UCD School of Electrical, Electronic and Communications Engineering

EEEN20090 Electrical Energy Systems II

Synchronous Machines

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Declaration

I declare that the work described in this report was done by the people named above, and that the description and comments in this report are my own work, except where otherwise acknowledged. I have read and understand the consequences of plagiarism as discussed in the EECE School Policy on Plagiarism, the UCD Plagiarism Policy and the UCD Briefing Document on Academic Integrity and Plagiarism. I also understand the definition of plagiarism.

Signed: Fergal Lonergan Date: 25/3/25

Acknowledgements

Summary

In this report I will explain the reason for which this lab was undertaken, explain the method used, present and interpret the results and findings and finally provide recommendations which I have drawn from undertaking the lab.

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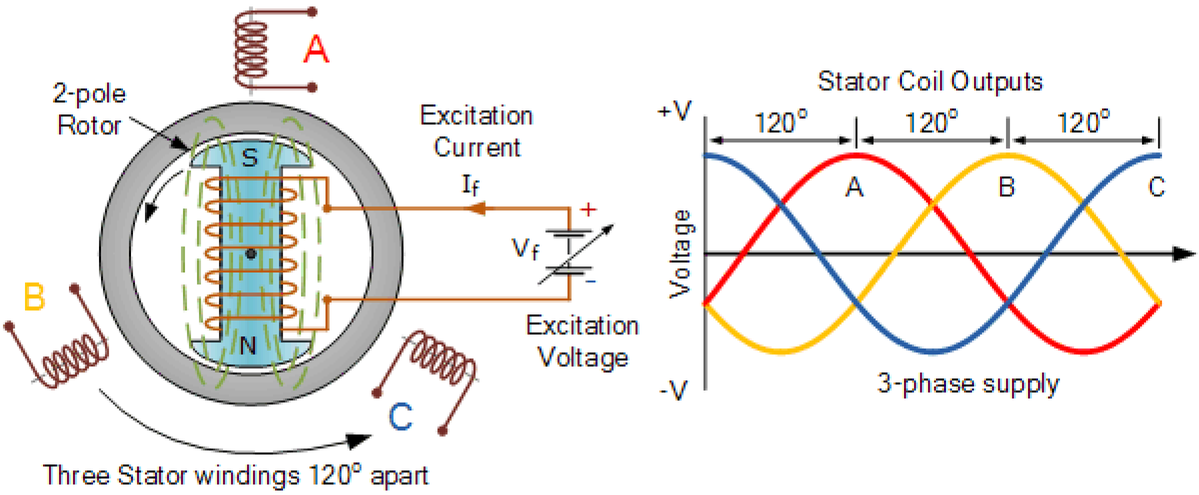
Introduction

In this lab we learned how a synchronous generator operates and also how it generates power for the power grid. We were tasked with first learning how the generator operates and how it can be controlled before we connected it to the synchronous machine and finally the grid, all the while learning how each machine can be manipulate in order to increase or decrease the power supplied to the grid as well as learning about what can go wrong and what factors vary when using these machines for power generation.

