Ministry of Science and Higher Education of the Russian Federation

Peter the Great St. Petersburg Polytechnic University

# SYNCHRONOUS GENERATOR TEST

## Training manual

Saint-Petersburg

2025

UDC 621.313.322

Vataev A.S **Synchronous generator test:**
training manual / A.S. Vataev, M.V. Sochava, N.A. Homitsevich – St. Petersburg, 2025. – 53 p.

The textbook is recommended for students of the energy specialties 13.03.02 and 13.04.02, studying the courses "Electric machines" and performing a cycle of laboratory work on the corresponding course. It is recommended for all students of the direction to familiarize themselves with the basics of the theory of synchronous machines and the methodology of their experimental research. It is intended to help students who do not speak Russian as their native language learn the material.

Table 15. Figures 15. References: 2 titles.

Peter the Great St. Petersburg
Polytechnic University, 2025

## CONTENT

# 1. NO-LOAD TEST

The no-load test, or the open-circuit test, is used to obtain parameters of a synchronous generator, such as the saturation factor, the unsaturated and saturated values of the synchronous reactance respectively $X_{d\infty}$ $X_d$, and the Potier reactance $X_p$. Also, it is used to estimate the saturation of the magnetic system of the machine. The no-load test is performed by

1) Generator is rotated at the rated speed.
2) No load is connected at the terminals.
3) Field current $I_f$ is increased from 0 to maximum.
4) Record values of the terminal voltage and field current value.

With the terminals open, the armature current $I_A$ is missing $I_A = 0$, so the induced EMF is equal to the terminal voltage $E_A = U_0$. It is thus possible to construct a plot of $E_A$ or $U_0$ vs $I_f$ graph as is shown in figure 1.1 This plot is called open-circuit characteristic (OCC) of a generator. With this characteristic, it is possible to find the internal generated voltage of the generator for any given field current. The figure 1.1 shows that the OCC is shifted to the left. It may be explained by residual magnetic system magnetization of the generator.

The OCC follows a straight-line relation as long as the magnetic circuit of the synchronous generator does not saturate. Since, in the linear region, most of the applied MMF is consumed by the air-gap, the straight line is appropriately called the air-gap line. The air-gap line is 0B segment in figure 1.1. Note that OB is the tangent to the linear region of the OCC curve.

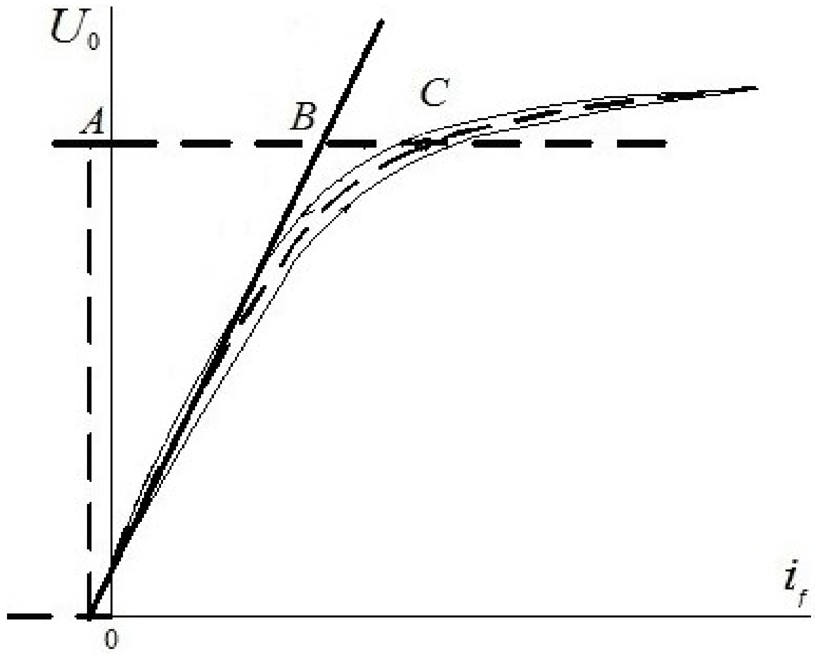


Figure 1.1 Open circuit characteristic of a generator

The saturation factor may be computed by formula

$$\kappa_{\mu} = \frac{AC}{AB} = \frac{AB + BC}{AB} = 1 + \frac{BC}{AB} > 1 \ . \qquad (1.1)$$

Where BC, AC and AB are lengths of corresponding segments shown in figure 1.1. Note that the saturation factor of the most of synchronous generators is $k_{\mu} \approx 1.1 \div 1{,}2$. So turbogenerators have $k_{\mu} \leq 1.2$, hydrogenerators have $k_{\mu} \leq 1.1$. Only low power standalone load running synchronous generators have $k_{\mu} = 1.3 - 1.6$.

The test circuit is shown in figure 1.2

## *INSTRUCTIONS*

1. Use DC ammeter A with 30A range. Set the higher range first.
2. The voltmeter $V_1$ is used to measure line-to-line voltages. It is useful to use probes to connect the voltmeter to terminals. Because of the

voltages to be measured are very different use two voltmeters with 60 V and 300 V range and change it when it is necessary. ***<u>WARNING! When using a multiple range meter always use the high range first to determine the feasibility of using a lower range.</u>***

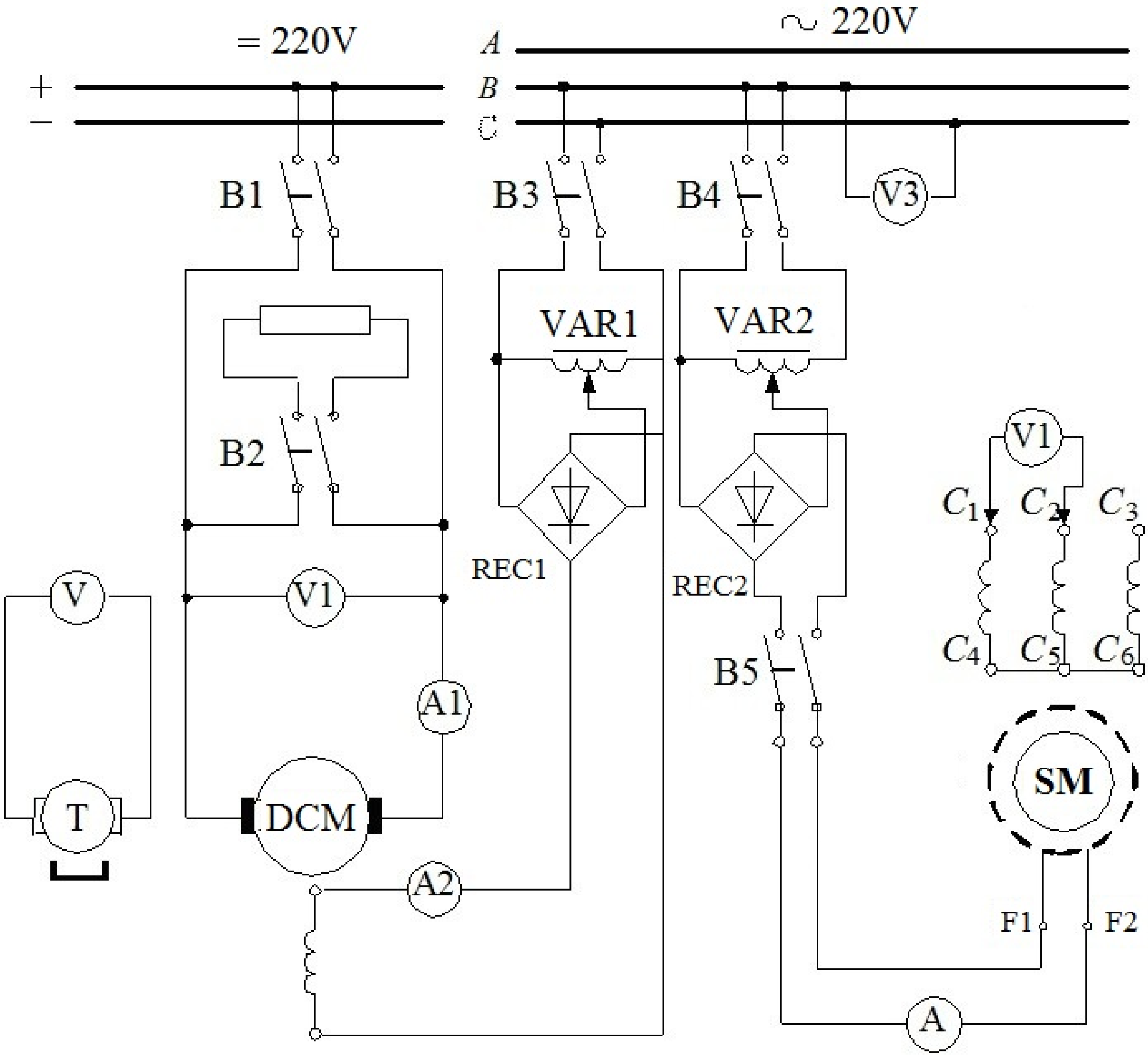


Figure 1.2 Test circuit of the generator under no-load test mode.

3. Connect the test circuit as shown in figure 1.2 Note that the test circuit of DC motor is already connected. **Don't make any changes without instructor guidance**.

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE LETHAL. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

4. Start DC motor and set rated speed by doing the following

- Set the minimum of the DC motor field current using the variable VAR1.
- Push black $B_3$ button to switch the field current of DC motor on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
- Set the maximum of DC motor field current by counterclockwise rotating the variable e VAR1 handle.
- Push black $B_2$ button to start the DC motor. Slowly decrease the field current by clockwise rotating of variable VAR1 handle until signal lamp of $B_2$ switch is brightly glows.

***Tip: If DC motor does not start try simultaneously press black $B_2$ button and slowly clockwise turn the VAR1 handle.***

- Set the rated speed of the DC motor using the variable VAR1 handle. Use V voltmeter to control the speed. The maximum of voltage corresponds to rated speed.

