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OPTIMUM DESIGN OF INDUCTION GENERATOR FOR RENEWABLE ENERGY CONVERSION

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Abstract*- Bangladesh is very much concerned about climate change and energy security. Introducing more and more renewable energy sources for electricity generation may reduce electricity crisis we are facing now in Bangladesh. We have a good potential of micro-hydro source in hilly region and to some extent, good wind energy source in the coastal region in Bangladesh. Induction generators play a vital role for cost effective energy conversion process of such renewable energy systems. Optimum design of induction generator would further reduce the cost of renewable energy conversion system. This paper deals with the optimum design of Induction Generator to be used for micro-hydro and wind energy conversion systems. An optimization model is developed for optimum designing of induction generator keeping in view not only minimizing the cost of the generator but also maximizing the efficiency of the same. Based on multiple objective functions and constrains the step by step design process of the induction generator is carried out and elaborated in the paper. Economical analysis shows that, optimum design is more cost effective as compared to that of traditional design. Finally the performances of the designed generator are simulated and encouraging results are obtained and presented in the paper.*

Keywords: Renewable Energy Conversion, Optimum Design, Induction Generator, MATLAB Optimization

1. INTRODUCTION

There is an increasing acceptance that we need to accelerate our efforts to produce energy from alternative sources of energy to meet our primary energy needs each year. Life on Earth currently faces a threat on a truly global scale: climatic change. If we are to avoid significant climatic change we must reduce emissions of greenhouse gases. A scientific consensus is emerging that civilization must reduce its emissions of global warming gases by more than half in less than 50 years. In remote regions of developing countries, like Bangladesh, the problem was and remains more serious. Insufficiency of supply of electrical energy from the national grid has obliged residents to use stand alone diesel generators to supply needed electrical energy, even they are aware for negative economical and environmental effects. Coastal area like, Saintmartin, Sandip, Kotubdia etc. in Bangladesh has totally out of supply of electrical energy from the national grid due to, it stands in the remote location from the national grid and power transmission lines and are impossible to access those regions. So, we have to find the environmental friendly techniques to fulfill the demand of electricity from non-conventional energy sources. As we get the continuous flow of wind in the coastal region, wind energy can be the most important and largely usable form for sustainable energy development. As a result we need to install the wind energy conversion system, where Induction Generator and wind turbine are the most costly part and cost of wind energy conversion depends on the optimum design of Induction Generator and wind turbine. On the other hand there is great potential in Chittagong region for installation of micro-hydro power plant. In this paper, we have proposed optimum design of induction generation and then simulated the performance of the generation. We have also compared the performances of traditional design (without optimization) and optimum design of the generator. We have got a noticeable variation of output performance between the two results. All these results are presented and discussed in the paper.

2. OPTIMIZATION

The design of electrical machines consists essentially of the solution of many complex and divers engineering problems and normally these problems are loosely interrelated. The design of electrical machines in fact presents a mathematically indeterminate problem with many solutions as the number of equations is less than the unknowns. The aim of optimization in the design of electrical machines is to choose the best solution for a given problem from the multitude of possible solutions. The optimization process, therefore, involve the choice of various variables in such a manner that the design in regard to a particular feature is the best, and at the same time satisfies all limitations or restraints imposed on its performance. Hence, optimization is the collective process of finding a set of conditions required to achieve the best results from a given situation. In order to achieve the best possible solution, it is necessary to define the objective of study. The objective may vary from one problem to another, but for industrial applications it may be either economic or technical. Such economic aims as maximum profit or minimum cost are in common, while possible technical objectives might include the largest yield of a particular product from a plant. Normally most industrial optimization has to be carried out within an economic frame work [1].

The characteristics feature of optimization in design of electrical machines is the presence of conflicting or opposing influences. For example, the cost of active materials in induction generator can be reduced by using high values of specific electric and magnetic loadings but these high values of specific loadings will result in unsatisfactory performance like high temperature rise and poor power factor. The choice of low values of specific loadings has the opposite effect that is high cost and better performance. The best design will be obtained by the compromise of two main factors, that is cost and performance, the two exerting opposing influences. The general objective in optimization is to choose a set of values of the independent variables, subject to various restrictions which will produce the desired optimum response for the particular problem under examination [1].

