Generator Synchronising Simulator

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SYNCHRONISING

Synchronising is the process of matching two a.c. supplies prior to closing a circuit breaker, paralleling the two supplies. The turbine/alternator conditions are termed ”incoming” and the system conditions called ”running”.

The parameters to be matched are, voltage, frequency (speed) and phase angle.

When the turbine/alternator is up to speed, the alternator field is excited and the voltage adjusted to match ”system” voltage.

A synchroscope indicates the difference in speed and phase angle, between the incoming and running supplies. If the incoming speed is faster than the running speed, the pointer on the synchroscope will rotate in a clockwise (fast) direction. If the speed is lower than the running speed, it will rotate anticlockwise (slow). When the pointer is stationary the incoming and running speeds are identical. The two supplies are in phase when the pointer is at 12 o’clock. It is preferable, at the point of closing the circuit breaker, that the incoming speed is slightly faster than the running speed, i.e. indicated by a clockwise rotation on the synchroscope. The pointer should also be at the 12 o’clock position, when the circuit breaker is closed. The slightly faster speed ensures that there will, immediately be a small MW output from the alternator. Matching the phase angle causes less disturbance to the system. Figure 1 shows a synchroscope.

Figure 1: Synchroscope

NOTE: When a cold machine is being brought up to speed it is sometimes necessary to warm-up the alternator rotor, so that there is no sudden thermal shock when the excitation is applied. A small amount of excitation at low speed will be enough to achieve the rotor warm-up.

EFFECTS OF FAULTY SYNCHRONISING

If timing, or voltage adjustment is markedly in error when a generator is connected to the system there will be a sudden flow of overcurrent which may damage the generator. The severity of the overcurrent surge will depend on the phase or voltage error, and the impedance of the generator-to-system loop. This loop includes the transient reactance of the generator itself, the reactance of its transformer (if present) and the internal impedance of the busbars (which is usually low). A "bad shot" at synchronising is likely to have similar effects on a generator to a three phase fault on the output side of its transformer. If the generator is paralleled when there is phase opposition the voltage available to produce fault current could approach twice normal voltage and so correspondingly increase current.

As with overcurrent from any other cause, the undesirable effects are those due to conductor heating and electo-magnetic forces.

In most cases of bad synchronising the periods during which the initial heavy current flows is fairly short and so the value of I^2R is not high and does not produce unacceptable heating in the conductors.

There is a very brief period after the CB is closed when a high transient current may flow.
It is the electro-magnetic forces produced by these sudden high current particularly in the unsupported parts of the conductors comprising the end turns of the generator windings which are likely to cause mechanical shock and distortion. This may cause damage to insulation particularly near the position where the conductors emerge from the stator slots.

Recall that two conductors while carrying current produce mutual, forces, which depend directly on the product of their two currents and inversely on their separation distance. The forces are increased if there is magnetic material nearby to increase the magnetic flux which is involved. Note that all factors conducive to producing forces are present in the above situation.

SYNCHRONISING SIMULATOR

The generator synchronising simulator as presented is based upon a 2 pole turbo-generator that will be connected to a 50 Hz grid. The operating window is based on a usual DCS screen layout however many unnecessary controls have been omitted for clarity.

Some liberties have been taken when constructing this simulator with the most obvious item being that the turbine runup for turning gear speed to near synchronise speed is rather quick. A typical steam turbine plant time would be anything from 30 minutes for a Hot start on a smaller turbine up to 12 hours or more for a Cold start on a larger turbine.

Layout of the controls

Figure 2: Overview of Synchronisation application display

A Status panel that shows the steps to complete generator synchronisation. Steps include;

- Turning gear ON
- Run to Speed
- Excitation ON
- AUTO runup Comp
- FSNL
- CB CLOSED

B Turbine START button.

C Synchroscope ON/OFF buttons.

D Synchroscope panel.

E Application QUIT button.