5. Set the minimum of field current of synchronous generator using the variable VAR2.
6. Push black $B_4$ button to switch the field current of the synchronous generator on. **<u>Don't push this button until the minimum of current is not set to avoid breakdown of the variable</u>**.
7. Increase slowly the field current using the variable VAR2 handle until the line-to-line voltage of the generator is it rated value (220 Volts). Use voltmeter $V_1$ to control this voltage.
8. Check the symmetry of the line to-line voltages. If the voltages are equal or different less than 5 % use any of them further. **<u>CAUTION! DON'T TOUCH ANY UNINSULATED PARTS OF PROBES WHEN MEASURING TO AVOID ELECTRIC SHOCK</u>**
9. Increase slowly the field current using the variable VAR2 handle until the line-to-line voltage of the generator is it maximum value (260 Volts). Maintain the rated speed of the generator.
10. Record the line-to-line voltage $U_{LL}$, and the field current of the generator $I_f$ in table 1.1
11. Repeat the previous step by reducing the current $I_f$ as shown in table 1.1 and record all values in table 1.1. Note that the last measurement is done when the field current of the generator is equal to ZERO. To make this test turn off the variable VAR2 and press the red button $B_4$.

| ***Table 1.1 Measured data for the no-load operation test*** | | |
|---|---|---|
| *$U_{LL}$, Volts* | *$U_P$, Volts* | *$I_f$, Amps* |
| 260 | | |
| 250 | | |
| 240 | | |
| 230 | | |
| 220 | | |
| 210 | | |
| 200 | | |
| 190 | | |
| 180 | | |
| 160 | | |
| 140 | | |
| 120 | | |
| 100 | | |
| 80 | | |
| 60 | | |
| 40 | | |
| 20 | | |
| | | 0 |

12. Stop the DC motor by pressing the red $B_1$ button.
13. Turn off the variable VAR1 and press the red button $B_3$.
14. Switch off the supply voltage

**WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!**

***Tip: This generator will also be used in the next part of the experiment, so leave the connections of field circuit of the generator intact when this part is finished.***

**REPORT**

1 Compute the phase voltage by formula and record the computed values in table 1.1

$$U_{\mathrm{P}} = \frac{U_{\mathrm{LL}}}{\sqrt{3}} \qquad (1.2)$$

2 Plot the voltage $U_{LL}$ against the current $I_F$.

3 Compute the magnetizing factor by using (1.1)

## 2 THREE PHASE SHORT-CIRCUIT TEST

The short-circuit test provides information about the current capabilities of a synchronous generator. It is performed by

1) Generator is rotated at rated speed.
2) Adjust field current to 0.
3) Short circuit the terminals.
4) Measure armature current or line current as the field current is increased.

The short-circuit characteristic (SCC) is shown in figure 2.1

SCC is essentially a straight line. To understand why this characteristic is a straight line, look at the equivalent circuit in figure.2.2 when the terminals are short circuited.

When the terminals are short-circuited, the armature current $I_A$ is:

$$\dot{U} = 0 = \dot{E}_A + \dot{E}_d - \dot{I}_A r_a = \dot{E}_A - j\dot{I}_d x_d - \dot{I}_A r_a \qquad (2.1)$$

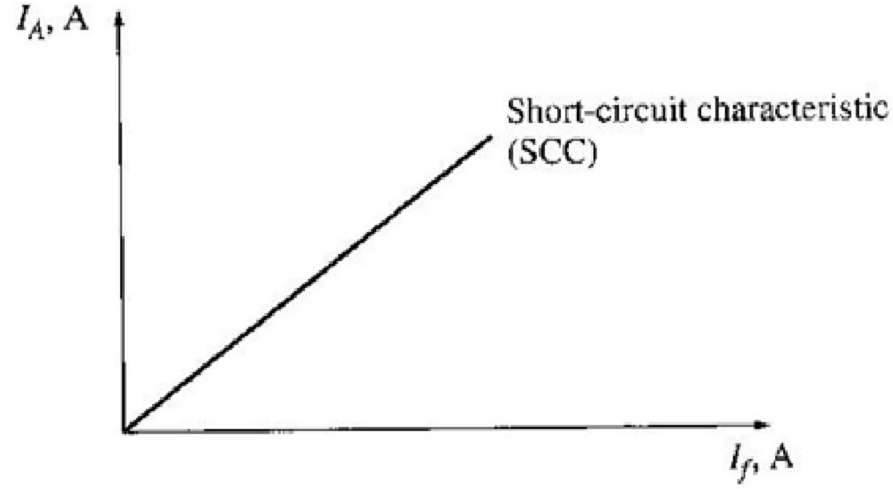


Figure 2.1 the short-circuit characteristic (SCC) of a synchronous generator

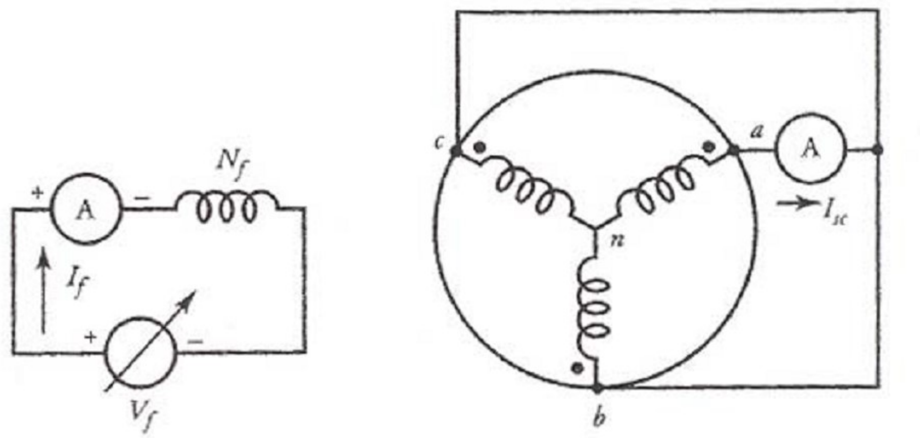


Figure 2.2 Circuit diagram to perform short-circuit test

In general, the resistance of armature winding of the generator is negligibly small $r_a = 0$ and its magnitude is

$$I_A = \frac{E_A}{x_d} = \frac{E_A}{x_{ad} + x_{\sigma a}} \qquad (2.2)$$

where: $x_d$ – direct-axis synchronous reactance;

$x_{\sigma a}$ – leakage reactance of stator winding;

$x_{ad}$ – direct-axis armature reaction reactance.

When $U = 0$ resultant flux leakage is equal to stator winding flux leakage. It's value is less than $(10-20)\,\%$ of rated flux. For this reason, the magnetic system of the machine is unsaturated therefore SCC is a straight line.

Short Circuit Ratio

Ratio of the field current required for the rated voltage at open circuit to the field current required for rated armature current at short circuit.

$$SCR = \frac{I_{fOC}}{I_{fSC}} = \frac{1}{\overline{X}_d} \qquad (2.3)$$

Using data of the open- and short-circuit characteristics, unsaturated and saturated d-axis synchronous reactance may be calculated by doing the following.

- Plot the open-circuit characteristic, the air-gap line (see paragraph 1.1) and the short-circuit characteristic at the same plot as shown in figure 2.3
- Determine the field current required for the rated voltage $U_n$ at open circuit $I_{fn.}$ and plot BD segment.
- Extend the BD segment to the intersections of the segment and the air-gap line.
- Plot C point as intersection of SCC line and the BD segment.

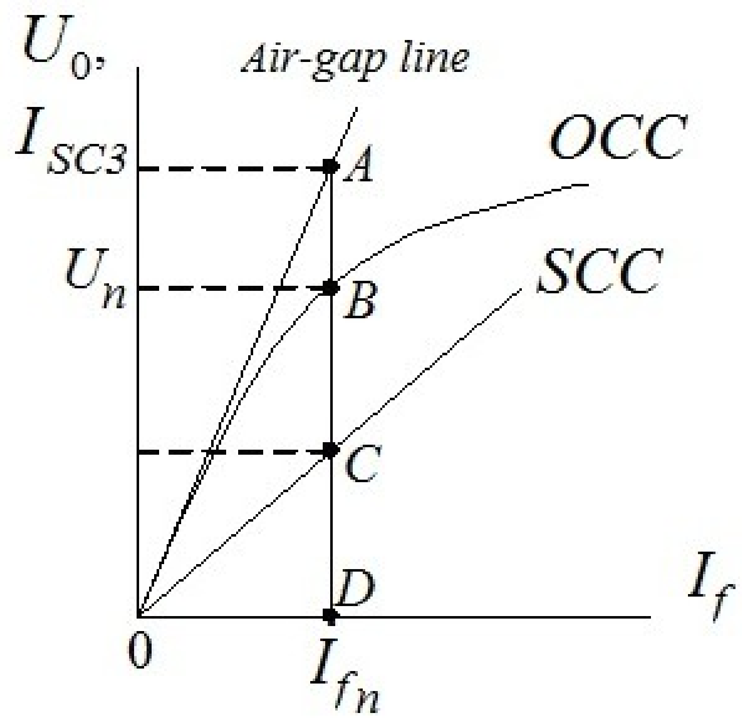


Figure 2.3. Determination of reactance $x_{d\infty}$ and $x_d$

Note that OCC and SCC need to be moved to the origin by parallel transferring.

The test circuit is shown in figure 2.4.

