Computer-Aided Design of Synchronous Machine Toolkit (GUI) using MATLAB

[1]Lokesh Wasanker*, Department of Electrical Engineering, University Institute of Technology, RGPV, Madhya Pradesh*

[2]Ayush Mamgain*,Department of Electrical Engineering, University Institute of Technology, RGPV, Madhya Pradesh*

[3]Garima Singh*,Department of Electrical Engineering, University Institute of Technology, RGPV, Madhya Pradesh*

[4]Ira Dwivedi*,Department of Electrical Engineering, University Institute of Technology, RGPV, Madhya Pradesh*

[5]Vidhi Singh*, Department of Electrical Engineering, University Institute of Technology, RGPV, Madhya Pradesh*

Abstract
With the advent of technology, many designers, academicians and researchers have been intrigued about the role of computers in the design of electrical machines. More aspects of the design process can be assisted by and taken over by computers as processors get more powerful. It is a common strategy to formulate the design of an electrical machine, or parts of it, as a multi-criteria optimization problem since the goal in designing electrical machines is to have a device that operates at the maximum possible performance, with the help of computervariable design parameters can conveniently be used for arriving at an optimum design.The Computer-Aided Design eliminates the tiresome and lengthy calculations and accelerates the process of designing. This work aims to eliminate the complications involved in the manual hand calculations of designing the machines, by using computerthe selection of most suited data can be used to get the optimum design.To give it an aesthetic look Graphical user interfaceare made in thein-built App Designer of MATLAB.
Keywords:*GUI, Computer-Aided Design of Electrical Machine, MATLAB, Optimization*

I. INTRODUCTION

Numerical techniques are used across the board in research and engineering to analyze complex problems.The highly mathematical nature of the discipline and its strong association with computer science, however, makes electrical engineering particularly suited to computational solutions. Professional engineers also employ the computers themselves to aid in their own design (a process known as bootstrapping,). In fact, the development and enhancement of software tools to allow the implementation of immensely complicated designs is the prime objective of the entire discipline of computer-aided design (CAD). It is the responsibility of a designer to model and simulate designs as much as we can before they are manufactured to obviate defects and reduce the number of iterations required to create the final product. On similar lines, this work is aimed to alleviate human intervention and to achieve optimum design in minimum possible time. The toolkit will be a reliable software to perform complex calculations required for designing various electrical machinery.

II. DESIGNING THE TOOLKIT

The advantage of using computers is that it can carry out many calculations in a fraction of a second. However, to leverage this power, one needs to write a set of instructions i.e. a program or algorithm. Depending on the type of machine, an algorithm/program was formulated using the MATLAB software. Graphical User Interface (GUI) was designed for Synchronous machine using MATLAB App Designer. The GUI was later packaged as a MATLAB App.

Beginning with a literature survey, since Computer-Aided Design of Electrical Machines is a relatively avant-garde approach of the conventional Design of Electrical Machines, the literature survey was aimed to provide a bird's eye view on the research done so far in the field of interest. Several textbooks & journals served as the basis for the theoretical and conceptual framework; these previous works also discussed numerous conflicts and challenges experienced by machine designers and are vital sources of programming techniques.

There is a market gap for software that allows a user to customize a product to their own tastes. As a result, the need to create more user-friendly tools arises that would demonstrate simple modifications to parts of a machine or the machine as a whole at the click of a button.

There are broadly two methods of Electrical Machine Design — Analysis Approach & Synthesis Approach. The latter approach has been utilized during the course of this work.In this method, the computer is used only for the purpose of analysis and reference. If the design is not satisfactory, the designer can manually make other suitable choice of the parameters to recalculate the performance. Various Objective Parameters/Functions in an Electrical Machine are:

(a) Higher Efficiency

(b) Lower weight for given kVA output (Kg/kVA)

(c) Lower Temperature-Rise

(d) Lower Cost

(e) Any other parameter like higher power factor for induction motor, higher reactance etc.[4]