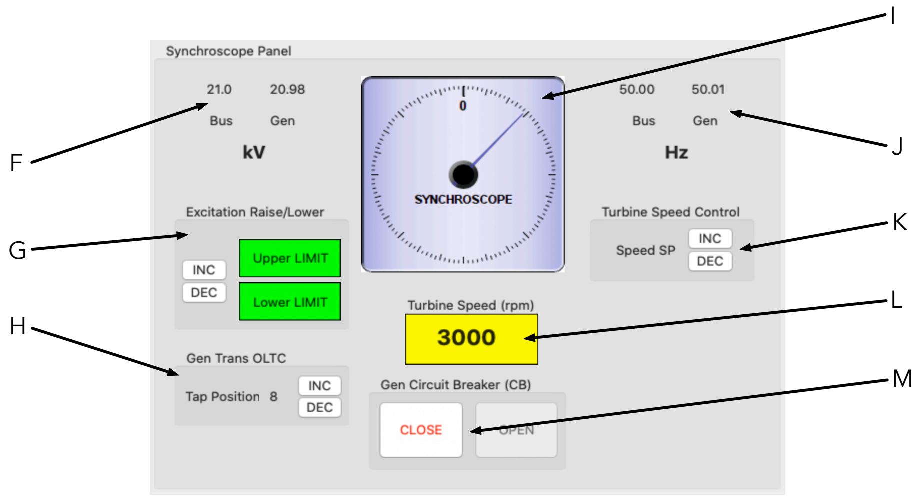

Figure 3: Detail of Synchronisation panel.

F Busbar and Generator Voltage indication.

G Generator Excitation control (Increase/Decrease).

H Gen Transformer OLTC (Increase/Decrease).

I Synchroscope.

J Busbar and Generator Frequency indication.

K Turbine speed control (Increase/Decrease).

L Turbine speed indication.

M Generator CB CLOSE button.

Starting the turbine and Synchronising

When the program is first loaded the display window will look as shown in image 4 below. The turbine will be rotating at or near 35 rpm, which is the turning/barring speed for this machine.

Figure 4: Initial view when program opened.

1. Push the Turbine Controller START button (item B on the layout picture - page 3).

   Once the START button is pushed the turbine will automatically increase speed from the turning speed of 35 rpm up to the AUTO runup Completed speed of 2950 rpm (approx).
   Turbine speed can be monitored using the speed indicator located under the synchroscope (item L on the layout picture - page 4).

2. At a turbine speed of 2900 rpm the generator excitation system will automatically start.

   This is indicated by the Excitation ON status box on the left of the display changing from GREEN to RED (RED means running, GREEN means stopped).

Also at this time the Generator voltage indication (item F on the layout picture - page 4) will start to show the generator terminal voltage.

3. Turn on the synchroscope (item C on the layout picture - page 3). The following will occur;
   - the synchroscope needle will start to rotate (probably anti-clockwise).
   - you now have control of the Excitation raise/lower buttons (items G on the layout picture - page 4).
   - you now have control of the Generator main CB (item M on the layout picture - page 4).

4. Adjust the Generator Transformer OLTC (On Load Tap Changer) and Excitation Raise/Lower controller (items H and G respectively on the layout picture - page 4) to match the Generator voltage to the Busbar voltage.

   NOTE: The transformer OLTC gives course control (large steps) whilst the Excitation raise/lower gives finer control, but has a limited span.

5. At a turbine speed of 2950 rpm the status indication on the left will change to 'AUTO runup Comp' and you will now have access to the Turbine Speed Control increase/decrease buttons (item K on the layout picture - page 4).

   NOTE: The Excitation ON status indication remains on as excitation is required for the entire time the generator is synchronised.

6. At some stage in the turbine runup the Generator frequency indication (item J on the layout picture - page 4) will start to function. This measurement does not work at low speeds.

7. Using the turbine speed control increase/decrease buttons increase the turbine speed (and hence the generator frequency) until the gen frequency matches the busbar frequency (50 Hz in this case).

8. Once the generator and busbar voltages are matched and the generator and busbar frequencies are matched it is only a matter of waiting until the synchroscope needle is approaching the 12 o'clock position (in a clockwise rotation) and then pushing the Gen CB CLOSE button [1].

