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Self Excitation in Induction Motor

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I am Salsabil Binte Islam, an undergraduate student in Electrical Engineering at University of Idaho. My academic interests include electric machines, renewable energy systems and power electronics. I have been conducting research under supervision of Dr. Herbert Hess on self excitation characteristics and laboratory applications related to DFIG based energy conversion.

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Herb Hess is Professor and Chair of Electrical and Computer Engineering at the University of Idaho. He received the PhD Degree from the University of Wisconsin-Madison in 1993. His research and teaching interests are in power electronics, electric machines and drives, and analog and mixed signal electronics, where he has written more than 150 technical and pedagogical papers. He is currently working on advanced specialized reluctance, inductance, and doubly fed machines and their electronic drives. His students have elected him to annual teaching awards eleven times. His papers have won several ASEE and IEEE awards. He has served in leadership pipelines in three ASEE divisions, where he is currently in his eleventh year as a Division Program Chair. He is a Fellow and a Life Member of the ASEE, though he has definitely not retired.

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Abstract

This paper represents an educational experiment designed to illustrate the principle of self-excitation in induction machines using a Type III Doubly-Fed Induction Generator (DFIG) system. In the setup, a three-phase induction motor which is here referred as Gold machine, was self-excited through a wye-connected capacitor bank with 66.7 μF per phase to provide the reactive power required for magnetization. Without an external excitation source, the machine was able to steadily function and build up voltage due to the generated reactive current. We operated the self-excited machine without a load and with a load.Through this configuration, students can directly observe how enduring magnetism, capacitor configuration, and how to run Induction motor by self excitation without using any extra power supply. The experiment provides a clear visualization of how reactive power supports self-excitation, and helpful for students to have hands on experience for the lab purpose.Instructors can use this configuration to effectively demonstrate the operations of induction generators in the classroom, which makes it a useful teaching tool for electrical machine and renewable energy courses.
Keywords— self-excited induction generator, induction motor, capacitor excitation, voltage regulation.

Introduction

To ensure reliable and autonomous electricity for remote houses or areas lacking grid connectivity, stand-alone power systems (SAPS) utilize renewable energy sources such as solar, wind, or hydro, in combination with battery storage and often a backup generator [1]. This enhances energy resilience and reduces dependence on traditional networks. In such system generators should be able to produce voltage and supply loads without relying on external grids. This plays a very crucial role in renewable energy system. A self-excited induction generator can generate its own terminal voltage both above and below synchronous speed; however, it produces real power to a load or grid only when operating above synchronous speed.

A self-excited induction generator's output is rectified and utilized to power DC loads like batteries, DC motors, or DC distribution systems in many stand-alone power systems. In these situations, the DC load appears as an effective resistive load on the generator's AC side. Thus, researching a self-excited induction generator coupled to a resistive load sheds light on how it behaves when providing useful DC loads.

In this research, a typical induction motor with a capacitor bank was used as a self-excited generator in a lab setting, and a three-phase resistive load bank was utilized to simulate a DC-equivalent load. As the electrical load was changed, the resulting voltage, current, power, and speed behavior were measured.

The goal of this study is to illustrate how a self-excited induction generator behaves when powering a DC-equivalent load and to explain how this system may be used as an easy and useful teaching experiment. This method enables students to investigate self-excitation, voltage regulation, and load-dependent speed behavior in a safe and convenient laboratory environment using just common lab equipment. The laboratory setup is meant to substitute for a conventional DC generator experiment, and the measured load-speed and power characteristics are explained using a DC generator analogy for educational purposes, even though all measurements and power flow in this experiment are fully AC.

Theory of Self Excitation in Induction Motor

The main theory behind a self-excited motor is based on an induction machine that refers to the ability of the machine to generate voltage when it operates as a generator without being connected to an external electrical grid. Self-excitation refers to a closed-loop process that uses a positive feedback mechanism to return an electric generator's energy to the excitation stage in order to achieve the desired terminal voltage and, consequently, the desired output parameters under conditions of a relatively high amplification factor [2].

