SYNCHRONOUS GENERATOR – SYNCHRONIZATION OF UNLOADED MACHINE TO THE GRID, V-CURVES

1. ASSIGNMENT:
   A) Connect synchronous generator to the grid.
   B) Measure V-curves of the generator.

2. SCHEMATICS:

   Figure 1: Measurement schematics

   Figure 2: Synchronizing apparatus
3. NOMINAL PARAMETERS OF MACHINES:

<table>
<thead>
<tr>
<th>Synchronous Machine</th>
<th>Dynamometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Power</td>
<td>10 kVA</td>
</tr>
<tr>
<td>Active Power</td>
<td>8 kW</td>
</tr>
<tr>
<td>Cos φ</td>
<td>0.8</td>
</tr>
<tr>
<td>Armature Voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Armature Current</td>
<td>14.5 A</td>
</tr>
<tr>
<td>Excitation Voltage</td>
<td>32 V</td>
</tr>
<tr>
<td>Excitation Current</td>
<td>7.6 A</td>
</tr>
<tr>
<td>Revolutions</td>
<td>1500 RPM</td>
</tr>
<tr>
<td>Power</td>
<td>5.7 kW</td>
</tr>
<tr>
<td>Armature Voltage</td>
<td>220 V</td>
</tr>
<tr>
<td>Armature Current</td>
<td>32,6 A</td>
</tr>
<tr>
<td>Revolutions</td>
<td>1600 RPM</td>
</tr>
</tbody>
</table>

4. CONDITIONS FOR SYNCHRONIZING:
   a) Same phase sequence of generator and grid.
   b) Similar frequencies in grid and generator (not the same!).
   c) Same amplitude and waveform of voltage of generator and grid.
   d) Minimal phase shift between corresponding phases of generator and grid in the moment of connection.

5. MEASUREMENT PROCEDURE:

5.1. Connecting the Apparatus
   Connect the measurement apparatus according the schematics in Figure 1. For measurement of active power and current in the first phase of the synchronous machine use the current transformer – use range 5 A both on ammeter and wattmeter and on the current transformer choose 10 A input.
   Connect the synchronization apparatus according Figure 2.

5.2. Synchronization
   To connect synchronous generator to the grid you need to meet the conditions listed in section 4. To do so, follow this procedure:
   a) Verify that there are the same phase sequences for the generator and the grid.
      - Connect a phase sequence meter to the grid terminal and examine the direction of rotation.
      - Connect a phase sequence meter to the generator terminal and examine the direction of rotation. (Voltage terminals are connected even when the synchronous machine control lever is not pressed). It should be the same as in the case of grid. If not, swap two mains of one of the systems or change rotation direction of the generator.
Note: *Phase sequence meter is based on principle of induction motor with large rotor resistance. It rotates in direction which depends on the phase sequence.*

b) Adjust the similar frequencies of the generator and the grid
- Control the generator frequency at frequency meter $f_g$.
- It should be similar to the grid frequency measured at frequency meter $f_s$. If not, adjust machine’s speed.

c) Adjust the same voltage
- Control generator voltage at voltmeter $V_g$ and grid voltage at voltmeter at $V_s$.
- If it is not the same, adjust the excitation current of the generator.

d) Control the phase shift
- At the same grid and generator voltage the difference voltmeter $\Delta V$ shows the voltage, which is proportional to the difference between the relevant phasors. It changes as phasors rotate in regard to each other.
- When the voltage at the difference voltmeter is equal to zero there is no phase shift between grid and generator.

When all conditions are met, it is possible to synchronize the generator to the grid without current surge.

5.3. V-Curves measurement

V-curve is a dependency of stator current $I_S$ on excitation current $I_E$ at constant active power:

$$I_S = f(I_E), P = \text{const.}$$

Example of V-curves is depicted in Figure 4. Non-zero value of stator current $I_{S\text{min}}$ for $\cos \varphi = 0, P = 0$ is caused by unequal shapes of grid and machine voltage waveforms.

Figure 4: V-Curves
• Measure with the setup according to Figure 1 with synchronous generator connected to the grid according to 5.2.
• Measure V-curve for four different values of active power $P$. Keep $P$ constant during the whole measurement of the V-curve at chosen active power. As first value of $P$ choose 0 W. For easier measurement you can choose values of active power equal to dynamometer torque values: 0 Nm (=0 W), 5 Nm, 10 Nm and 15 Nm.
• Set the excitation current in the way that stator current would be equal to $1.1 I_S$ of nominal value.
• Record the values of stator current $I_S$ on excitation current $I_E$.
• Control the mechanical power by voltage at the dynamometer armature in the way that active power of the machine remains constant.
• Decrease the excitation current during the measurement until it reaches zero or the generator falls out of synchronism.
• If the generator falls out of synchronism, end the measurement of the V-curve at given $P$, connect synchronous generator to the grid according to 5.2 and start the measurement of the next V-curve.

6. MEASUREMENT REPORT:

Each student will create measurement report. The report will contain:
• Name of laboratory exercise.
• Date of measurement.
• Student’s name.
• Assignment.
• Schematics.
• A brief summary of the procedure.
• Measured data (only for V-curves).
• Graphs plotting measured data – create them in the similar way as in Figure 4 (only for V-curves).
• Conclusion – evaluate the measurement (evaluate both – phasing and V-curves).