   The Generator CB will close no matter the frequency, voltage or phase angle error on this machine as it has no protection due to cost overruns. To achieve a good synchronisation and limit damage to the machine try and stay within the following parameters;
   - Gen frequency should be slightly greater than Busbar frequency (e.g. this will be obvious in that it causes the synchroscope needle to rotate clockwise). This is done to ensure the extra momentum of the

[1] However if it was that easy - where would be the challenge. On smaller grids such as the Northern Territory, Australia, or even New Caledonia the system frequency is rather unstable and therefore you need to match the generator speed (frequency) to the grid/busbar frequency at any particular moment. Also voltage can be unstable, especially in New Caledonia due to large arc furnaces at the various nickel smelters, so this is also a moving target during synchronising.

generator rotor will start to generate power as soon as the CB is closed. If synchronised in an anti-clockwise direction, the power will need to come from the busbar back to speed up the generator rotor and this may result in the power being negative until stability is obtained. This negative power may be enough to operate the reverse power relay and trip the generator.

- The speed difference between the generator rotor and the Busbar rotating field should be less than 2 rpm to ensure the best score. This translates to a frequency difference of less than 0.033 Hz.
- Gen CB should be closed just before the 12 o'clock position. If too early then the generator rotor will be pulled into synchonisium causing possible damage. If too late then the force to pull the rotor into synchonisium will be even greater. Gen CB should be closed between 350° and 0° to ensure the best score.
- The difference between generator and busbar voltage needs to be less than 0.2 kV (200 Volts) to ensure the best score. In the case of voltage it can be ± 200 Volts.

9. Once the Generator CB is closed and the machine synchonised to the Busbar your score will be displayed (see Figure 5). Anything less than 50% will result in damage to the turbine and/or generator and involve a long maintenance outage.

10. Once you have analysed your score, just press OK to dismiss the dialog box and you will be returned to the main simulator screen with the turbine back on turning gear ready for another attempt.

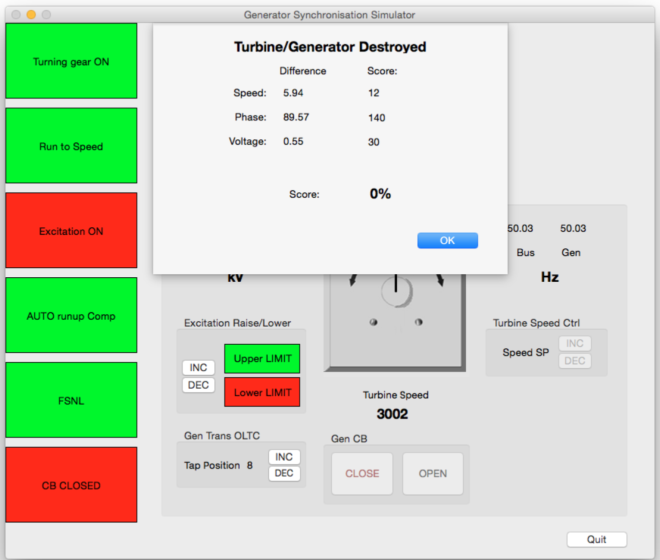

Figure 5: Not a good result

Additions to v1.2

I was never happy with the display of the rotating needle in version 1 of this software and this is the first thing that was updated when the opportunity/time presented itself. The new rotating needle display is much nicer visually.

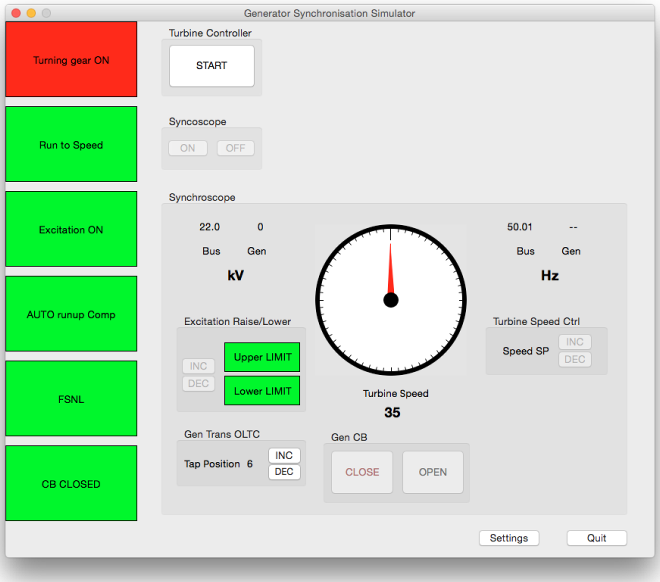

Figure 6: Version 1.2 screenshot with new improved rotating needle display.