3. SOLUTION OF UNCONSTRAINED OPTIMIZATION PROBLEMS

A number of methods that is numerical algorithms are available for solving an unconstrained minimization problem. Broadly, these methods can be classified as, Grid and random methods, univariate method and Gradient methods. The number of methods in each of these categories is so large that it will be impossible to describe them even briefly. Therefore, only a few, in particular those that are applicable for an optimal design of an Induction Generator, are listed here. These are the Random search methods, Simplex methods, Hooke and jeeves methods, Powell method and Davidon- Fletcher-powell (DFP) method [1].

In each of these methods, the uni-modality of the function F(X) is assumed. From the above we select simplex method to optimize the design program, hence we find a satisfactory result. Overall Design algorithm used in this experiment is represented in Figure 1.

4. SIMULATION OUTPUT OF TRADITIONAL AND OPTIMIZED DESIGN

The constrains of the single phase Induction Generator are listed in table 1(a) and simulated comparison between traditional and optimum design output for Single phase Induction Generator are represented in the table 1(b). On the other hand in table 2(a) constrains of the three phases Induction Generator and in table 2(b) simulated output both for traditional and optimized design are presented.

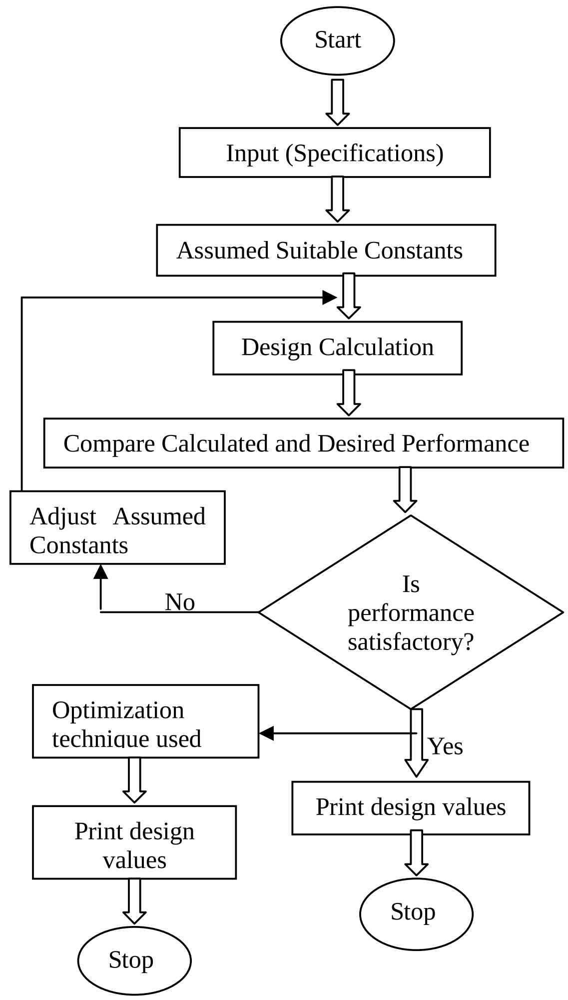

Fig. 1: Overall design algorithm for optimum design of Induction Generator

Table 1(a): Constrains of the single phase Induction Generator

Parameter	Values
Output in Watts	60
No of Phase	1
Magnetic Loading	0.4000
Frequency in Hz	50
Supply Voltage in V	220
Electric Loading	2500

Table 1(b): Simulated comparison between traditional and optimized design output for single phase Induction Generator