When the motor is connected to the source with the motor controller closed, a rotating magnetic field is created between the stator winding and the rotor winding of the induction motor in the air gap. This rotating magnetic field can be considered as stored energy. When the motor is turned off while still rotating, the stored energy in the air gap starts to collapse, creating a current in the rotor winding. This rotor current produces a voltage on the stator winding and the motor's unconnected terminals, causing the motor to behave as a generator [3].

The initial voltage needed to start the generation process is provided by the residual magnetic field; however, it is not sufficient to maintain the air-gap flux or terminal voltage. An external source of reactive power, typically provided by capacitors connected across the stator terminals, is required to achieve continuous voltage build-up.

This reference demonstrates the capacitor excitation phenomenon in the induction generator for off-grid applications [4]. An external continuous reactive power source provides the necessary excitation, and for this purpose pre-charged capacitors are typically used. Two requirements must be satisfied for the induction generator to operate as a self-excited generator in off-grid mode: (i) the rotor must operate above synchronous speed, meaning the slip is negative; and (ii) the stator must be connected to a properly rated pre-charged capacitor bank to supply the required reactive power.

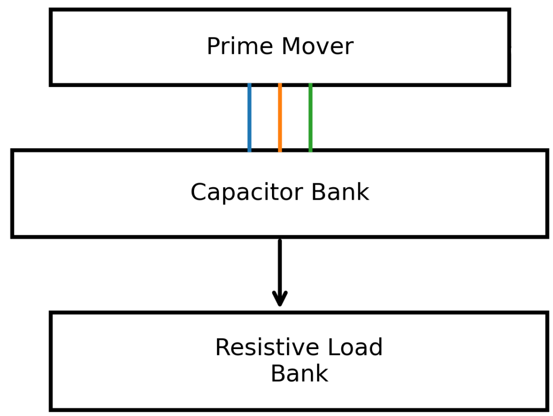

Figure 1: Block Diagram of Machine Setup

Experimental Setup

The experimental results in this study were achieved using a doubly-fed induction generator (DFIG) accessible in the laboratory, even though the self-excitation theory applies to induction machines in general. The experimental test bench was created by mechanically coupling two induction machines on the same shaft. The Silver machine, a Type III doubly-fed induction generator (DFIG), was used to track mechanical and electrical values throughout the test, while the Gold machine, a three-phase induction motor, served as the self-excited generator. Regulated excitation and measurement were made possible by the mechanical connection, which guaranteed that both machines rotated at the same speed.

A 66.7 µF per phase wye-connected capacitor bank was applied to the generator side of the coupled system to enable self-excitation. The capacitor value was selected experimentally to achieve stable voltage build-up during self-excitation. As we observed during the preliminary testing a delta-connected capacitor bank caused imbalanced voltages and audible mechanical noise, we decided to stay with wye-connected for full experiment. A three phase resistive load bank was connected across the stator terminals in parallel with capacitor bank to allow for controlled loading self excited generator.

The Silver machine acted as the prime mover and controlled the shaft speed, while the Gold machine operated as the self-excited induction generator. The Silver DFIG, which gave access to both stator and rotor electrical parameters, was the main tool used to measure voltage, current, power, and speed. This arrangement allowed for the observation of the terminal voltage's rise, stabilization, and decline during self-excited operation.