III. MACHINE DESIGN & GUIs
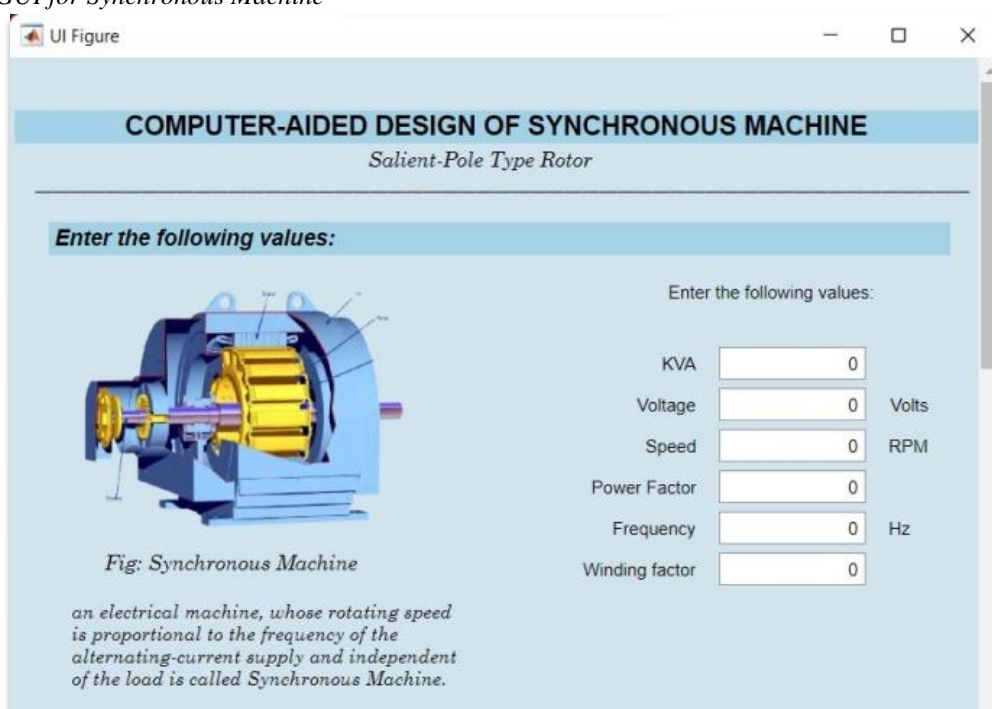
A.   *GUI for Synchronous Machine*

Figure 1 |GUI for Synchronous Machine

The proposed GUI toolkit allows the designer to choose any arbitrary set of variables to analyze the performance, cost, magnetic loading and other deciding factors.Data Sheet/Reference is also provided for choosing suitable values of variables like Specific Magnetic Loading (B_{av}), Specific Electrical Loading (a_c), Ratio of core length to pole pitch etc. depending on the machine. The Data Sheets serve as a guide for the machine designers in order to easily achieve optimum design &swiftly undertake iterations instead of repeatedly referring textbooks.

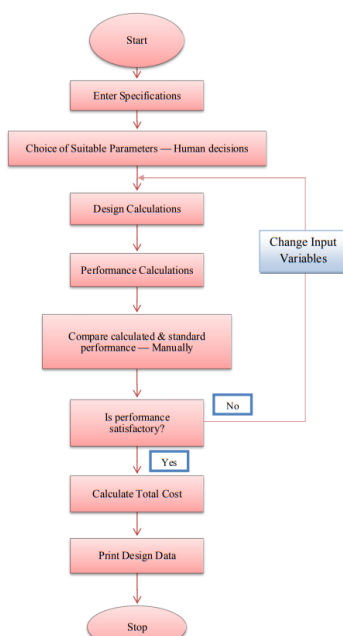The flowchart followed for the overall design of electrical machines is shown in figure 2.

Figure 2 | Overall Design Flowchart

B. COST ANALYSIS

The final step in the design is Cost/or Economic Analysis. A simple cost model has been developed that allows the calculation of various costs viz. material, labour, etc The model has been normalized as a function of weight of components in order to accommodate different power ratings and sizes. The simplest case is when the cost of the component in question is a direct function of its size/weight; then cost is simply the product of its specific cost/market price ($\square$/weight or size) and the weight or size.

The Electrical Machine is broken down into its main constituting elements, the cost of each element as per current market prices are determined and related to a simple yet significant parameter such as weight (in kg). The selling price is worked as under-

The cost of the complete machine is determined by adding the individual element costs plus the cost of assembly, testing, labour, factory overhead, etc.

COST ANALYSIS

Selling Price = Cost of Production + Profit

Cost of Production = Prime Cost (Directmaterial cost + Direct Labour cost + Direct Expenses)+ FactoryOverhead/Expenses

IV.RESULTS

The three-phase synchronous machine is a doubly - excited AC machine also known as alternators synchronous generators, and are universally employed for the generation of three-phase power.

A D.C source is always used to power the field winding. Synchronous generator's armature winding provides A.C power to external circuits, while synchronous motors import A.C power. With the aid of the prime mover, the rotor of synchronous generator is turned. Under steady-state condition, the frequency of the armature currents and the quantity of field poles determine the synchronous machine's speed.

Synchronous machines are rotating devices that revolve at a pace determined by the supply frequency and the number of poles, and the speed at which they do so is known as synchronous speed.

Synchronous machines, in general, are classified as: **Synchronous generators** are the synchronous machines that are driven by steam or hydraulic turbines and generate electricity.