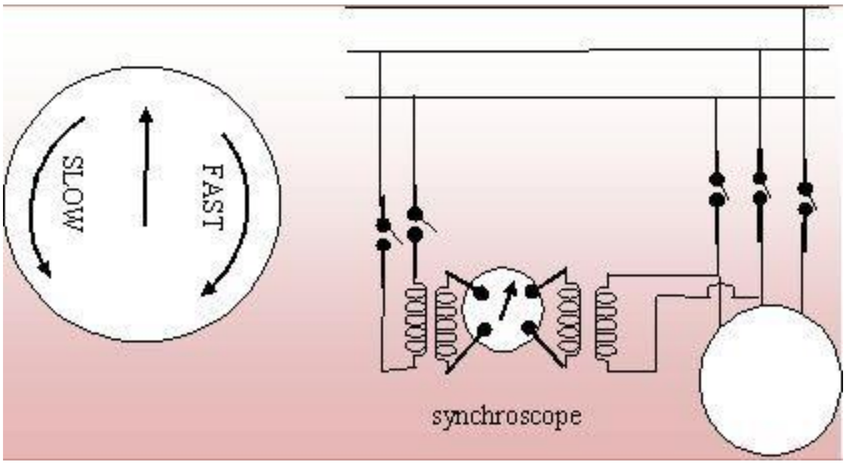
Generator

The generator is powered by a motor that can be controlled depending on the voltage and current put across it and ran through it respectively. This motor is joined to a stator in the generator by a coupling, the coupling which we will shine the strobe light on later. The stator then spins inside the generator where it is surrounded by a series of three different windings each separated by 60°, and so as the magnetic field of the stator forces current through ach of the windings they are each 60° out of phase with each other. This is what is meant by our three phase synchronous system. Our generator is a 6-pole generator as a result. A diagram shows the inside of the synchronous generator and more information about synchronous generators can be found by following one of the links in the references section.



Synchronous machines

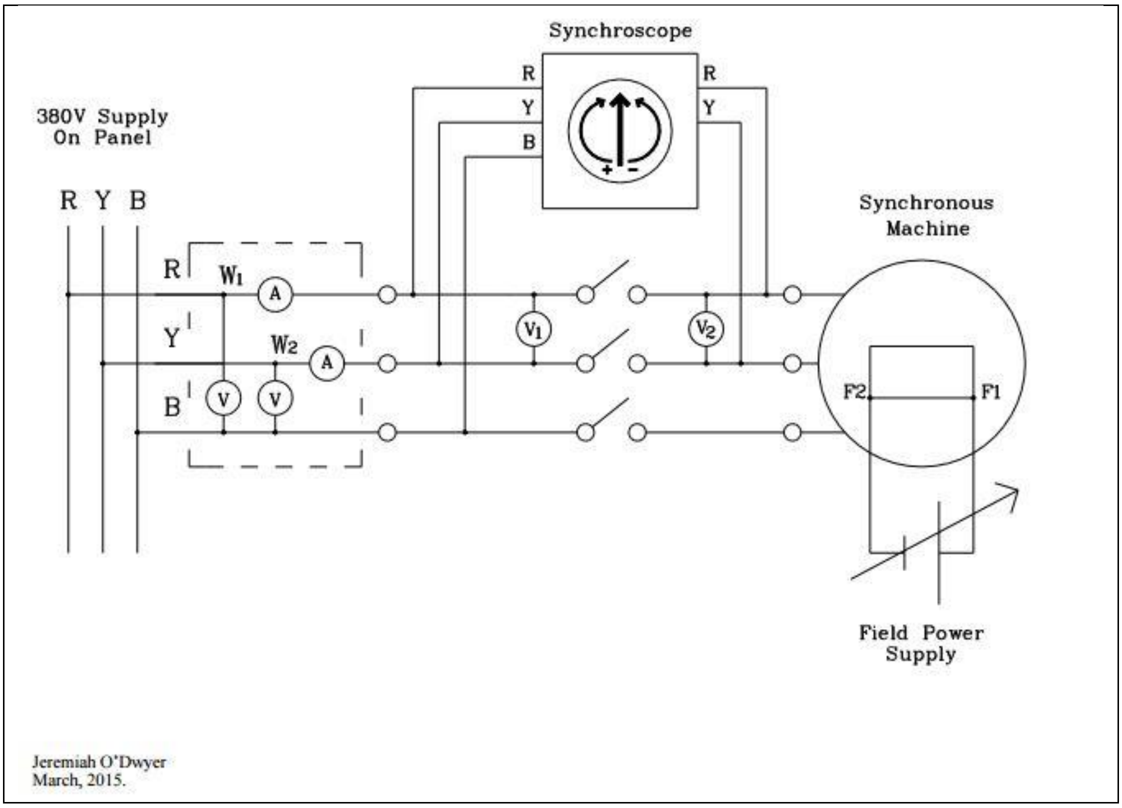
A synchroscope is a machine that measures the extent to how two systems phases are in sync with each other, in our case our synchronous generator and the mains. In order to supply power to the grid we must ensure that our systems are in phase otherwise we will have interference which will damage the quality of supply. Most our electrodynamic systems and rotate continuously depending on the magnetic fields applied to it before the two systems are in phase. When they are in phase the synchroscope then points at 12 o’clock as shown in the image below.