Parameter	Traditional Design	Optimized Design
Stator:		
Diameter bore in m	[0.0678]	[0.0667]
Core length in m	[0.0532]	[0.0523]
Iron length in m	[0.0505]	[0.0497]
Pole pitch in m	[0.1065]	[0.1047]
Phase voltage in V	[209]	[219.4500]
Flux per pole in wb	[0.0023]	[0.0022]
Turns per phase	[519.3519]	[563.3486]
Insulated Dia. in mm	[0.5710]	[0.5710]
Area in mm2	[0.1206]	[0.1094]
I den in A per mm2	[5]	[5]
L of mean turn in m	[0.3513]	[0.3456]
Phase R at 75 deg	[67.8132]	[81.0977]
Outer dia in mm	[78.4478]	[77.3544]
Loss per kg in W	[11.5000]	[11.5000]
Vol. of core in m3	[5.0741e-004]	[4.8324e-004]
Total Cu loss in W	[25,4160]	[23.0836]
Rotor:		
L of air gap in mm	[0.3000]	[0.3000]
Diameter of in mm	[67.1791	[66.0857]
Slot pitch in mm	[4.7966]	[4.7185]
Rotor bar current	[9.8641]	[9.7050]
Area in mm2	[32.1000]	[32.1000]
Length in mm	[5.9151]	[5.8197]
End ring I in A	[69.0763]	[67.9620]
Area in mm2	[17.2691]	[16.9905]
Diameter in mm	[42.1791]	[41.0857]
R of each ring	[5.3514e-005]	[5.2126e-005]
Loss per kg in W	**[** 13**]**	[13]
Others:		
Core loss in W	[24.8229]	[24.7853]
F and W loss in W	[2.4000]	[2.4000]
Leakage reactance	[4.5226]	[5.2103]
Total resistance	[70.1919]	[83.8381]
Short circuit Z	[70.3375]	[83.9998]
Short circuit I	[2.9714]	[2.6125]
Losses in Watt	[50.3456]	[50.2689]
Output in Watt	[60]	[60]
Input in Watt	[110.3456]	[110.2689]
Efficiency	[54.3746]	[54.4125]
Temp rise in Deg	[34.6445]	[33.8589]

Table 2(a): Constrains of the three phases Induction Generator

Parameter	Values
Output in Watts	26110
No of Phase	3
Magnetic Loading	0.4500
Frequency in Hz	50
Supply Voltage in V	400
Electric Loading	23000

Table 2(b): Simulated comparison between traditional and optimized design output for three phases Induction Generator

Parameter	Traditional Design	Optimized Design
Stator:		
Diameter bore in m	[0.2843]	[0.2797]
Core length in m	[0.1487]	[0.1463]
Iron length in m	[0.1338]	[0.1317]
Pole pitch in m	[0.0991]	[0.0975]
Phase voltage in V	[400]	[400]
Flux per pole in web	[0.0149]	[0.0145]
Turns per phase	[126.9649]	[131.1626]
Insulated Dia. in mm	[3.2000]	[3.2000]
Area in mm2	[6.7155]	[6.3957]
I den in A per mm2	[4]	[4.0000]
L of mean turn in m	[0.7653]	[0.7569]
Phase R at 75 deg	[0.2382]	[0.2584]
Outer diameter in mm	[360.0025]	[353.4741]
Loss per kg in W	[13]	[13]
Vol. of core in m3	[0.0043]	[0.0041]
Total Cu loss in W	[1.2905e+003]	[1.2425e+003]
Rotor:		
L of air gap in mm	[0.6500]	[0.6500]
Diameter of in mm	[282.9807]	[278.3947]
Slot pitch in mm	[26.1474]	[25.7237]
Rotor bar current	[495.1657]	[487.1777]
Area in mm2	[100]	[100]
Length in mm	[188.6788]	[186.2803]
End ring I in A	[1.3397e+003]	[1.3181e+003]
Area in mm2	[223.2890]	[219.6869]
Diameter in mm	[243.9807]	[239.3947]
R of each ring	[1.2382e-004]	[1.2149e-004]
Loss per kg in W	[13]	[13]
Others:		
Core loss in W	[487.7402]	[463.6679]
F and W loss in W	[391.6500]	[391.6500]
Leakage reactance	[1.0489]	[1.0644]
Total resistance	[0.6515]	[0.7140]
Short circuit Z	[1.2348]	[1.2818]
Short circuit I	[323.9373]	[312.0713]
Losses in Watt	[2.1699e+003]	[2.0978e+003]
Output in Watt	[26110]	[26110]
Input in Watt	[2.8280e+004]	[2.8208e+004]
Efficiency	[92.3272]	[92.5629]
Temp rise in Deg	[41.3364]	[27.5103]

5. ANALYSIS OF THE RESULT AND DISCUSSION

The relations of simulated normal and optimized different outputs are analyzed with graphs presented in Figure 2 to Figure 15. Despite of having a narrow range of difficulty this design is most important for induction generator design engineer. To get maximum efficiency with minimum cost the design of induction generator needs to be optimized. From analysis we get some encouraging result which are presented in below-