Synchronous motors are the machines that work on general power supply networks at 50 Hz, 60 Hz and sometimes at 25 Hz too. They are also used in constant speed drives for compressors, blowers, etc.Synchronous motors operating at a leading power factor are Synchronous Compensators, which provide reactive power to a network of power systems.

Specific electric loading for water wheel alternator is given as $a_c = 20,000 - 40,000$ ampere-conductor per metre of periphery. Specific magnetic loading in air gap is between 0.8 to 1.0 T for water wheel alternators.[2]

The flowchart followed for the overall design of synchronous machines is shown in figure 3.
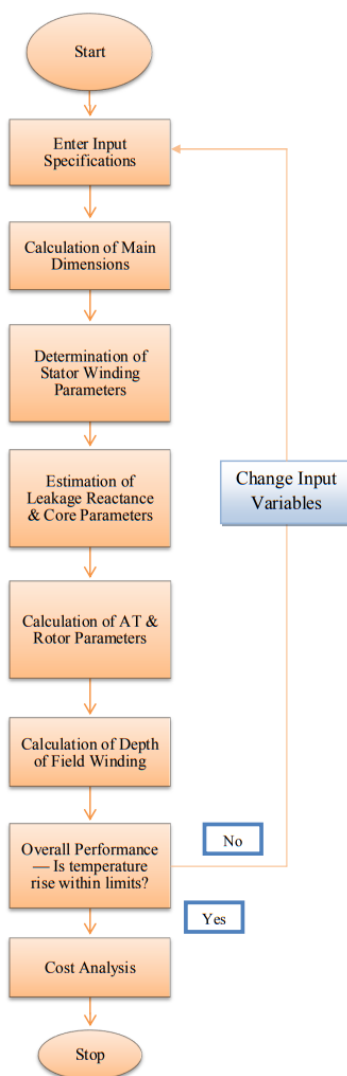
Figure 3 | Flowchart for Synchronous Machine Design

The synchronous machine GUI enables the user to calculate the following parameters:

Stator main dimensions: peripheral speed, kW input to motor, pole pitch, number of poles, flux per pole, conductors per slot, phase current, slot pitch, turns per phase, number of stator slots, slot loading.

Design of stator winding and reactance calculations: conductor area of CS, number of teeth under pole arc, tooth width airgap, slot width, conductor thickness, height of slot, mean length of turn, stator winding resistance per phase, D.C copper loss, weight of stator copper, average loss factor, eddy current losses, total copper losses in stator winding at 2.3 mm length per pole pitch and 3 slots per pole per phase, 9 ventilating ducts, 10 mm width of ventilating ducts and 0.9 as the iron factor.

Leakage reactance and core parameters: specific permanence of slot,slot leakage flux, leakage factor, over hang leakage flux, total leakage flux, leakage reactance, flux in core, depth of core, outer diameter of core.

Rotor and ampere-turn calculation: AT per pole, airgap flux density, rotor diameter, axial length of pole, iron length of pole, flux in pole body, area of pole, width of pole.

Depth of field winding: depth of field winding, height of field coil, depth of rotor core, weight of rotor, height of the pole.

Losses and efficiency: total losses, efficiency, field current, number of field winding turns, resistance of field winding, weight of field copper, brush loss at slip rings, total field copper loses, exciter losses, friction and windage losses, iron losses in teeth, mean diameter of stator core, weight of core, total iron losses, total losses at rated load.

Temperature - rise and weights: temperature rise in stator and field winding, copper losses in slot portion, total losses dissipated by stator core surface, weight of total copper, weight of active iron, weight of total active materials.

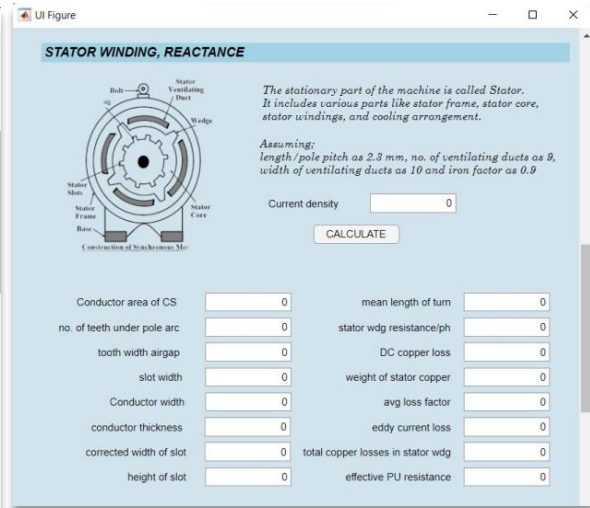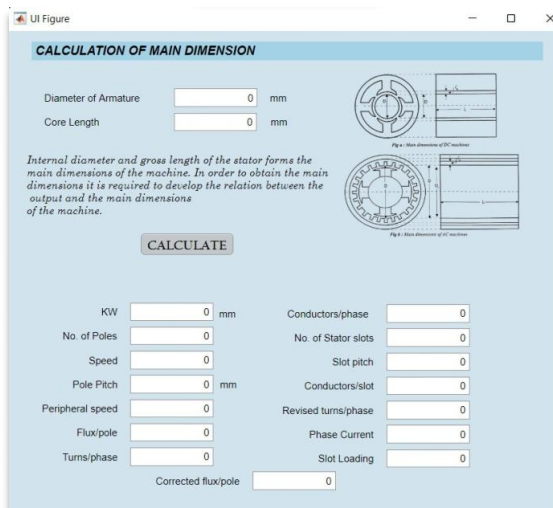**Economic analysis:** prime cost, cost of production, selling price.