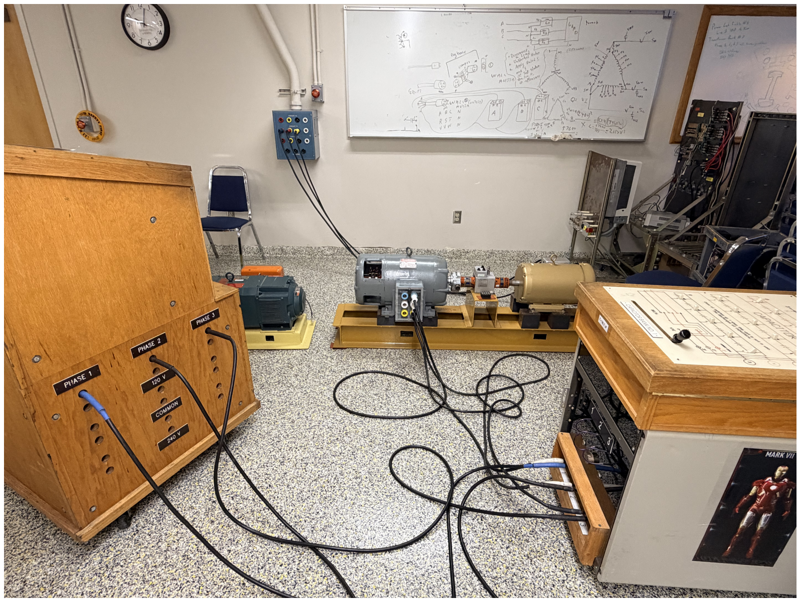

Figure 2: Complete self-excited induction generator laboratory setup

How Machine worked

When the capacitor bank was connected and the rotor speed was above synchronous, the induction machine started operating as self excited generator. As the voltage at the stator terminals increased, electricity was sent to the attached load, which in this case was a three-phase resistive load bank that represented the AC-side equivalent of a rectified DC system.The ultimate terminal voltage, current, and power output were determined by the interaction among the generator, the capacitor bank, and the load.

The output of a self-excited induction generator is typically rectified and connected to a DC load via a DC-DC converter in useful stand-alone applications like battery charging. In this setup, the generator's AC side receives the DC load as an adjustable resistive load whose value is determined by the converter duty ratio. Thus, how this effective AC resistance affects voltage build-up, power extraction, and stability can be used to examine the interaction between the DC load and the self-excited generator [5].

The connected load receives electrical power from the stator terminals when the self-excited induction generator generates voltage. In this experiment, the machine's actual power is absorbed by a three-phase resistive bank. The rotor's mechanical input generates this real power, which is then transformed into electrical power via electromagnetic torque. The more the load increased , the more current was drawn from stator. If the load becomes too large, the speed decreases below a critical value, the voltage collapses, and self-excitation is lost.

Due to this feature, a standard induction motor, capacitor bank, and resistive load can be used as a stand-alone laboratory experiment to replace conventional DC generators.Students can simulate various DC power demands, such as light charging, heavy charging, or overload circumstances, and see how self-excitation and voltage regulation react by changing the load resistance. In real-world systems, a resistive load bank would be replaced by a rectifier and DC-DC converter. However, the laboratory arrangement offers the same electrical behavior as a real DC load system because these converters reflect an equivalent resistive load to the AC side [5].Here capacitor sizes control the reactive power generation and hence the voltage of the generator while the resistive controls the output real power. This separation will allow student to independently study excitation and loading effects. Students can vary load and observeve the self excitation in lab through this process.

Results and Discussion

The generator's terminal voltage, current, and output power fluctuated with rotor speed and load during self-excited operation. The measured electrical quantities for various operating circumstances are displayed in Table 1.

The output power delivered to the load dropped from around 4.9 kW to 2.03 kW when the rotor speed climbed from about 1645 rpm to 1767 rpm, while the stator current dropped from roughly 21 A to 11 A. This result suggests that the generator was able to run faster and closer to no-load circumstances due to a decrease in effective electrical loading. In the meantime, we observed the stator voltage was comparatively steady around 233–235 V, indicating that the capacitor bank kept the excitation level constant despite changes in the load.The most significant finding was that the self-excited induction generator performed similarly to a DC generator serving a varied load since the rotor speed rose when the load was decreased.

This structure corresponds to the behavior of a DC-load via a rectifier and converter interface. stronger stator current, stronger electromagnetic torque, and more real power extraction are the outcomes of a lower effective AC resistance, which is correlated with a bigger DC load. The generator used less torque and produced less electrical power when the DC-equivalent load was decreased, which allowed the rotor speed to rise [5].