In Figure 2 when output of induction generator increases both traditional and optimized design diameter increases but optimized diameter is less than traditional design diameter. In Figure 3 we see an inverse relation between stator diameter and efficiency in both traditional and optimum design. Optimum stator diameter is less than traditional design diameter but we observe that in optimum design stator diameter decreases as increases of efficiency until a certain value, from where diameter increases with respect to efficiency increases i.e: this is the minimum optimized point. In Figure 4, optimized stator diameter is always less than traditional design diameter for the same power factor. In Figure 5, core length required is less in optimized design with respect to output, so optimum design is cost effective. In Figure 6 optimized core length is always less than traditional design core length for the same efficiency needed. From the Figure 7, we see that less core length is required in optimized design rather than traditional design for any power factor from 0.6 to unity. From the Figure 8 to Figure 10 we can conclude that stator volume needed less in optimized design when it is plotted with respect to output, efficiency, power factor rather than traditional design.
From the Figure 11 to Figure 13 we see total loss is less in optimum design simulation in comparison to normal design when total loss is plotted with respect to output, efficiency, and power factor respectively. On the other hand efficiency is more in optimum design with respect to traditional design and these phenomena appears when efficiency is plotted with respect to output and power factor.

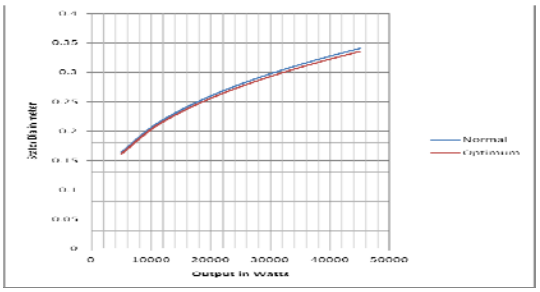

Fig. 2: Curve of stator diameter Vs output

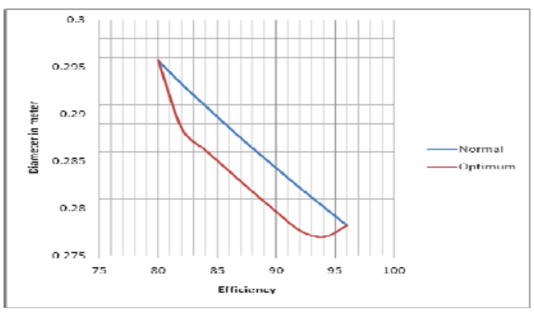

Fig. 3: Curve of stator diameter Vs efficiency

