for the NREL 5MW case that should be monitored. As discovered in Figure 6, the Reynolds manifold remains elevated (i.e., Re > 106) on most people who operate wind turbines. With highly excessive Reynolds numbers, the final versions of the lift coefficient operating below the contact go with minimal flow, as tested in Figure 7 (a) and 7 (b) for the NACA 64-618 and DU21 wings. -A17. Without the optimization, it can be seen that the changes in drag due to Reynolds number versions are minor. The final impact on wind turbine design will be minimal. Therefore, it is assumed that the versions of the Reynolds numbers are insignificant and now do not need to be incorporated into the design improvement.

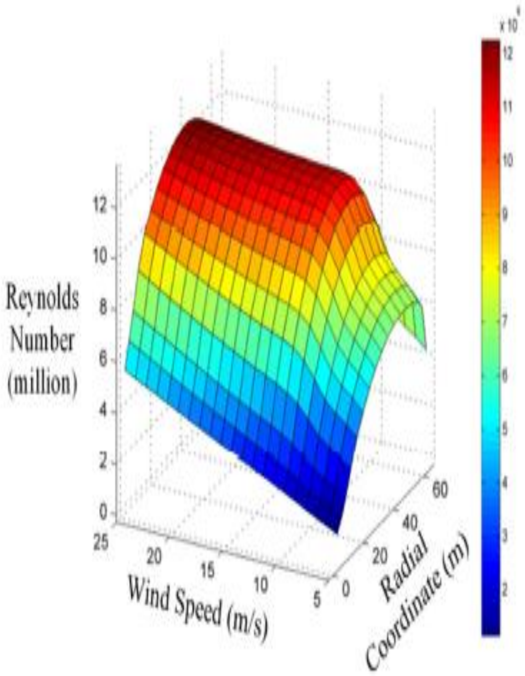

Fig.6 Reynolds number distribution along blade span over the entire operating mean wind speed range

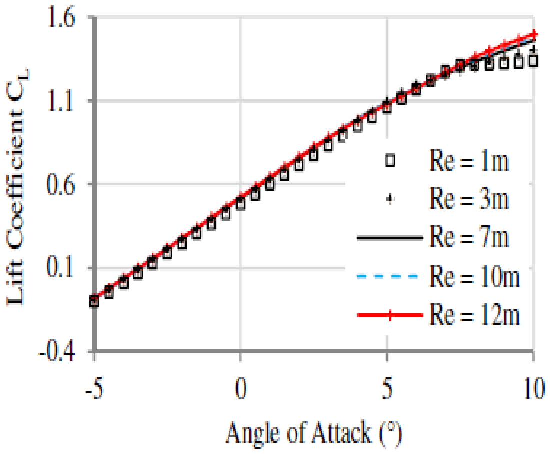

Fig.7 (a) NACA 64-618

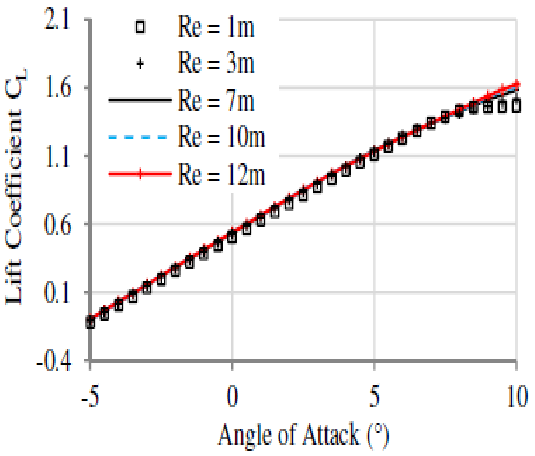

Fig. 7(b) DU 21-A17 aerofoils sensitivity to Reynolds number (Re = 1m = 1million).

V. CONCLUSION

This paper investigated a manufacture-based aerodynamic optimization method for wind turbine blades. It turns out that the proposed method obtains a design that is close to ideal. This research also confirmed that incorporating manufacturing constraints into optimization has significant advantages. First, implementing production constraints in optimization ensures that the final design is improved. Also, not thinking about simplifying manufacturing during optimization is likely to result in a performance loss at some point in your deployment optimization simplifications. Second, finite manufacturing-based optimization requires a smaller range of variables during optimization; Thus, resulting in smaller design space and fewer residents

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