Design Problems for Machines and Transformers

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OBJECTIVE

This project is meant to develop design problems for the different type of DC, Synchronous, and Induction machines as well as Transformers. The design problems have to be well selected and implemented within the capacities of Junior (300-Level) students.

Background

DC Machine: it is an electric machine that links between an electrical and mechanical systems. It transforms energy from electrical to mechanical or vice versa. The direction of the conversion defines the name of the machine as a motor that produces mechanical energy or a generator that produces electrical energy. The design ideas of the DC machine are all about controlling the speed of the motor. There are several types of DC motors one of them is the DC shunt motor. The speed of the shunt motor can be controlled by varying the armature resistance, the field resistance or the terminal voltage.

Induction Machine: it is an AC electric motor in which the electric current in the rotor is being produced by induction rather than physically connecting the wires(brushless). The three phase induction motor is the most widely used. Almost 80% of the mechanical power used by industries is provided by it because of its low cost, simple construction and reliability. The design idea for this machine is about controlling the speed by varying the terminal voltage.

Synchronous Machine: it is an AC rotating machine whose speed under steady state condition is proportional to the frequency of the current and the number of poles of the machine. It's most commonly used as a generator. The design ideas for this machine is about synchronous condensers and rotary converters of frequency. The synchronous condenser is a synchronous motor that operates at no load which makes it produce reactive power just like capacitor banks. The rotary conversion is achieved by connecting a motor with a specified number of pole to a generator with a different number of poles to produce a different frequency depending on the synchronous speed given by the motor.

Transformer: it is an electrical device that transfers energy between two circuits through electromagnetic induction. A transformer may be used as a safe and efficient technique to change the AC voltage at its input to a higher or lower voltage at its output. Other uses include current conversion, isolation with or without changing voltage and impedance conversion. The design ideas for the transformer were about voltage matching using step-down or step-up transformers and avoiding electric false consequences.

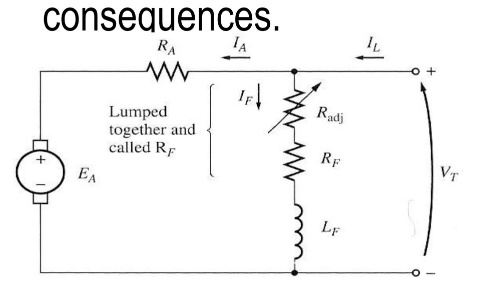


FIGURE 1: EQUIVALENT CIRCUIT FOR DC SHUNT MOTOR.

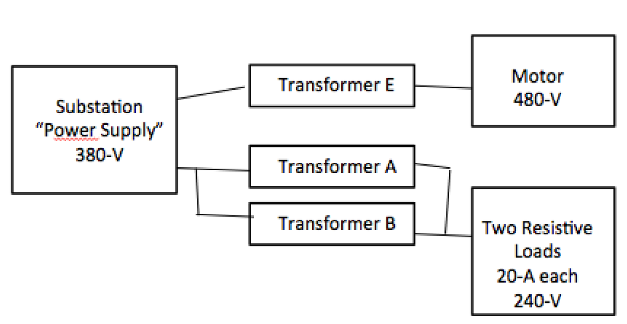


FIGURE 4: ANSWER FOR QUESTION 5, PROJECT CIRCUIT.

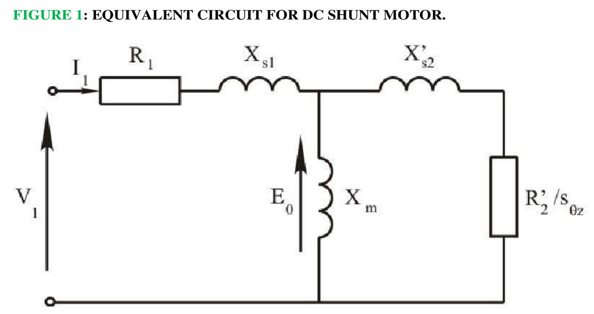


Figure 2: Equivalent circuit of the induction motor

Synchronous Machine

Power Factor correction:

The student will be given a factory with a certain load and a low power factor. He will be asked to improve the power factor using either one of two available tools and compare between their cost and how much saving each method will save and choose the one that saves the most. The first one is a synchronous condenser and the second is a capacitor bank. The tariff in this question is based on the KVA/hour that the factory consumes to charge for the low power factor and give the factory an incentive to improve it's power factor to acceptable range. The cost of each tool will be provided and their fixed cost.

The goals of this design problem is for the student to see a real life application of the synchronous machine and learning how to choose the best of the available options based on their economic analysis.

Rotary Frequency Converter:

A factory with a certain load is running on a diesel engine with a specified rating and this factory is running on 50Hz. The power network around this factory is working on 60Hz. The student will study if it's better for this factory to change it's power resource and start taking it from the power network instead of the diesel engine. The factory will need two synchronous machines one motor and one generator. The idea is for the two connected machines to have the same synchronous speed but with different frequencies. This is done by changing the number of poles of each machine.

$n_s = \frac{120f}{p}$.

The following figure3 shows the connection of the rotary frequency converter.

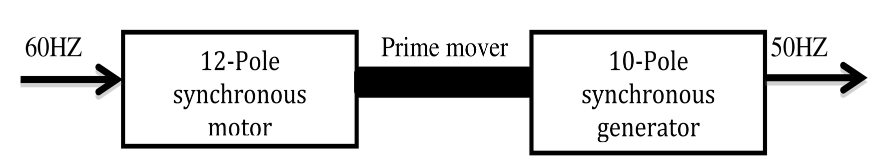


Figure 3: Connection of 60/50 Hz rotary converters.