A delta-connected capacitor bank generated imbalanced phase voltages and audible mechanical noise during first testing. For all final trials, a wye-connected capacitor bank was employed to increase stability. Compared to delta arrangements, wye-connected capacitor banks are less susceptible to imbalance and electrical stress because they operate at lower line-to-neutral voltages and provide a neutral reference [3].

This experiment served as a teaching vehicle for one-on-one individual instruction on a self-excited induction machine. The student (this paper's first author) received a few classroom lessons in induction machines. She had no prior laboratory experience with induction machines. Before this self-excitation experiment and under the guidance of an experienced instructor (this paper's second author), she set up and tested a squirrel cage induction motor with a fixed frequency, fixed voltage source. In so doing, she learned the basics of induction machine behavior, modeling, and performance. She then used the Silver induction machine, a doubly fed induction machine, to expand her understanding of induction machines as generators, indeed

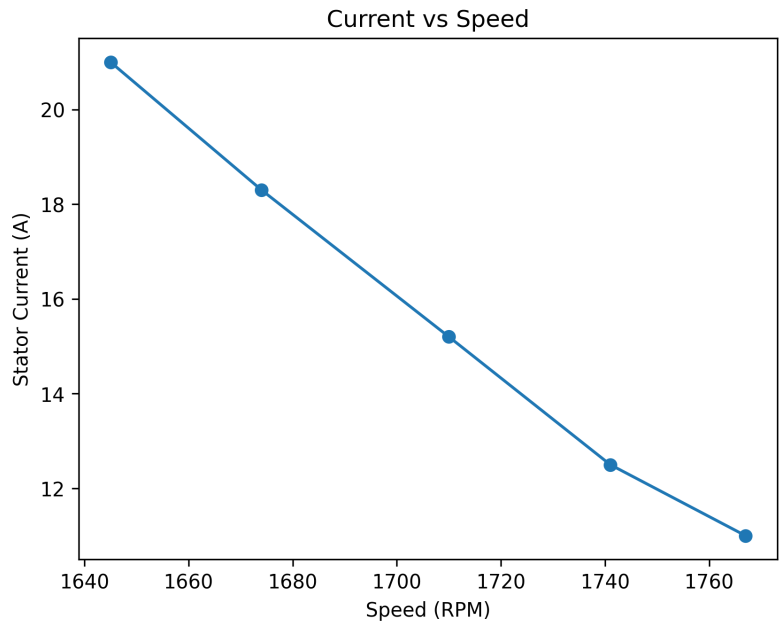

Figure 3: Current vs Speed Curve

Table 1: Self-excited induction generator supplying a DC-equivalent load.

Speed (RPM)	Terminal Voltage (V)	Stator Current (A)	Output Power (kW)
1645	233	21.0	4.9
1674	234	18.3	4.2
1710	234	15.2	3.5
1741	234	12.5	2.7
1767	235	11.0	2.03

as controllable generators. As this point, she began the experiment described in this paper. She configured the Silver (doubly fed) induction machine as a drive motor directly coupled with the Gold (self-excited) induction machine as a generator with a parallel capacitor bank and a parallel resistive load bank. From what she learned in this progression, she then wrote this paper. As a final examination, an industry partner asked for help with detailed modeling and performance evaluation of the Silver doubly fed induction machine. She designed and connected the entire performance evaluation experiments, advising the industry partner on all pertinent aspects of induction machine performance. The industry partner used the data that he gathered for design of protection algorithms for Type III wind turbines. So far, this instruction has been one-on-one between the two authors. This paper serves as evidence for the reader to determine the effectiveness of this method of learning induction machines in the manner described.