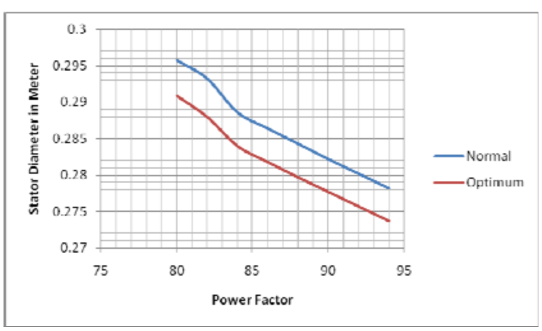

Fig. 4: Curve of stator diameter Vs power factor

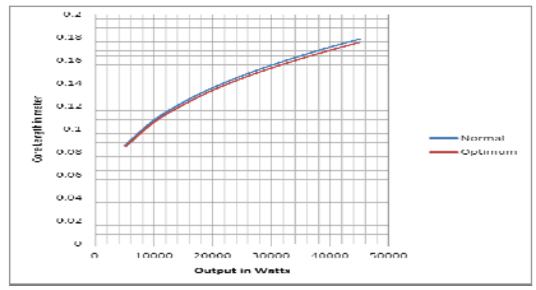

Fig. 5: Curve of core length Vs output

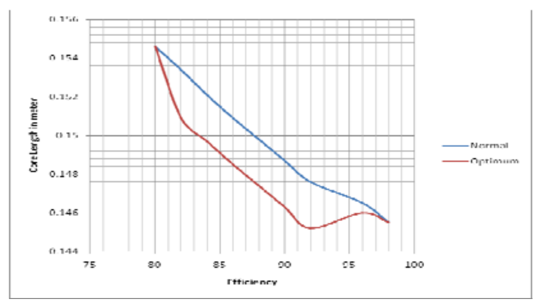

Fig. 6: Curve of core length Vs efficiency

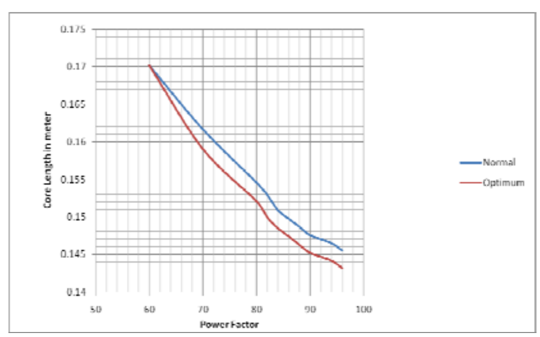

Fig. 7: Curve of core length Vs power factor

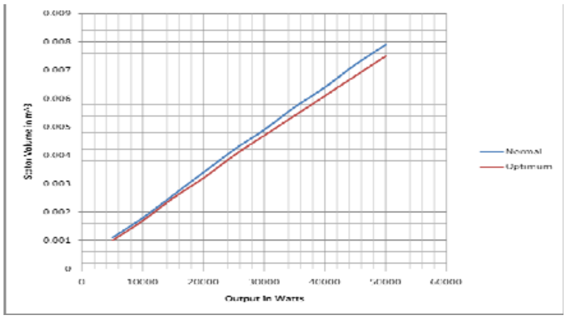

Fig. 8: Curve of stator volume Vs output

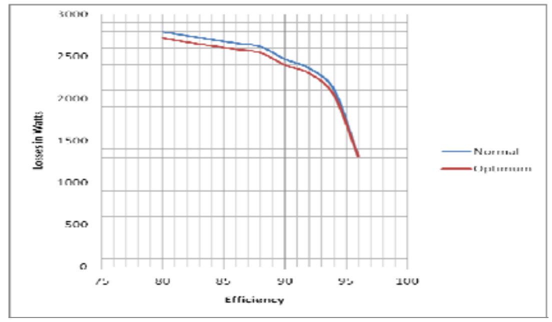

Fig. 12: Curve of total losses Vs efficiency

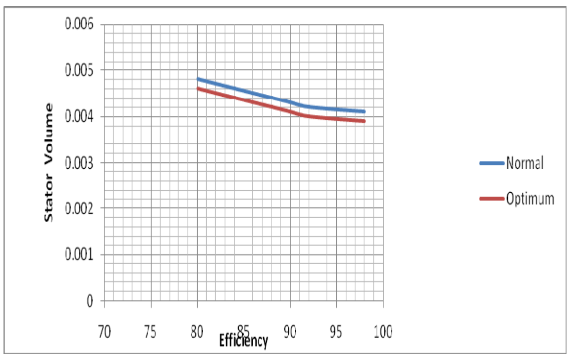

Fig. 9: Curve of stator volume Vs efficiency

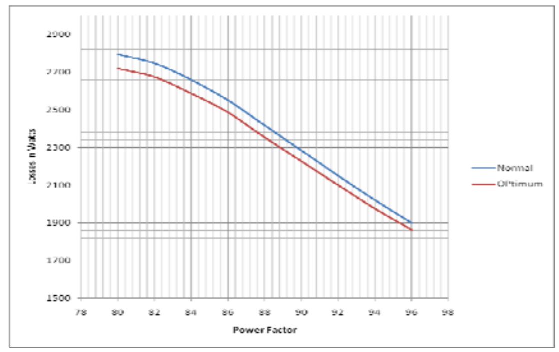

Fig. 13: Curve of total losses Vs power factor

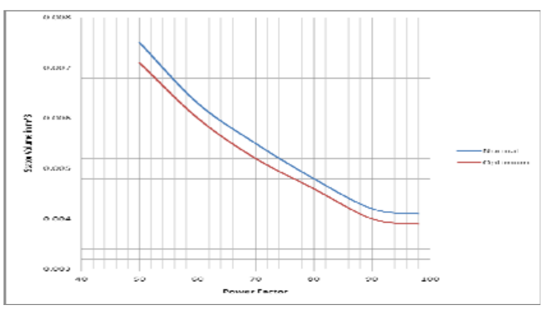

Fig. 10: Curve of stator volume Vs power factor

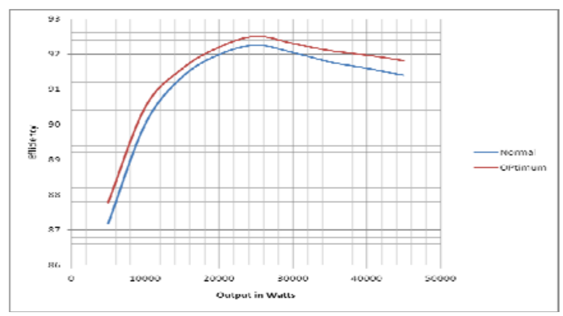

Fig. 14: Curve of efficiency Vs output

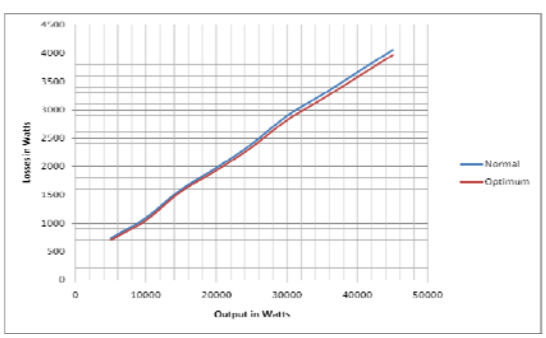

Fig. 11: Curve of total losses Vs output

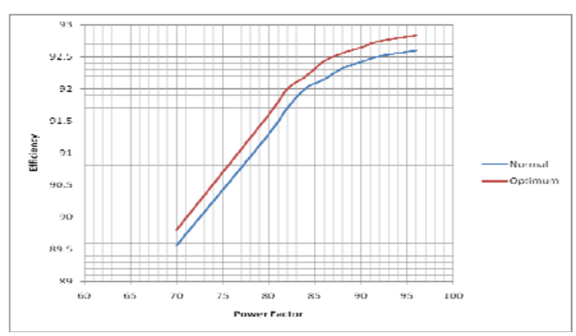

Fig. 15: Curve of efficiency Vs power factor

6. LIMITATION

The constants used in design program would be best for the ranges of values are given below:

For three phase induction generator, electric loading can be varied from 15000 A/m to 25000 A/m, magnetic loading can be varied from 0.45 wb/m^2 to 0.6 wb/m^2 and efficiency be 85% to 94% and finally output will be from 2000 watts to 35000 watts. For single phase induction generator, electric loading can be varied from 2500 A/m to 4000 A/m, magnetic loading can be varied from 0.40 wb/m^2 to 0.55 wb/m^2 , efficiency will be 48% to 58% and output will be from 50 watts to 80 watts [2], [3] [4].