Procedure

Generator Controls

This lab was divided into three parts, the first of which involved learning how the generator works and how it can be manipulated in order to produce more or less power. Our initial setup involved connecting the circuit up as shown below with our Voltage input set at 300V, and our field current at 0.5A, which forced our frequency to be around 39.7Hz (the generator is connected to the synchronous machine by a coupling).



We then varied our voltage input in steps of 100V, by increasing our field current, and noted how the frequency and field current changed accordingly and also if there was any change in motor speed. Next we kept the field current in the generator constant and increased our input voltage in steps of 50V and noted how the speed of the motor increased as well as its voltage but that the current entering the motor remained relatively constant.

Synchronisation

After understanding the controls of the generator we moved onto part two of the lab and connected the synchronous machine up to the synchroscope before connecting our generator to the grid. The synchroscope points at a 12 o'clock position when the system is in phase. In order to do this we had to match the voltage and frequency of the grid to the voltage and frequency of our synchronous generator. Once matched the synchroscope keeps the synchronous machine and the grid in phase. We then manipulated the voltage input for our generator and the field current and recorded how these affect both the real and reactive power which our machine generated.

Stroboscopic examination

The final stage of the lab was a demonstration by a teaching assistant in which a strobe light was hooked up to the mains so it flashed at the same frequency as the current, around 50 Hz. Seeing as the motor was spinning at the same frequency as the strobe light being flashed onto it we note that the coupling between the motor and generator appears to be stationary even though we know it is rotating.

For more on procedure see EEEN 20090 Synchronous machines lab link in references section.

Findings (evidence)

Generator

We noticed that if we increased the field current entering the synchronous machine, whilst keeping the input voltage constant at 300V, that the voltage output from the machine would increase however the frequency of the generator and its voltage and current intake remained relatively stable. We then tried keeping the field current entering the synchronous machine constant at 0.5 A whilst increasing the voltage into the synchronous generator the frequency, voltage and current of the motor all increased respectively and thus increased the generated voltage Vout.

Table 1 changing field current to see how it affects motor speed

Voltage out (V)	Frequency of generator (Hz)	Field Current (A)	Voltage across motor (V)	Current through motor (A)
0	40.2	0	175	1
100	40.1	0.15	-	-
200	40.0	0.39	-	-
300	39.8	0.7	-	-
400	39.3	1.43	-	-

Table 2 Increasing the Voltage input to increase speed of motor

Voltage out (V)	Frequency of generator (Hz)	Field Current (A)	Voltage across motor (V)	Current through motor (A)
100	15.2	0.5	75	0.5
150	15.8	-	110	1
200	34.2	-	145	1
250	42.3	-	180	1
300	50.6	-	215	1

Synchronisation

In order to synchronise our synchronous generator to the mains supply we first had to ensure that both our generator and the supply were operating at the same frequency and voltage, approximately 50Hz and 380V in our case respectively. To do this we first manipulated our generator using the tools which we learned from the first part of our lab and matched them to the readings which we were receiving from the mains. Seeing as we had yet to close the switches connecting our synchronous generator to the mains our synchroscope was spinning round in a circle. The synchroscope points at 12 o'clock when the phases of both our generator and the mains our matched so we had to slow down the spinning of the synchroscope and then wait until it was pointing close to the 12 o'clock before we closed the switch and allowed our synchronous machine to hook up to the mains. It is very important that you both slow down the synchroscope and wait for it to be close to a 12 o'clock position as in order for the synchroscope to get our generator and the mains in

phase a significant amount of current is passed through the generator.
For the size of our generator this process is not as important as our generator is so small, however, on a larger scale generator the current needed to sync the phases would be so large that the magnetic force on a current carrying conductor "Bil" forces in the generator would be great enough to pull the windings out of shape and in doing so destroy the generator. Again had this happened in our generator the damages would not have been that bad as the windings are small as is the generator, however in a larger scale generator these windings increase these forces exponentially to the point where results would be catastrophic.
For most large scale generating plants they would have a system in place that would sync the generators to the mains autonomously in order to avoid these sort of occurrences.
We then as a test decided to sync two phases that we knew were 60° out of phase in order to see what happened and our synchroscope pointed at 2 o'clock, or in other words 60° on from what an in phase sync would show.
Finally we tried affecting a few factors such as the motor speed in order to see would this change and even though we increased the input voltage into the generator the motor's its speed, and voltage and current intake remained constant. What changed was the voltage across the coils which increased the current going through them. This allowed us to increase the torque of the motor and the power generated. In the table below we see how these factors affected our real and reactive power generated by the generator.