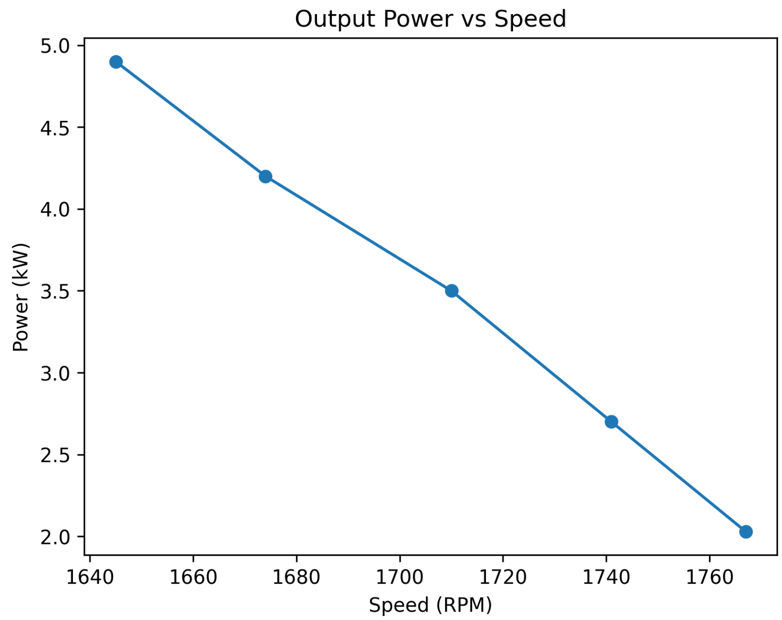

Figure 4: Power vs Speed Curve

Educational Implementation and Assessment

The participant in this pilot laboratory study was the first author of this paper.

i.Implementation in Course :. The experiment was conducted out as a learning evaluation to evaluate the students' conceptual understanding of how induction machines work.The student was exposed to steady-state induction motor operating in the classroom prior to the lab. The purpose of the activity was to evaluate whether a self excited induction generator improves the understanding of concept compared to conventional motor testing laboratories.

The student put the generator system together in the lab by joining the resistive load bank, capacitor bank, and induction machine and observed voltage climbed, stabilized, and collapsed under various loading scenarios. This activity placed a strong emphasis on direct observation of energy conversion mechanisms and operating modes, in contrast to standard machine laboratories that mostly concentrate on efficiency and comparable circuit parameters.

ii.Learning Outcome :. During the experiment, the student saw that when rotor speed exceeded synchronous speed and capacitive reactive power was applied, terminal voltage generated without the need for an external electrical supply. The student also got to understand residual magnetism in initiating voltage build up.

The student distinguished motor operation from generator operation and explained rising electrical load increased stator current and electromagnetic torque while decreasing rotor speed.The student estimated that self-excitation would be lost due to insufficient reactive power when excessive loading resulted in terminal voltage fall.The experiment resulted in measurable improvement in the student's understanding of self-excitation behavior in induction generators.

iii.Student Assessment:. Before and after the lab exercise, the lecturer assessed the student to determine the level of their understanding. The student only connected externally excited synchronous devices with voltage generation before the experiment. After finishing the task, the student accurately described how induction generators need capacitive reactive power in order to maintain voltage generation.

Additionally, the student was able to estimate how the system would behave, such as increasing speed when the load was low and collapsing the voltage when the load was high. Measurably better conceptual knowledge of induction machine functioning is demonstrated by the capacity to describe and anticipate these operating conditions.

Conclusion

The study has confirmed that an induction motor can be used as self excited generator in lab. When it supplies a resistive load, it can also display DC-equivalent load behavior. This work has also demonstrated the fact that the capacitor primarily controlled the reactive power and generator voltage, while the connected resistive load controlled the output real power, current, and electromagnetic torque.The behavior of a DC generator delivering a varying load is consistent with the generator speed increasing and the provided power decreasing when the load was reduced.

Students can easily perform this in laboratory.Employing standard laboratory equipment, this approach will allow students to observe self-excitation, voltage regulation, and speed characteristics that depend on the load. The results indicate that, within a regulated laboratory environment, self-excited induction devices can serve as an effective educational resource for understanding DC power generation and renewable energy concepts.

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