Additionally version 1 of this software had only a single preset for instabilities in the voltage and frequency so as to make the synchronising process slightly more difficult. This was realisitic for a small sized grid (approx 100 MW) however a larger grid would be substantially more stable.

Version 1.2 adds a settings screen (see below) that allows both the voltage and frequency instability to be set at Heavy, Medium, Light and None. This window opens when the program is started or may be opened at a latter stage by using the Settings button at the bottom of the main window.

The Heavy setting is still a challenge to attain a good score, whilst the None setting makes it too easy.

When set to Heavy, Medium or Light the instabilities are generated randomly and do not follow a sinusoidal path as previously used.

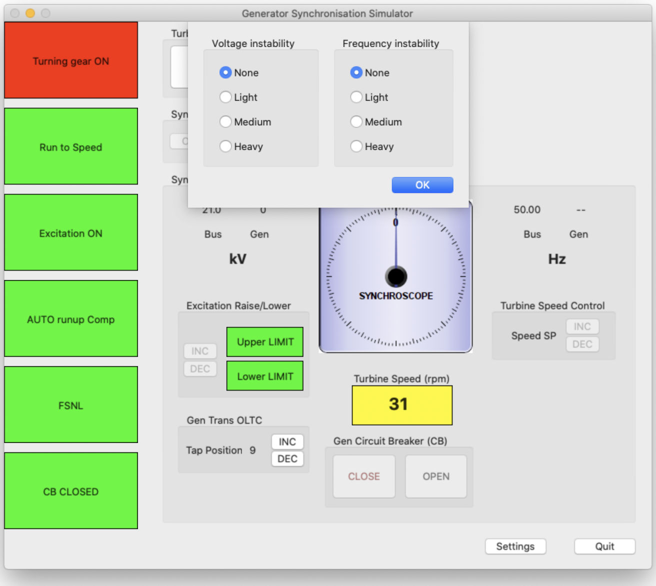

Figure 7: Voltage and frequency instability settings

Additions to v1.4

Code compiled as 64 bit application under macOS.

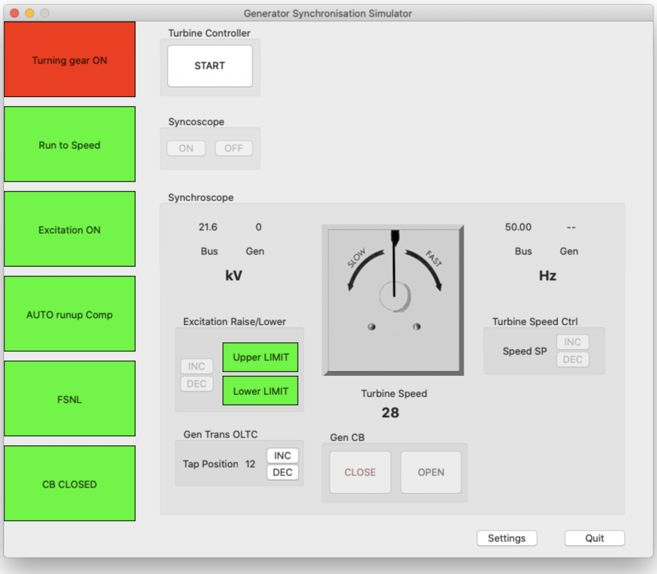

Figure 8: Synchroscope dial has reverted to earlier version as v1.2 upgrade components were not 64 bit compatible.

Additions to v1.5

Code compiled as 64 bit application under macOS for both Intel and ARM processors.

Figure 9: Synchroscope dial has been improved again.