The student will make an economical comparisons between the two possible ways to get the power based on the operational cost and the fixed cost of the two methods and the life cycles of the two. The goal of this design problem is to show another new way to use the synchronous machines and to make its characteristics work to our advantage and to show how every new path a company or a factory decide to go through is always decided after doing a feasibility study.

DC Machine

DC Shunt Motor Speed Control:

The student will be given certain specifications of a DC shunt motor. He will be asked to control the speed of the motor using the three different control parameters in order to achieve a specified speed. In order to do so he has to use each parameter individually which are field resistor, armature resistor and variable voltage. Also, the student will do a cost analysis to see which parameter will the best choice cost wise. The shunt dc motor has fixed speed applications such as automotive windscreen wipers and fans.

Short Compound DC Motor Speed Control:

A company wants to increase its elevator speed which is a short compound DC motor. The company is also has a budget that can not be exceeded. So, the student is required to design the motor with the given specification in order to reach the speed that need while putting in mind the budget that he has. The short compound DC motors are inexpensive to manufacture and are used in variable speed household appliances such as sewing machines and power tools. Its high starting torque makes it particularly suitable for a wide range of traction applications such as elevators.

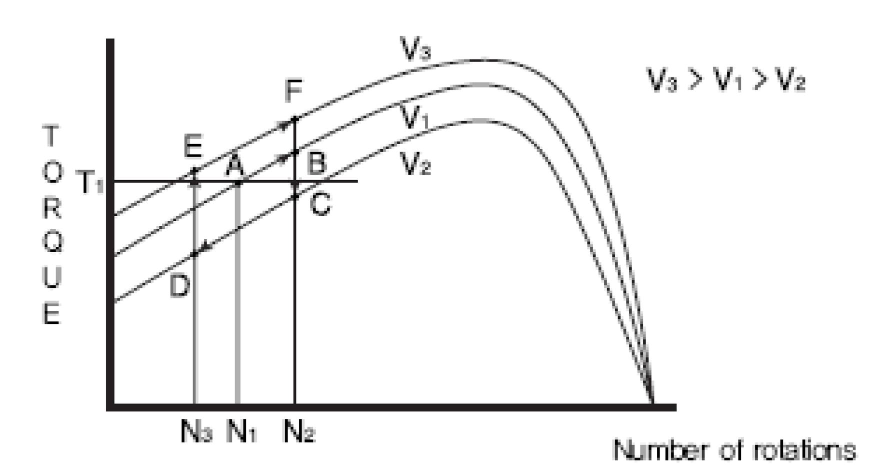
Induction Motor

Controlling the Speed of an Elevator System:

It is very important to control the speed of induction motors in industrial and engineering applications. An example of that is an elevator system.

An electric elevator in a hospital is using a 3-phase induction motor with the need specifications and parameters. We want the elevator to move up and down with a high speed smoothly. We want the student to control the mechanical speed of this elevator by changing the line voltage to obtain a speed in the range of +10% and -10% of the initial speed. The initial speed is given as the full-load speed.

The goal of this idea is to give the student the ability to adjust the speed of induction motors as required by any certain application by manipulating the supply voltage. The speed at different line voltages is shown below



(Fig. 4)

Transformers

Voltage Matching Using Step-down or Step-up Transformers

380-V substation feeds two loads in parallel. The first load is an induction motor (10 hp, 480-V, 3-phase, 0.85 lagging p.f, and 90% efficiency), and the second one consists of two 3-phase resistive loads (each requires 20-A, 240-V). [8][14]

It is required to connect the best combination of transformers between the substation and the loads.. There are *five* 3-phase electrical transformers available with different parameters.

#	A	B	C	D	E
Transformer kVA	9	9	18	9	9
Power Factor	0.85 Lagging				
Ratio V/V	380/240	380/240	380/240	380/480	380/480
Efficiency	90%	97%	90%	95%	99%
Cost (SR)	1100	1600	2800	1900	2300

- Design the best combination of transformers between the substation and the two loads. If one kWh costs 0.05 Saudi Riyals, and the operation time is 18 hours per day for 10 years.

Avoiding Electric Failure Consequences

13.8k-V substation feeds two loads in parallel. The first load is a hospital (200kVA, 380-V, and 0.8 p.f. lagging) in Dammam. The second load is a nearby Mall (80kVA, 380-V, and 0.9 p.f. lagging). In case of power interruption, 60% of the hospital rating (kVA) has to be maintained for Intensive Care units, and 20% of the Mall rating (kVA) has to be maintained for evacuation. In this project, it is required to find the low-cost suitable connection of transformers and back up generators between the substation and the two loads. Ignore fixed and operation costs.

Transformer #	Ratio in V/V	Power Factor	Rating in kVA	Efficiency	Quantity	Each Costs in SR
A	13.8k/380	0.95 lagging	150	98%	2	800,000
B				93%	2	730,000
C				90%	2	700,000
D			300	98%	1	1,450,000

Generator #	Power Factor	Rating in kVA	Efficiency	Each Costs in SR
A	0.90 Lagging	150	90%	200,000
B			93%	350,000
C			98%	450,000

- Design (1), select two transformers to be connected between the 13.8k-V substation and the 380-V two loads, taking into account that if one of the transformers interrupts, the other must recover the amount of kVA needed for emergency.
- Design (2), select one transformer and an back-up generator from the tables, so that the transformer would run all time unless it fails.
- If the failure rate consumption of the two loads is 323 hours per year, the cost of one kWh from the 13.8k-V is 0.05 SR and from the chosen generator is 0.08 SR. Calculate the total cost for design (1) and design (2) after 25 years, and comment on your results.