Outside the range, previously stated, the design parameter would not be best and some parameters value would be get abnormal. The optimization function 'fminsearch' is used in our program and this is the best for solving nonlinear unconstrained multivariable optimization problem. Also have others optimization function as like as 'fminunc', 'fminbnd', 'fmincon', 'fminimax' . In 'fminunc' function gradient is needed. In 'fminbnd', function is only for one variable, In 'fmincon', function constrained is needed, In 'fminimax' multiple equation is needed, [5], which are impossible for our program.

7. POSSIBLE FUTURE WORK

The Method of Boundary search along active constraints and Han-Powell methods can be applied for optimization. The Fuzzy Logic Toolbox can be applied for optimization. The constants used in program can be varied. BFGS Quasi-Newton (no gradient provided) method can be applied for Optimization [5].

8. CONCLUSIONS

As an alternative source micro-hydro and wind energy conversion system may be the great sources to mitigate the power crisis in our present trends of power condition. So main part of the micro-hydro and wind energy conversion system Induction Generator design is the prime issue in this paper. Based on multiple objective functions and constrains the step by step design process of the Induction Generator is carried out and imposed one optimization technique. By simulating the design program in MATLAB, we get traditional output and optimized output. Both of them are compared and we get an encouraging result.

Here it is to be noted that we use here only one of the optimization technique but it can be used other existing methods also, which will really be helpful to find out, which one is the best optimum design. Obviously we get a satisfactory result in our simulation. It can be conclude that optimum design is the best solution for design because it gives optimum output such as maximum efficiency and minimum cost of the generator.

9. REFERENCES

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