***INSTRUCTIONS***

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.
2. The voltmeter V is used to measure third order harmonic of voltage. It is useful to connect them to $C_1$ – $C_6$ terminals with wires. Because of the voltages to be measured may be very different use voltmeter with 60 V range and change it when it is necessary. ***WARNING! When using a multiple range meter always use the high range first to determine the feasibility of using a lower range.***

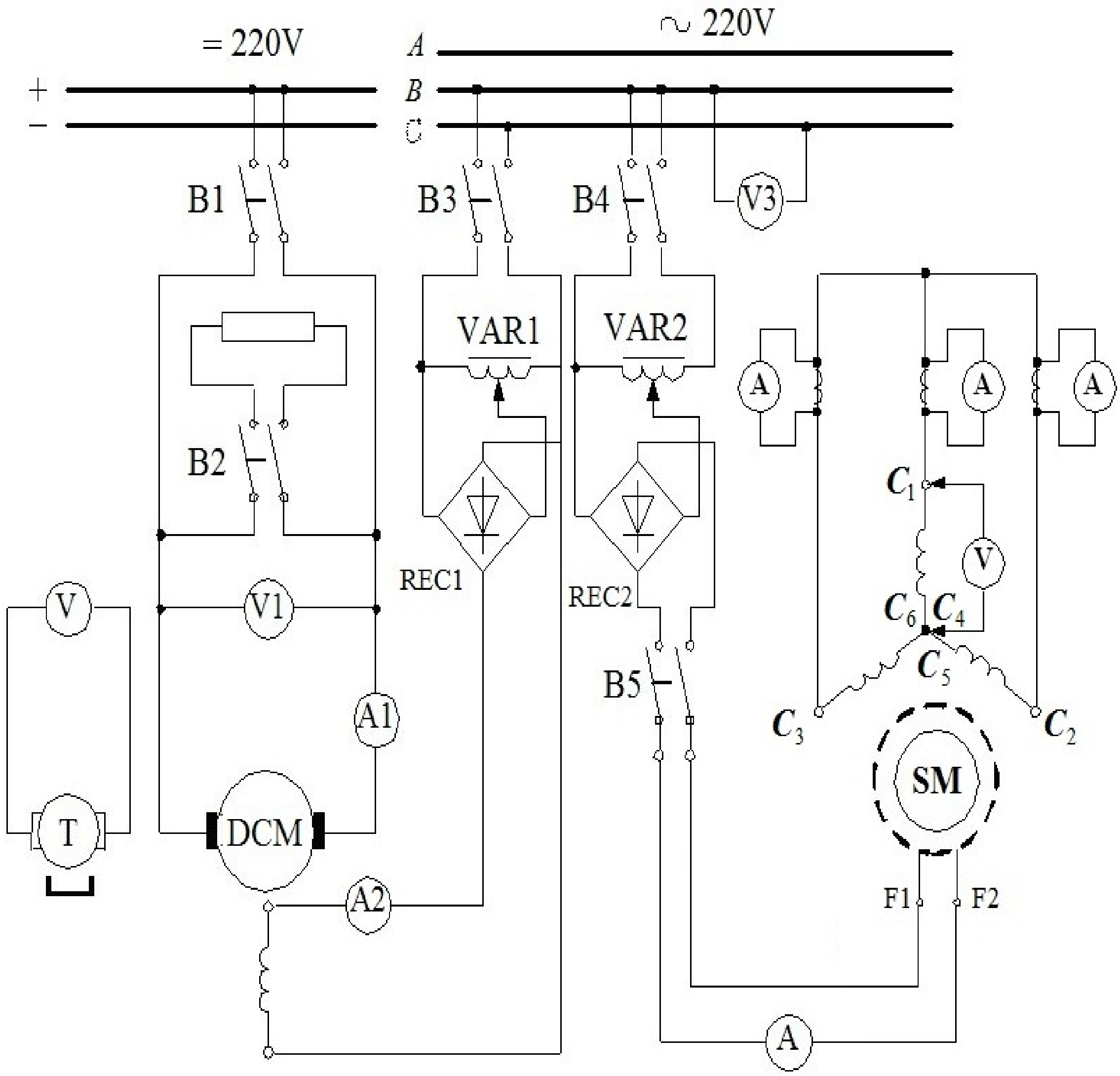


Figure 2.4. Test circuit of the generator under short-circuit test.

3. Connect the test circuit as shown in figure.2.4

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE <u>LETHAL</u>. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE**

**CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

4. Start DC motor and set rated speed as described in paragraph 1
5. Set the minimum of field current of synchronous generator using the variable VAR2.
6. Push black $B_4$ button to switch the field current of the synchronous generator on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
7. Increase slowly the field current using the variable VAR2 handle until the armature current of the generator is it rated value (16 Amps). Use ammeters to control the currents.
8. Record all phase currents $I_A$, $I_B$, $I_C$, and the field current of the generator $I_f$ in table 2.1
9. Repeat the previous step by reducing the current $I_f$ as shown in table 2.1 and record all values in table 1.1. Note that the last measurement is done when the field current of the generator is equal to ZERO. To make this test turn off the variable VAR2 and press the red button $B_4$.

***Table 2.1 Measured data for the short-circuit test***

| $I_A$, Amps | $I_B$, Amps | $I_C$, Amps | $I_{sc3}$, Amps | $I_f$, Amps |
|---|---|---|---|---|
| 16 | | | | |
| 14 | | | | |
| 10 | | | | |
| 5 | | | | |

10. Stop the DC motor by pressing the red $B_1$ button.

11. Turn off the variable VAR1 and press the red button $B_3$.

12. Switch off the supply voltage

**WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!**

***Tip: This generator will also be used in the next part of the experiment, so leave the necessary connections intact when this part is finished.***

**REPORT**

1 Calculate the average value of the short-circuit current by formula

$$I_{SC3} = \frac{I_A + I_B + I_C}{3}$$

2 Plot the current $I_{SC3}$ against the current $I_F$.

3 Compute unsaturated and saturated d-axis synchronous reactance by using (2.4)

## 3. UNDER-LOAD SYNCHRONOUS GENERATOR TEST

In general, at the laboratory synchronous generators are tested under autonomous load. Three star-connected regulated resistors are used in the experimental setup as an active load. The induction regulator is used as an reactive load. To change the reactive load the rotation of the induction regulator rotor is used. The under-load test of the generator are full-load zero power factor, voltage regulation, and external characteristics. The test circuit that is used to make these tests is the same and shown in figure 3 Note that the DC motor circuit is not shown in figure 3.

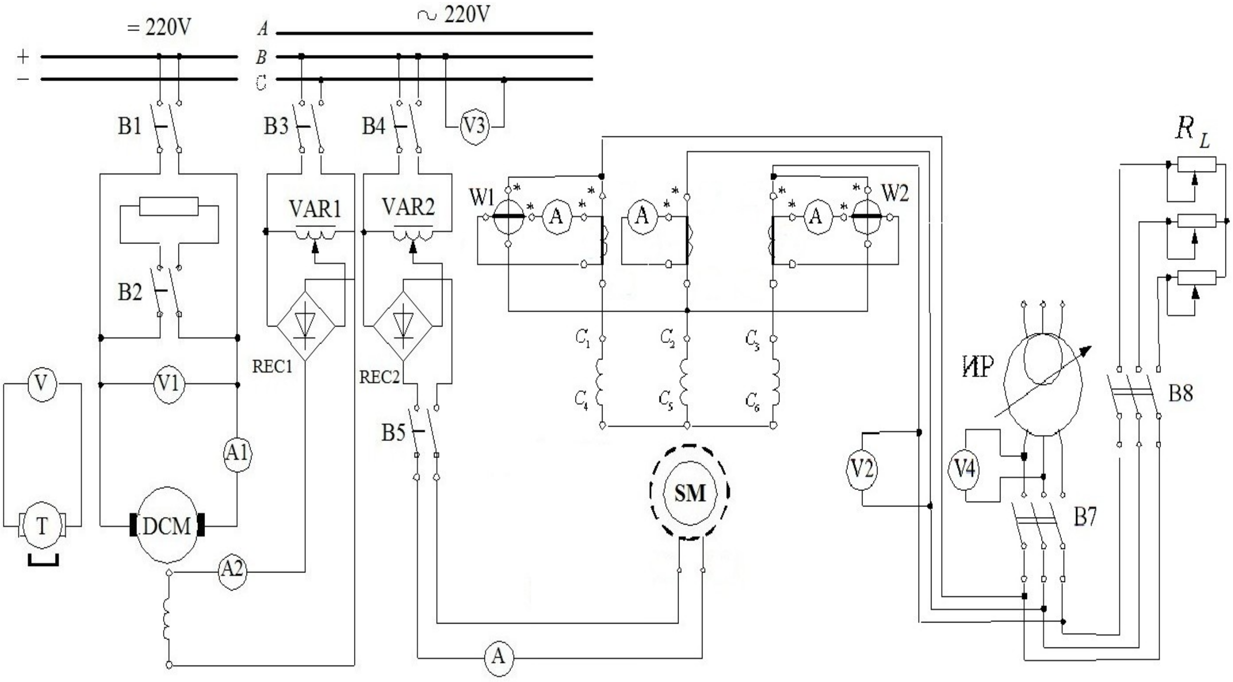


Figure.3 Test circuit of the generator under load tests.

## 3.1 Full-load zero power factor test

Under load characteristics of a synchronous generator is the relationship $U = f(i_B)$. It is performed by

1) Generator is rotated at the rated speed.
2) Load is connected at the terminals so that the armature current and power factor are the constant
3) Field current $I_f$ is increased from 0 to maximum.
4) Record values of the terminal voltage and field current value.

It is clear that no-load test is a special case of load characteristic when armature current is equal to zero ($I = 0$).

In practice the full-load zero power factor test is used to determine the Potier reactance $X_p$. In this case power factor is equal to zero ($\cos\varphi = 0$) and the armature current is equal to rated value. Note that the field current of the generator when $U = 0$ is equal to field current in three-phase short-circuit mode when the armature current is it rated value ($I = I_{\text{SC3Rated}}$).