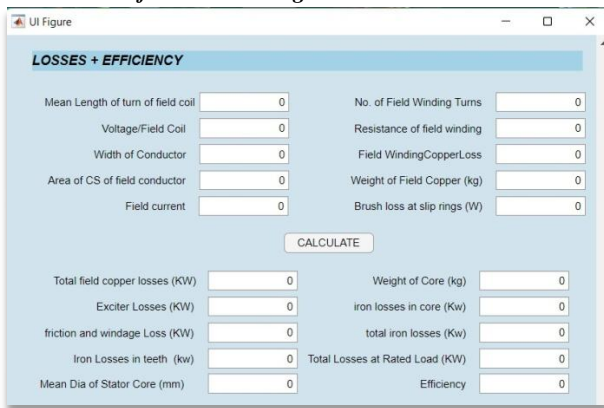**Figure 4 | Main DimensionsFigure 5 | Calculation of Stator Winding Parameters**
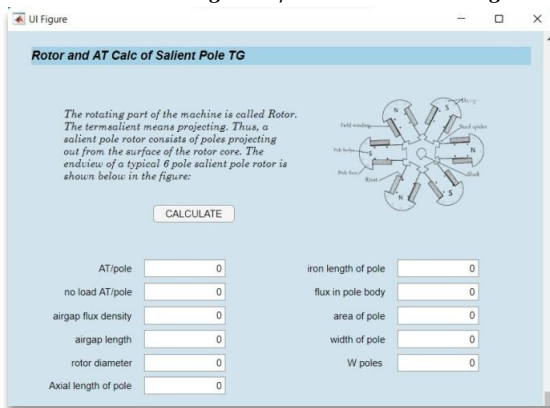

Figure 6 | Calculation of Rotor Parameters & AtsFigure 7 | Overall Performance
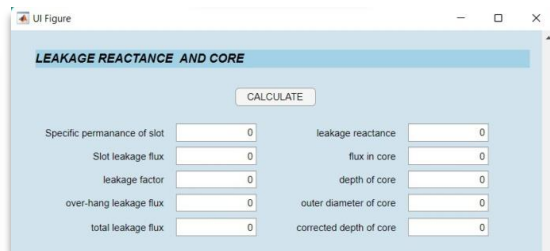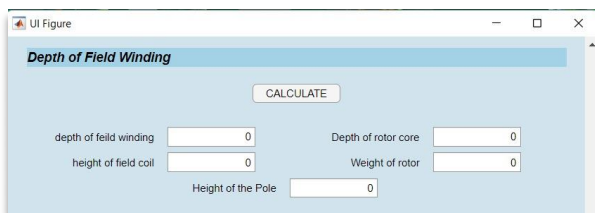

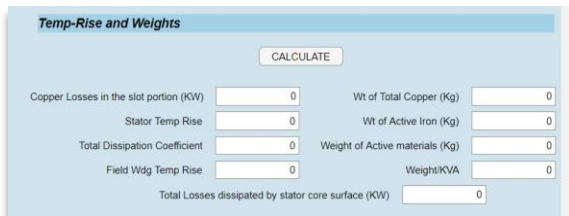**Figure 8 | Depth of Field WindingFigure 9 | Leakage Reactance & Core Parameters**

Figure 10 | Temperature-Rise & Weight CalculationFigure 11 | Cost Analysis

IV. CONCLUSION

Graphical User Interface (GUI) was successfully designed and was found to be fully functioning. Design parameters and results were corroborated by performing manual calculations. The Toolkit was eventually packaged as a MATLAB App. Such apps can be utilized not only in industrial applications but also in educational institutions to provide holistic and pragmatic ways of teaching Computer-Aided Design of Electrical Machines. The toolkit provides a great amount of flexibility and success in designing an electrical

machine not only from the limited available information/specifications but also in a short span of time. To complete the designing procedure of Synchronous Machine, the toolkit enables the designer predict the machine's overall expenditure.

ACKNOWLEDGEMENT

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