Table 3 Changing V input to affect power generated

Voltage input (V)	Real Power (Watts)	Reactive Power (Mvar)	Torque (Nm)	Actual Power (W)	Power generated (W)	Efficiency (%)
300	10	25	0.8	26.9	251.3	10.7
310	-245	-86	2.1	259.7	659.7	39.4
320	-515	-160	3.8	539.3	1193.8	45.2
330	-770	-290	5.4	822.8	1696.5	48.5
340	-1060	-495	7.1	1169.9	2230.5	52.5
350	-1300	-755	8.8	1503.3	2764.6	54.4
365	-1495	-1205	10.2	1920.2	3204.4	59.9

Results are negative due to meter. We are actually generating power.
We see unsing the $s^2=p^2+q^2$ formula we can get the actual power and then using the torque we can find the power generated and measure the efficiency of the generator. we notice that the generator is much more efficient when generating at higher levels than at lower levels (10.9%-59.9).

Table 4 Changing field current in order to manage the reactive power generated.

Field Current (A)	Reactive power (Mvar)	Vinput
0.5	-125	300
0.75	84	-
1	123	-
1.25	-290	-
1.5	-400	-

Real power does not change with a change in field current. This does not change frequency or voltage once in phase.

We see that the reactive power generated increases with the field current applied to the windings.

Stroboscopic examination

Finally during the stroboscopic examination we shone a light on the coupling joining the motor to the generator at a rate of 50 Hz and the coupling appeared to be stationary proving that the generator was rotating at a rate of 50Hz and so was generating electric power at the same rate as the mains. We also tried to increase and decrease different factors which affected the motors speed previously in the lab and noticed that this had no effect on the speed at which the motor spun. This was due to synchroscope keeping everything in phase.

We noticed that sometimes this frequency fluctuated slightly above or below 50Hz depending on the load vs generation of the system. If the load was above the level of power generated then the frequency would drop below 50Hz, if it was less the frequency would rise. It is important to maintain a steady supply in order to ensure that appliances do not malfunction, i.e. appliances can work between a certain range of frequencies but outside of this range they cease to work correctly.

Conclusions

From the results we have obtained above we can see that:

- In order to affect the generators speed one must increase the power going into the motor and keep the field current constant and that changing the field current has no effect on motor speed.
- We also know that in order to increase power generated one must increase the torque in the generator.
- The reactive power generated can be controlled by manipulating the field current.
- When syncing the synchronous generator to the mains one must wait for the synchroscope to be in or around the 12 o'clock point before closing the switch and also ensure that the voltage and frequency of both systems are the same.
- The generator and the electricity received from the mains are both in or around 50Hz.
- Another thing to note is that our generator was quite small however in a large generator if you add a significant amount of power to the grid you must also be very wary of the voltage as it may increase also.

References/bibliography/sources

EEEN 20090 course notes

EEEN 20090 Electrical Energy Systems II Synchronous Systems Lab
https://elearning.ucd.ie/bbcswebdav/pid-799368-dt-content-rid-3842466_1/courses/EEEN20090/SynchronousMachine_Lab_EEEN20090.pdf

Three phase synchronous generators: http://www.alternative-energy-tutorials.com/wind-energy/synchronous-generator.html

Synchroscopes: Terrell Croft, Wilford Summers (ed.), *American Electricians' Handbook Eleventh Edition*, Mc Graw Hill, 1987 ISBN 0-07-013932-6 pp. 7-46 - 7-48
http://educypedia.karadimov.info/library/eet_ch6.pdf