The Potier reactance may be computed using the OCC and the full-load zero power characteristic (ZPFC). It is performed by follows

- Plot the open-circuit characteristic, the air-gap line (see paragraph 1) and the full-load zero power characteristic at the same plot as shown in figure 3.1

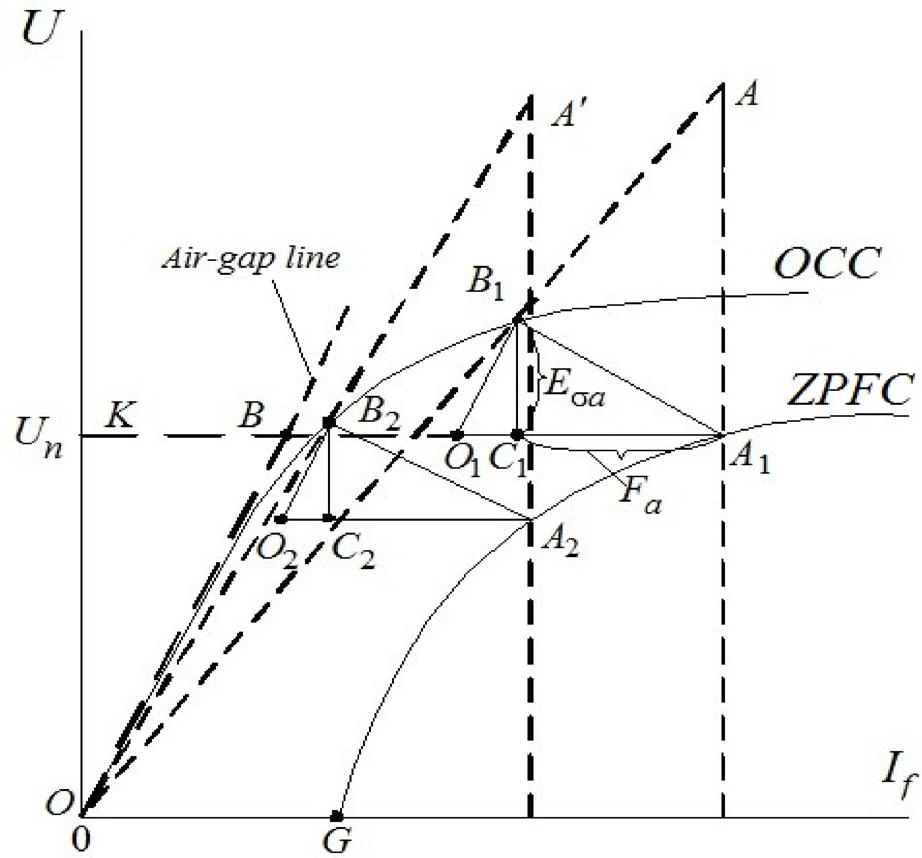


Figure 3.1. Determination of the Potier reactance

- Plot a segment $O_1A_1 = OG$ through the point $A_1$ corresponding to the rated voltage on ZFCC. Note that this time $OG = I_{fsc3}$ is the field current corresponding to three-phase short-circuit mode when the armature current is it rated value. Use SCC to plot the $OG$ segment if necessary.
- Draw a line through the point $O_1$. This line should be parallel to the air-gap line. The point $B_1$ is the intersection point of the line and the OCC curve.
- Draw a perpendicular line through $B_1$ point. The point $C_1$ is the intersection point of the perpendicular and the segment $O_1A_1$.
- Length of the segment $A_1C_1$ is equal to direct-axis demagnetizing armature reaction MMF $F_a$ that is scaled in field current units.
- The leakage EMF $E_{\sigma a} = B_1C_1$ determined by above method is equal to $\dot{E}_{\sigma a} = jX_p\dot{I}$. Correspondingly the inductive reactance which is named as Potier reactance may be computed by

$$X_P = \frac{B_1 C_1}{I} \qquad (3.1)$$

***INSTRUCTIONS***

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.
2. The voltmeter $V_2$ is used to measure line-to-line voltage. Because of symmetry of the generator and the load it is useful to connect them to $C_1 - C_2$ terminals with wires. User the voltmeter with 300 V range only!
3. Connect the test circuit as shown in figure 3

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE LETHAL. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

4. Start DC motor and set rated speed as described in paragraph 1.
5. Set the minimum of field current of synchronous generator using the variable VAR2.
6. Push black $B_5$ button to switch the field current of the synchronous generator on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
7. Increase slowly the field current using the variable VAR2 handle until the line-to-line voltage of the generator is 240 Volts. Use voltmeter $V_2$ to control the voltage.
8. Set the maximum inductive reactance of the load by using the induction regulator ИР handle. Make sure that the "Max" lamp is brightly glows.
9. Push black $B_7$ button to switch the induction regulator on as inductive load of the generator.
10. Set the rated value of the armature current of the generator (16 Amps) using the induction regulator ИР handle. Maintain

simultaneously the rated speed of the generator and line-to line voltage (240 Volts) using respectively VAR1 or VAR2 handles.

11. Record the field current of the generator $I_f$ and line-to-line voltage $U_{LL}$ in table 3.1

| ***Table 3.1 Measured data for the full-load zero-power factor operation test*** | |
|---|---|
| *$U_{LL}$, Volts* | *$I_f$, Amps* |
| 240 | |
| 220 | |
| 200 | |
| 180 | |
| 160 | |
| 140 | |
| 120 | |
| 100 | |

12. Repeat the previous step by reducing the voltage $U_{LL}$ as shown in table 3.1 and record all values in table 3.1. Note that the current and the speed of the generator should be maintained at the rated value. In order to do this ***set first*** the voltage $U_{LL}$ by turning VAR2 handle and then set the current by turning ИР handle.

13. Set the maximum inductive reactance of the load by using the induction regulator ИР handle. Make sure that the “Max” lamp is brightly glows.

14. Push red $B_7$ button to switch the induction regulator off.

15. Turn off the variable VAR2 and press the red button $B_5$.
16. Stop the DC motor by pressing the red $B_1$ button.
17. Turn off the variable VAR1 and press the red button $B_3$.
18. Switch off the supply voltage

**WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!**

***Tip: This generator will also be used in the next part of the experiment, so leave the necessary connections intact when this part is finished.***

**REPORT**

1. Plot the open-circuit characteristic, the air-gap line (see paragraph 1.1) and the voltage $U_{LL}$ against the current $I_F$ at the same plot as shown in figure 3.1
2. Calculate the Potier reactance as described above.

## 3.2 External characteristic mode test

The external characteristics of a synchronous generator are the relation $U = f(I)$ for $I_f$ = const and cos φ = const.

Under inductive load with $0 < \varphi < \pi/2$, the armature reaction and the voltage drop $R_a\dot{I} + jX_{\sigma a}\dot{I}$ cause the voltage to fall. For a leading cos φ, which corresponds to $0 > \varphi > -\pi/2$, these factors act to increase the voltage and, therefore, with a reduction of cos φ the voltage rise increases. With

U = 0 (short circuit) all the characteristics intersect at one point corresponding to the value of the three-phase short-circuit current.

At the laboratory the external characteristics research test is often conducted when cos φ = 0.8. It is useful to use phasemeter to control cos φ . The wiring diagram of a phasemeter connection is shown in figure 3.2. Note that only one phasemeter is used.

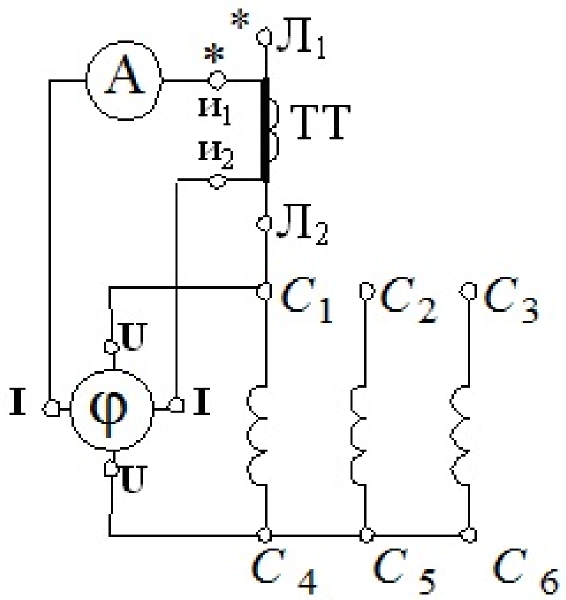


Figure 3.2 The wiring diagram of a phasemeter connection.

In order to estimation of the armature reaction influence it is useful to make two external characteristics research tests with different values of cos φ. The most interest values of cos φ are 0 and 1.0. Using these values in test conducting is the way to simplify the tests because in this case there is not need to use the phasemeter and wattmeters.

### *INSTRUCTIONS*

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.

2. The voltmeter $V_2$ is used to measure line-to-line voltage. Because of symmetry of the generator and the load it is useful to connect them to $C_1 - C_2$ terminals with wires. User the voltmeter with 300 V range only!
3. Connect the test circuit as shown in figure 3.

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE LETHAL. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

4. Start DC motor and set rated speed as described in paragraph 1
5. Set the minimum of field current of synchronous generator using the variable VAR2.
6. Push black $B_5$ button to switch the field current of the synchronous generator on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
7. Increase slowly the field current using the variable VAR2 handle until the line-to-line voltage of the generator is 220 Volts. Use voltmeter $V_2$ to control the voltage.

8. Set the maximum inductive reactance of the load by using the induction regulator ИР handle. Make sure that the "Max" lamp is brightly glows.
9. Push black $B_7$ button to switch the induction regulator on as inductive load of the generator.
10. Set the rated value of the armature current of the generator (16 Amps) using the induction regulator ИР handle. Maintain simultaneously the rated speed of the generator and line-to line voltage (220 Volts) using respectively VAR1 or VAR2 handles.
11. Record the phase currents of the generator $I_A$, $I_B$, $I_C$, and line-to-line voltage $U_{LL}$ in table 3.3

***Table 3.3 Measured data for the external characteristic test when cos φ = 1***

| $I_A$, *Amps* | $I_B$, *Amps* | $I_C$, *Amps* | *I, Amps* | $U_{LL}$, *Volts* |
|---|---|---|---|---|
| 16 | | | | |
| 14 | | | | |
| 10 | | | | |
| 5 | | | | |
| 0 | | | | |

12. Repeat the previous step by reducing the load by turning the ИР handle and set phase currents as shown in table 3.3 and record all values in table 3.3. Note that the field current and the speed of the generator should be maintained. The last one measurement is made when the induction regulator is switched off. To do this set the

maximum inductive reactance of the load by using the induction regulator ИР handle (the “Max” lamp is brightly glows) and push red $B_7$ button.

13. Set the rated value of the line-to-line voltage of the generator (220 Volts).
14. Set the maximum active resistance of the load by using the active resistance handle. Make sure that the “Max” lamp is brightly glows.
15. Push black $B_8$ button to switch the active resistance load of the generator.
16. Repeat the 11-12 steps and fill the table 3.4

***Table 3.4 Measured data for the external characteristic test when cos φ = 1***

| $I_A$, Amps | $I_B$, Amps | $I_C$, Amps | $I$, Amps | $U_{LL}$, Volts |
|---|---|---|---|---|
| 16 | | | | |
| 14 | | | | |
| 10 | | | | |
| 5 | | | | |
| 0 | | | | |

17. Set the maximum active resistance of the load by using the active resistance handle. Make sure that the “Max” lamp is brightly glows.
18. Push red $B_8$ button to switch the active resistance load off.
19. Turn off the variable VAR2 and press the red button $B_5$.

20. Stop the DC motor by pressing the red $B_1$ button.

21. Turn off the variable VAR1 and press the red button $B_3$.

22. Switch off the supply voltage

**<u>WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!</u>**

***Tip: This generator will also be used in the next part of the experiment, so leave the necessary connections intact when this part is finished.***

**REPORT**

1 Calculate the average value of the short-circuit current by formula

$$I = \frac{I_A + I_B + I_C}{3}$$

And record the calculated value in tables 3.3 and 3.4

2 Plot at the same plot the voltage $U_{LL}$ against the current $I$ using data of tables 3.3 and 3.4.

3 Calculate the voltage drop in p.u. by formula

$$\Delta U = \frac{U_0 - U_n}{U_n} \cdot 100\,\%$$

where $U_0$ – is the line-to-line voltage when $I = 0$, and $U_n$ – is the rated value of the line-to-line voltage of the generator.

## 3.3 Regulation characteristic mode test

The external characteristics of a synchronous generator are the relation $I_f = f\,(I)$ for $U$ = const and cos φ = const.

To maintain the voltage *U = const* with an increasing inductive load, it will be necessary to increase the excitation current, while under a capacitive load the excitation should be decreased – as can be seen from the external characteristics. With a reduction of cos φ, a corresponding greater change of the excitation is required.

At the laboratory the external characteristics research test is often conducted when cos φ = 0.8. It is useful to use phasemeter to control cos φ as shown in paragraph 3.2.

In order to estimation of the armature reaction influence it is useful to make two external characteristics research tests with different values of cos φ. The most interest values of cos φ are 0 and 1.0. Using this values in test conducting is the way to simplify the tests because in this case there is not need to use the phasemeter and wattmeter's.

***INSTRUCTIONS***

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.
2. The voltmeter $V_2$ is used to measure line-to-line voltage. Because of symmetry of the generator and the load it is useful to connect them to $C_1$ – $C_2$ terminals with wires. User the voltmeter with 300 V range only!
3. Connect the test circuit as shown in figure 3.

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE <u>LETHAL</u>. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING**

**HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

1. Start DC motor and set rated speed as described in paragraph 1.
2. Set the minimum of field current of synchronous generator using the variable VAR2.
3. Push black $B_5$ button to switch the field current of the synchronous generator on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
4. Increase slowly the field current using the variable VAR2 handle until the line-to-line voltage of the generator is 220 Volts. Use voltmeter $V_2$ to control the voltage.
5. Set the maximum inductive reactance of the load by using the induction regulator ИР handle. Make sure that the "Max" lamp is brightly glows.
6. Push black $B_7$ button to switch the induction regulator on as inductive load of the generator.
7. Set the rated value of the armature current of the generator (16 Amps) using the induction regulator ИР handle. Maintain simultaneously the rated speed of the generator and line-to line voltage (220 Volts) using respectively VAR1 or VAR2 handles.
8. Record the phase currents of the generator $I_A$, $I_B$, $I_C$, and the excitation current of the generator $I_f$ in table 3.5

| ***Table 3.5 Measured data for the regulation characteristic test when cos φ = 1*** | | | | |
|---|---|---|---|---|
| $I_{A,}$ *Amps* | $I_{B,}$ *Amps* | $I_{C,}$ *Amps* | $I_,$ *Amps* | $I_f$, *Amps* |
| 16 | | | | |
| 14 | | | | |
| 10 | | | | |
| 5 | | | | |
| 0 | | | | |

9. Repeat the previous step by reducing the load by turning the ИР handle and set phase currents as shown in table 3.5 and record all values in table 3.5. Note that the voltage and the speed of the generator should be maintained. The last one measurement is made when the induction regulator is switched off. To do this set the maximum inductive reactance of the load by using the induction regulator ИР handle (the "Max" lamp is brightly glows) and push red $B_7$ button.
10. Set the rated value of the line-to-line voltage of the generator (220 Volts).
11. Set the maximum active resistance of the load by using the active resistance handle. Make sure that the "Max" lamp is brightly glows.
12. Push black $B_8$ button to switch the active resistance load of the generator.
13. Repeat the 11-12 steps and fill the table 3.6

| *Table 3.6 Measured data for the external characteristic test when cos φ = 1* | | | | |
|---|---|---|---|---|
| $I_{A,}$ *Amps* | $I_{B,}$ *Amps* | $I_{C,}$ *Amps* | $I_{,}$ *Amps* | $I_{f,}$ *Amps* |
| 16 | | | | |
| 14 | | | | |
| 10 | | | | |
| 5 | | | | |
| 0 | | | | |

14. Set the maximum active resistance of the load by using the active resistance handle. Make sure that the “Max” lamp is brightly glows.
15. Push red $B_8$ button to switch the active resistance load off.
23. Turn off the variable VAR2 and press the red button $B_5$.
24. Stop the DC motor by pressing the red $B_1$ button.
25. Turn off the variable VAR1 and press the red button $B_3$.
26. Switch off the supply voltage

**WARNING! DON’T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!**

***Tip: This generator will also be used in the next part of the experiment, so leave the necessary connections intact when this part is finished.***

## REPORT

Calculate the average value of the short-circuit current by formula

$$I = \frac{I_A + I_B + I_C}{3}$$

Record the calculated value in tables 3.5 and 3.6

1 Plot at the same plot the voltage $U_{LL}$ against the current $I$ using data of tables 3.5 and 3.6.

2 Calculate the field current delta in p.u. by formula

$$\Delta I_f = \frac{I_{fr} - I_{\mathrm{f0}}}{I_{\mathrm{fr}}} \cdot 100\ \%$$

where $I_{f0}$ – is the excitation current under no-load, and $I_{fr}$ is the value of the excitation current when the current is the rated value

# 4. ASYMMETRICAL STEADY-STATE MODES OF A THREE-PHASE SYNCRONOUS GENERATOR

Asymmetrical loading of a three-phase synchronous generator occurs when single-phase loads are non-uniformly distributed in the network, this leading to asymmetrical distribution of the current between the separate stator phase windings in the generator. As with asymmetrical load on a three-phase transformer, in the general case, if the generator has an earthed neutral, the asymmetrical currents in the stator winding phases may consist of all three symmetrical components: of the positive $I_1$, negative $I_2$, and zero $I_0$ phase sequences. Asymmetrical short circuits are the special case of asymmetrical steady state modes of a three-phase synchronous generator.

Asymmetrical short circuits occur quite often in network connected to synchronous machines, in view of which it is of great practical importance to study these conditions.

Note that the stator MMF due to the negative currents $I_2$ creates a field rotating at double speed relative to the rotor and opposite to rotor rotation. In this case the addition losses vibrations mechanical overload and overheat of rotor elements occur.

Asymmetrical short circuit test allows to estimate generator properties in case of strong asymmetry and to determine parameters to calculate the transient modes when asymmetrical loading or fault occurs.

At the laboratory phase-to-phase, phase to neutral, phase-to-phase-to-neutral short circuit test are conducted. All of these characteristics are the relationships $I = f(i_{\mathrm{f}})$ at the rated speed $n = n_{\mathrm{rated}} = \mathrm{const}$.

## 4.1. Phase-to-phase short circuit test

The phase-to-phase short circuit test is used to determine the phase negative-sequence reactance $x_2$, the phase negative-sequence impedance $z_2$, and phase negative-sequence resistance $r_2$. They may be calculated by formulae

$$z_2 = \frac{U_{\mathrm{CK}}}{\sqrt{3}\, I_{\mathrm{K}2}} \qquad (4.1)$$

$$x_2 = \frac{P_{\mathrm{CK}}}{\sqrt{3}\, I_{\mathrm{K}2}^2} \qquad (4.2)$$

$$r_2 = \sqrt{z_2^2 - x_2^2} \qquad (4.3)$$

Where $U_{CK}$ – is the voltage that is measured between free and short-circuited phases as shown in figure 1.4.1, $I_{K2}$ – is the short-circuit phase-to phase current, $P_{CK}$ – is the virtual power that is formed with short-circuit current, and is measured with wattmeter connected as shown in figure 4.1.

The test circuit is shown in figure 4.1

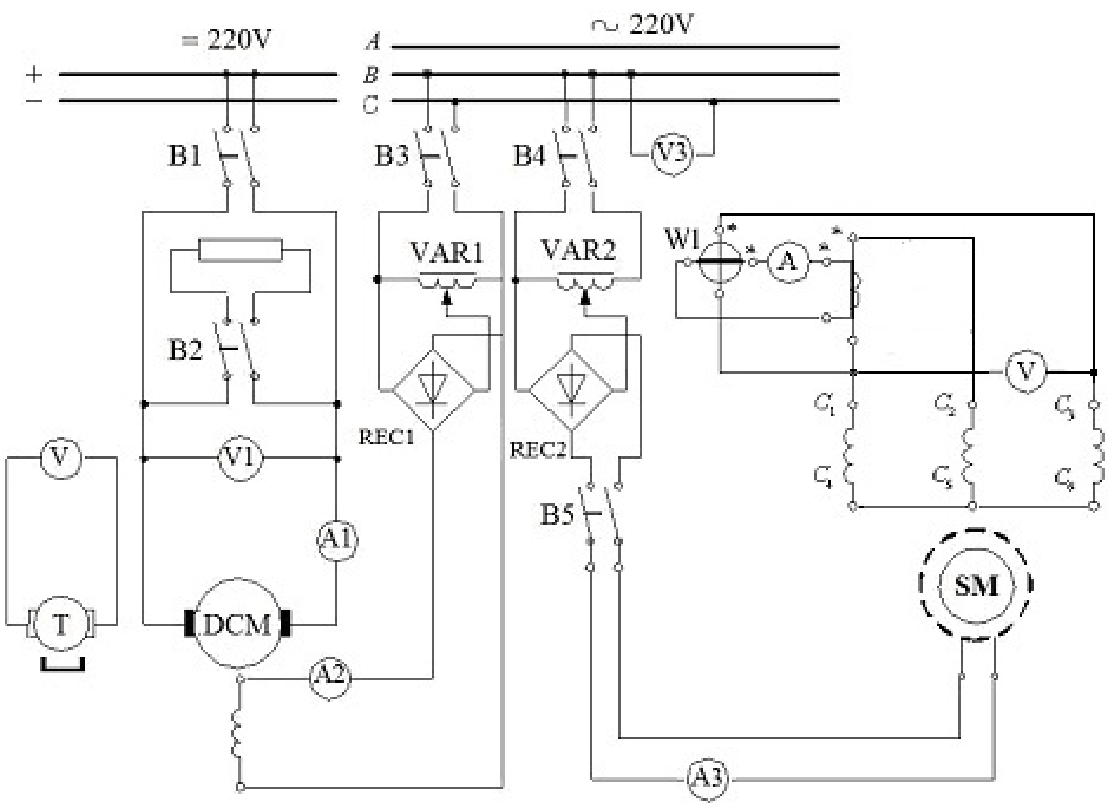


Figure 4.1. Test circuit of the generator under phase-to phase short-circuit test.

### *INSTRUCTIONS*

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.
2. The voltmeter V is used to measure the voltage between free and short-circuited phases (see figure 4.1). It is useful to connect them to $C_1$ – $C_3$

terminals with wires. Because of the voltages to be measured may be very different use voltmeter with 150 V range and change it when it is necessary. ***WARNING! When using a multiple range meter always use the high range first to determine the feasibility of using a lower range.***

3. Connect the test circuit as shown in figure 4.1

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE LETHAL. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

4. Start DC motor and set rated speed as described in paragraph 1.
5. Set the minimum of field current of synchronous generator using the variable VAR2.
6. Push black $B_4$ button to switch the field current of the synchronous generator on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
7. Increase slowly the field current using the variable VAR2 handle until the short-circuit current of the generator $I_{SC2}$ is it rated value (16 Amps). Use ammeter A to control the currents.
8. Record current $I_{SC2}$, voltage $U_{CK}$, field current $I_f$, and the virtual power $P_{CK}$ in table 4.1

| ***Table.4.1 Data for the phase-to phase short-circuit test*** | | | | | | |
|---|---|---|---|---|---|---|
| $I_{SC2}$, *Amps* | $U_{CK}$, *Volts* | $P_{CK}$, *Watts* | $I_f$, *Amps* | $Z_2$, *Ohms* | $X_2$, *Ohms* | $r_2$, *Ohms* |
| 16 | | | | | | |
| 12 | | | | | | |
| 10 | | | | | | |
| 5 | | | | | | |
| | | | 0 | | | |

9. Repeat the previous step by reducing the current $I_f$ as shown in table 4.1 and record all values in table 4.1. Note that the last measurement is done when the field current of the generator is equal to ZERO. To make this test turn off the variable VAR2 and press the red button $B_4$.
10. Stop the DC motor by pressing the red $B_1$ button.
11. Turn off the variable VAR1 and press the red button $B_3$.
12. Switch off the supply voltage

**<u>WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!</u>**

***Tip: This generator will also be used in the next part of the experiment, so leave the necessary connections intact when this part is finished.***

## REPORT

4 Calculate the phase negative-sequence reactance $x_2$, the phase negative-sequence impedance reactance $z_2$, and phase negative-sequence

resistance $r_2$ by formulae (4.1-4.3) and record computed values in table 4.1.

5 Plot the current $I_{SC2}$ against the current $I_f$

## 4.2 Phase-to-phase-to-neutral short circuit test

The phase-to-phase-to-neutral short circuit test is used to determine the phase zero-sequence reactance $x_0$, the phase zero-sequence impedance $z_0$, and phase zero-sequence resistance $r_0$. They may be calculated by formulae

$$z_0 = \frac{U_{C1}}{I_{K20}} \qquad (4.4)$$

$$x_0 = \frac{P_{C1}}{I_{K2}^2} \qquad (4.5)$$

$$r_0 = \sqrt{z_0^2 - x_0^2} \qquad (4.6)$$

Where $U_{C1}$ – is the voltage that is measured between free and short-circuited phases as shown in figure 1.4.2, $I_{K20}$ – is the short-circuit current, $P_{C1}$ – is the virtual power that is formed with short-circuit current, and is measured with wattmeter connected as shown in figure 4.2.

The test circuit is shown in figure 4.2

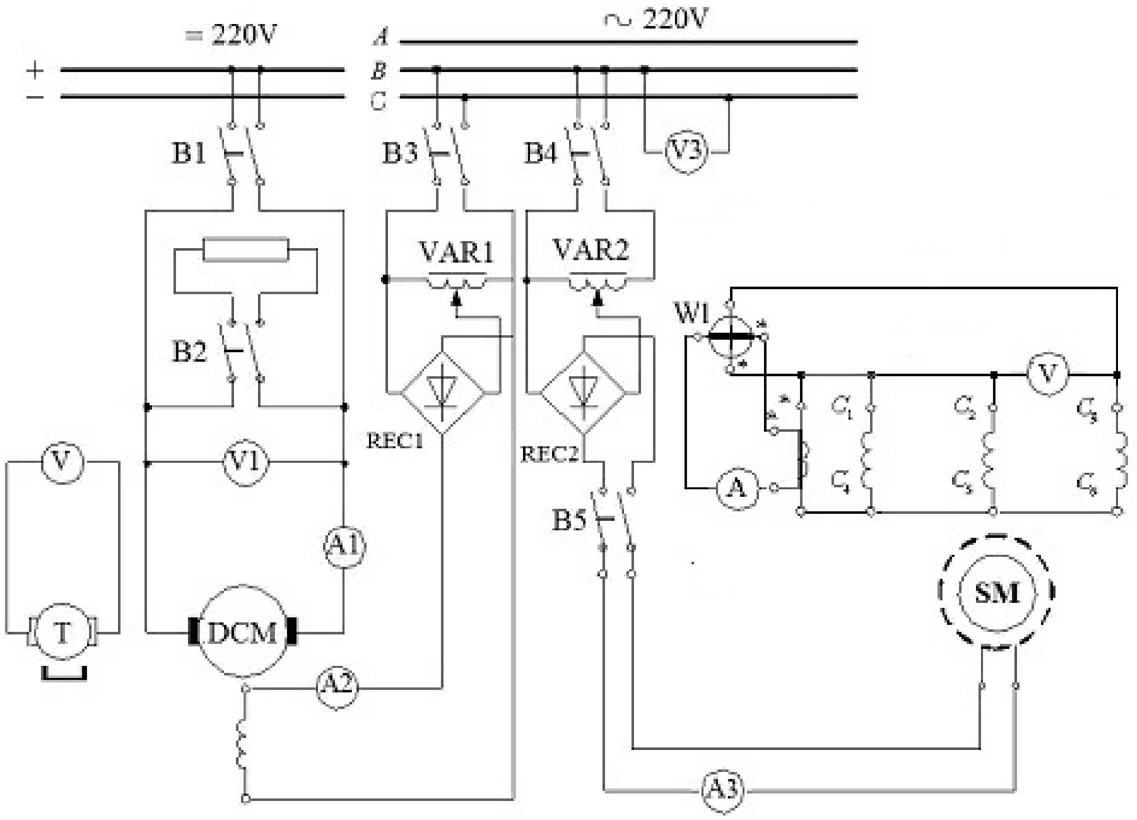


Figure 4.2. Test circuit of the generator under phase-to phase short-circuit test.

## INSTRUCTIONS

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.
2. The voltmeter V is used to measure the voltage between free and short-circuited phases (see figure 4.2). It is useful to connect them to $C_1 - C_3$ terminals with wires. Because of the voltages to be measured may be very different use voltmeter with 150 V range and change it when it is necessary. ***WARNING! When using a multiple range meter always use the high range first to determine the feasibility of using a lower range.***
3. Connect the test circuit as shown in figure 4.2

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE LETHAL. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

4. Start DC motor and set rated speed as described in paragraph 1.
5. Set the minimum of field current of synchronous generator using the variable VAR2.
6. Push black $B_4$ button to switch the field current of the synchronous generator on. **Don't push this button until the minimum of current is not set to avoid breakdown of the variable**.
7. Increase slowly the field current using the variable VAR2 handle until the short-circuit current of the generator $I_{K20}$ is it rated value (16 Amps). Use ammeter A to control the currents.
8. Record the current $I_{K20}$, the voltage $U_{C1}$, the field current $I_f$, and the virtual power $P_{C1}$ in table 4.2

***Table 4.2 Data for the phase-to phase short-circuit test***

| $I_{K20}$, Amps | $U_{C1}$, Volts | $P_{C1}$, Watts | $I_f$, Amps | $Z_0$, Ohms | $X_0$, Ohms | $r_0$, Ohms |
|---|---|---|---|---|---|---|
| 16 | | | | | | |
| 12 | | | | | | |
| 10 | | | | | | |
| 5 | | | | | | |
| | | | 0 | | | |

9. Repeat the previous step by reducing the current $I_f$ as shown in table 4.2 and record all values in table 4.2. Note that the last measurement is done when the field current of the generator is equal to ZERO. To make this test turn off the variable VAR2 and press the red button $B_4$.
10. Stop the DC motor by pressing the red $B_1$ button.
11. Turn off the variable VAR1 and press the red button $B_3$.
12. Switch off the supply voltage

**WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!**

***Tip: This generator will also be used in the next part of the experiment, so leave the necessary connections intact when this part is finished.***

**REPORT**

- Calculate the phase negative-sequence reactance $x_2$, the phase negative-sequence impedance reactance $z_2$, and phase negative-sequence resistance $r_2$ by formulae (4.4-4.6) and record computed values in table 4.2.
- Plot the current $I_{K20}$ against the current $I_f$

## 4.3. Phase-to-neutral short circuit test

The phase-to-neutral short circuit test is used to determine currents and voltages that occur at this mode.

The test circuit is shown in figure 4.3

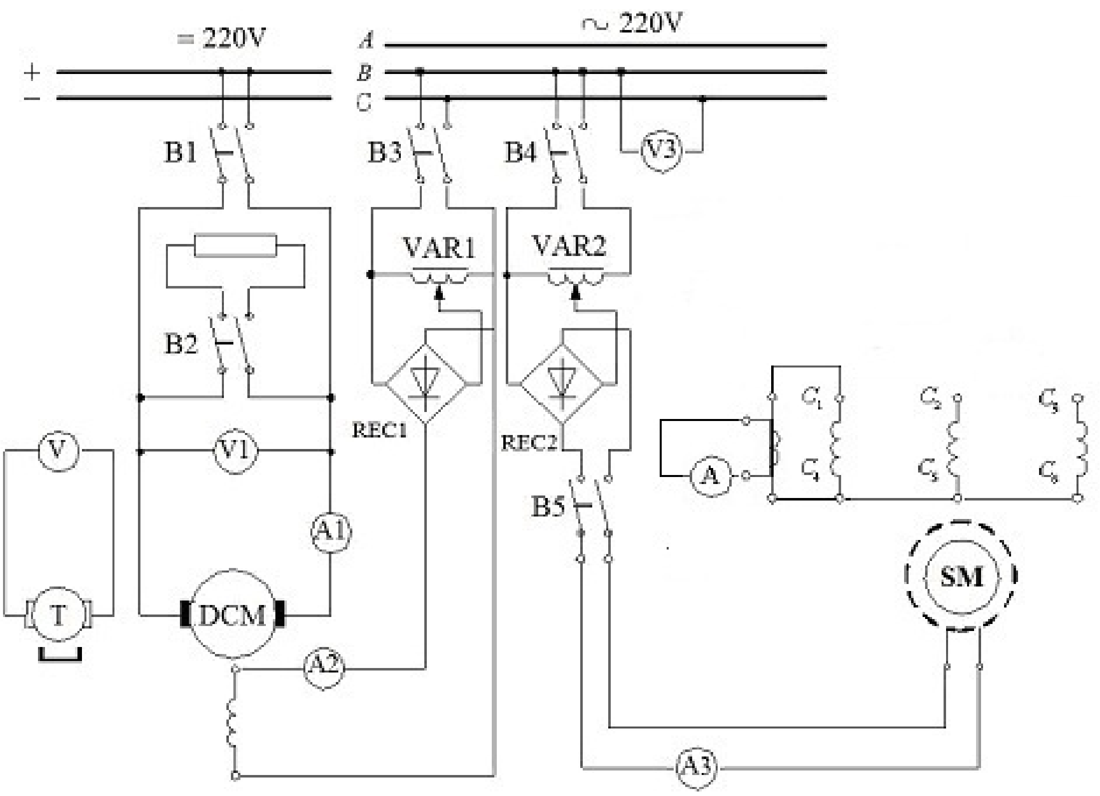


Figure 4.3. Test circuit of the generator under phase-to phase short-circuit test.

## *INSTRUCTIONS*

1. Choose ammeters with 5A range or set this limitation by turning the switch handle.
2. Connect the test circuit as shown in figure 4.3

## WARNING!

**THE VOLTAGES USED IN THIS EXPERIMENT ARE <u>LETHAL</u>. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING**

**NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

3. Start DC motor and set rated speed as described in paragraph 1.
4. Set the minimum of field current of synchronous generator using the variable VAR2.
5. Push black $B_4$ button to switch the field current of the synchronous generator on. **<u>Don't push this button until the minimum of current is not set to avoid breakdown of the variable</u>**.
6. Increase slowly the field current using the variable VAR2 handle until the short-circuit current of the generator $I_{K10}$ is it rated value (16 Amps). Use ammeter A to control the currents.
7. Record current $I_{K10}$, and the field current $I_f$ in table 4.3

| ***Table 4.3 Data for the phase-to phase short-circuit test*** | |
|---|---|
| $I_{K10}$, *Amps* | $I_f$, *Amps* |
| 16 | |
| 12 | |
| 10 | |
| 5 | |
| | 0 |

8. Repeat the previous step by reducing the current $I_f$ as shown in table 4.3 and record all values in table 4.3. Note that the last measurement is done when the field current of the generator is equal to ZERO. To make this test turn off the variable VAR2 and press the red button $B_4$.
9. Stop the DC motor by pressing the red $B_1$ button.

10. Turn off the variable VAR1 and press the red button $B_3$.

11. Switch off the supply voltage

**WARNING! DON'T DISASSEMBLE OR MODIFY A CIRCUIT OR TOUCH ANY TERMINALS UNTIL THE MOTOR IS STOPPED!**

**REPORT**

Plot the current $I_{K10}$ against the current $I_f$

# 5. EQUIVALENT CIRCUITS SYNCHRONOUS MACHINE PARAMETERS DETERMINATION

## 5.1 Subtransient inductive reactacne determination by using static method

The subtransient direct axis and quadrature axis inductive reactances $x''_d$ and $x''_q$ are used to calculate sudden transient modes such as for example sudden short-circuit. In this case influence of mutual inductance links between stator and rotor windings must be taken into account.

Equivalent circuits for d-axis and q-axis subtransient inductive reactances are respectively shown in figures 5.1 and 5.2.

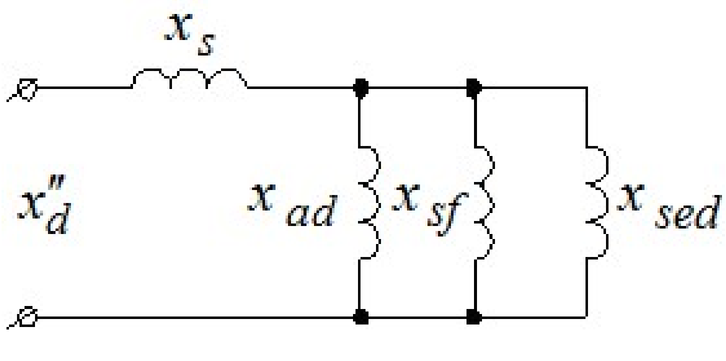


Figure 5.1 Equivalent circuit for d-axis subtransient inductive reactance

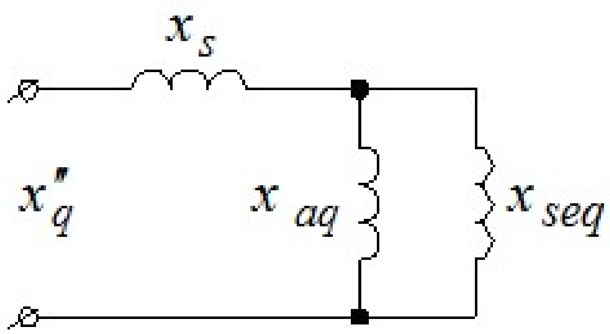


Figure 5.2 Equivalent circuit for q-axis subtransient inductive reactance

Where $x_s$ – leakage reactance of stator winding; $x_{sf}$ – leakage reactance of field winding; $x_{sed}$ – d-axis leakage reactance of damp winding; $x_{seq}$ – q-axis leakage reactance of damp winding; $x_{ad}$ – direct-axis armature reaction reactance; $x_{aq}$ – quadrature-axis armature reaction reactance.

These reactances may be determined experimentally when rotor is fixed and the field winding is shorted. In this case stator circuit must be fed by reduced sinusoidal form fixed frequency voltage.

Note that the electric transient usually runs faster than mechanical, so the air-gap field may be considered as fixed. For this reason, during the test the magnetic field in the air gap must be pulsing and fixed, and the rotor must be fixed so that its direct or quadrature axis matches to the axis of the air gap magnetic field. When the direct axis of the rotor matches to the axis of the air gap magnetic field the d-axis subtransient inductive reactance $x''_d$ may be evaluated, and when the quadrature axis of the rotor matches to the axis of the air gap magnetic field the q-axis subtransient inductive reactance $x''_q$ may be evaluated.

In normal symmetrical feeding there is a time point when currents in two phases are equal but opposite in sign, and the current of the third phase is equal to zero. This distribution of current is realized with using the test circuit shown in figure 5.3

The reactance $x''_d$ may be calculated by formulae:

$$z''_d = \frac{U}{2I}; \qquad r''_d = \frac{P}{2I^2}; \qquad x''_d = \sqrt{z''^2_d - r''^2_d} \qquad (1.5.1)$$

The reactance $x''_q$ may also be calculated by (5.1)

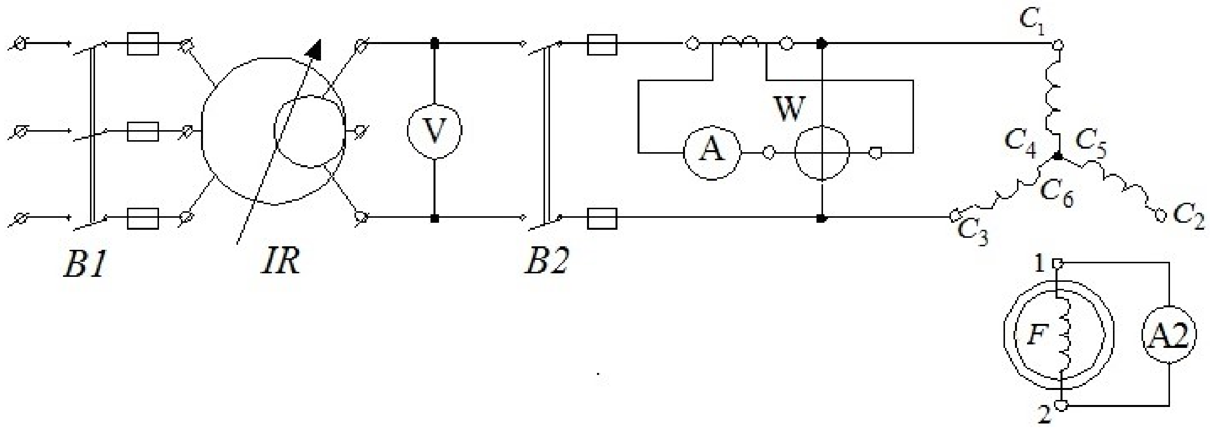


Figure 5.3 Test circuit for subtransient inductive reactance determination

## *INSTRUCTIONS*

1. Choose ammeters with 5A range or set this limitation by turning the switch handle. Use the current transformer to connect ammeter A2.
2. Use the voltmeter $V_3$ with 150 V range to measure the voltage.
3. Use the wattmeter 5A range and 150V range when making measurement.
4. Connect the test circuit as shown in figure 5.3

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE <u>LETHAL</u>. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH**

**THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

5. Set the switcher on the back panel of setup into STATIC mode. Make sure that the “C” lamp is brightly glows.
6. Set the minimum test voltage by using the induction regulator IR handle. Make sure that the “Min” lamp is brightly glows.
7. Push black $B_1$ button to switch the induction regulator on.
8. Push black $B_2$ button to switch the test voltage on.
9. Increase slowly the voltage using the induction regulator IR handle until the test voltage U is 100 V. Record the voltage *U*, the current *I* , the power *P* in table 5.1

| ***Table 5.1 Measured data for determining $x''_q$ reactance*** | | |
|---|---|---|
| *U, Volts* | *I, Amps* | *P,, Watts* |
| 100 | | |
| 50 | | |

10. Repeat the previous step by reducing the voltage *U* in 50 V and record all values in table 5.1
11. Increase slowly the voltage using the induction regulator IR handle until the test voltage U is 100 V.
12. Rotate slowly the rotor of synchronous machine until the test current I is maximum value. Fix the rotor and record the voltage

$U$, the current $I$ , the power $P$ in table 5.2. **Warning don't increase the voltage and move the rotor when measuring.**

| *Table 5.2 Measured data for determining $x''_d$ reactance* | | |
|---|---|---|
| *U, Volts* | *I, Amps* | *P,, Watts* |
| 100 | | |
| 50 | | |

13. Release the rotor and turn off the voltage and consequently press red $B_2$ and $B_1$ buttons to switch off the supply voltage.

**REPORT**

1. Compute the parameter $x''_d$ by formulae (5.1) and record all calculated parameters in table 5.3

| *Table 5.3 Calculated data for determining $x''_d$ reactance* | | |
|---|---|---|
| *$R''_d$, Ohms* | *$Z''_d$, Ohms* | *$X''_d$, Ohms* |
| | | |
| | | |

Then calculate the average value of resistance, reactance, and impedance.

2. Compute the parameter $x''_q$ by formulae (5.1) and record all calculated parameters in table 5.4

| Table 5.4 Calculated data for determining $x''_q$ reactance | | |
|---|---|---|
| $R''_q$, Ohms | $Z''_q$, Ohms | $X''_q$, Ohms |
| | | |
| | | |

Then calculate the average value of resistance, reactance, and impedance.

## 5.2 Zero sequence parameters measurement test

The zero sequence parameters measurement test is used to determine impedance $Z_{0n}$, resistance $R_{0n}$ and reactance $X_{0n}$ that is used to calculate zero-sequence components of currents and voltages that occur in unsymmetrical modes.

The test circuit is shown in figure 5.4.

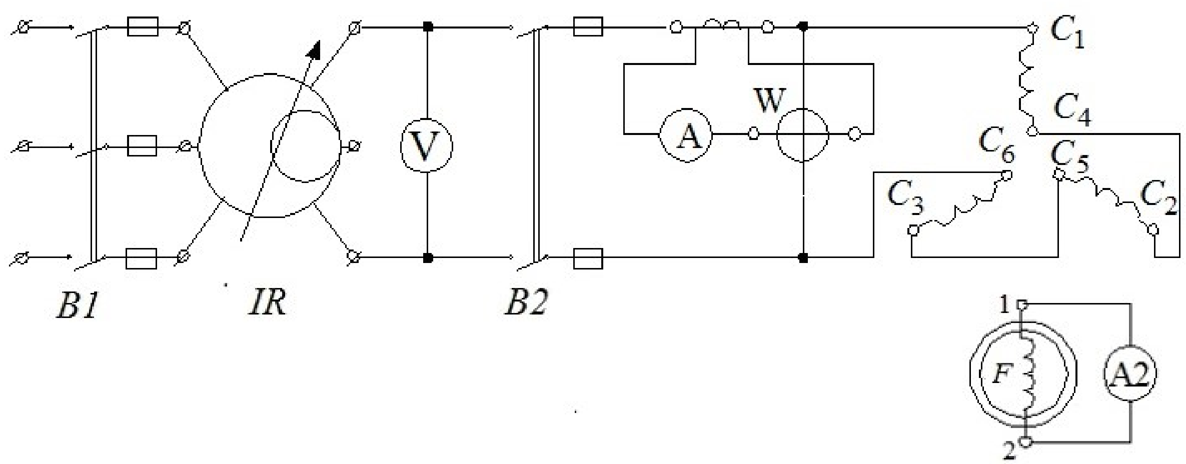


Figure 5.4. Test circuit for the zero-sequence inductive reactance determination

### *INSTRUCTIONS*

1. Choose an ammeter A with 5A range or set this limitation by turning the switch handle.

2. Use the voltmeter $V_3$ with 150 V range to measure the voltage.
3. Use the wattmeter 5A range and 150V range when making measurement.

***<u>WARNING! When using a multiple range meter always use the high range first to determine the feasibility of using a lower range.</u>***

4. Connect the test circuit as shown in figure 5.4.

**WARNING!**

**THE VOLTAGES USED IN THIS EXPERIMENT ARE <u>LETHAL</u>. ASSEMBLE OR MODIFY A CIRCUIT ONLY WITH THE BREAKERS OFF. DO NOT APPLY POWER UNTIL THE WIRING HAS BEEN CHECKED BY AN INSTRUCTOR. DO NOT TOUCH ANY NODE OR COMPONENT OF A LIVE CIRCUIT. BE CAREFUL WHEN MOVING NEAR A CIRCUIT SO THAT A WIRE IS NOT ACCIDENTALLY SNAGGED.**

5. Set the minimum of voltage using the induction regulator ИР1. Make sure that the “Min” indicator lamp lights.
6. Push black $B_1$ button to switch the induction regulator on.
7. Push black $B_2$ button to switch the test voltage on.
8. Increase slowly the voltage using the induction regulator ИР1 handle until the test circuit current $I_0$ is 10 Amps. Use ammeter to control this current.
9. Record the voltage $U_0$, the current $I_0$ , the power $P_0$ in table 5.5

| *Table 5.5 Measured data for determining zero-sequence parameters* | | |
|---|---|---|
| *$I_0$, Amps* | *$U_0$, Volts* | *$P_0$, Watts* |
| 10 | | |
| 5 | | |

10. Repeat the previous step by reducing the current $I_0$ in 5 A and record all values in table 1.5.5
11. Turn off the voltage and consequently press red $B_2$ and $B_1$ buttons to switch off the supply voltage.

**REPORT**

Compute the parameter $R_{0n}$ and $X_{0n}$ by first calculating

$$Z_{0n} = \frac{U_0}{3I_0} \qquad (1.2)$$

$$R_{0n} = \frac{P_0}{3{I_0}^2} \qquad (5.3)$$

The above results can then be used to find

$$X_{0n} = \sqrt{{Z_{0n}}^2 - {R_{0n}}^2} \qquad (5.4)$$

Record all calculated parameters in table 5.6

| *Table 5.6 Calculated data for determining zero-sequence parameters* | | |
|---|---|---|
| *$R_{0n}$, Ohms* | *$Z_{0n}$, Ohms* | *$X_{0n}$, Ohms* |
| | | |
| | | |

Then calculate the average value of resistance, reactance, and impedance.

## THE LIST OF THE USED LITERATURE


1. Vol'dek A.I., Popov V.V. Jelektricheskie mashiny. Mashiny peremennogo toka. SPb: Piter, 2010.
2. Zherve G.K. Promyshlennye ispytanija jelektricheskih mashin. L: Jenergija, 1968, 574s.