

Generator Synchronising Simulator

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The sole purpose of this document is to provide a guide to the accompanying application.

Use the information contained at your own risk.



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Acknowledgements

Whilst writing the associated application and preparing this documentation and various tutorial videos, I have managed to combine my hobby of computer programming and my years working at various power plants around the world for my own enjoyment and satisfaction.

Whilst I am happy of the outcome, I do realise that improvements could be made. It may be in the future I will take another look at this program and update/improve it further.

I would like to acknowledge the following people and/or programming utilities that both inspired me and allowed this program to be written.

All the great training provided by the New Zealand Electricity Department/ Electriccorp/Genesis Energy during my time as a young technician.

Some great power plants around the world that allowed me to contribute and share knowledge, including Huntly - New Zealand, Paiton - Indonesia, MapTaPhut - Thailand, Manjung - Malaysia, Babelan - Indonesia, Koniambo - New Caledonia, Tihama Power - Saudi Arabia.

Christian Schmitz MBS (MonkeyBread Software)) Chart Director plugin used for various gauges/instruments.



Application files can found on my webpage at richardspowergenerationpage.com

Tutorial videos can be found on YouTube at <https://www.youtube.com/@RichardSmith-zc9zi>



1 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 "running" 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 dial face

2 Effects of Faulty Synchronising

If frequency, phase angle, or voltage is markedly in error when a generator is connected to the system there will be a sudden flow of current which may damage the generator. The severity of the current 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 flow.

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

3 Synchronising Simulator

The generator synchronising simulator as presented is based upon a 2 pole turbo-generator that will be connected to a 50 or 60 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. Gas turbine based plant can be quicker than that, especially if they are designed as peaker units and a 10 minute startup from cold to synchronising is not unheard of.

3.1 Settings

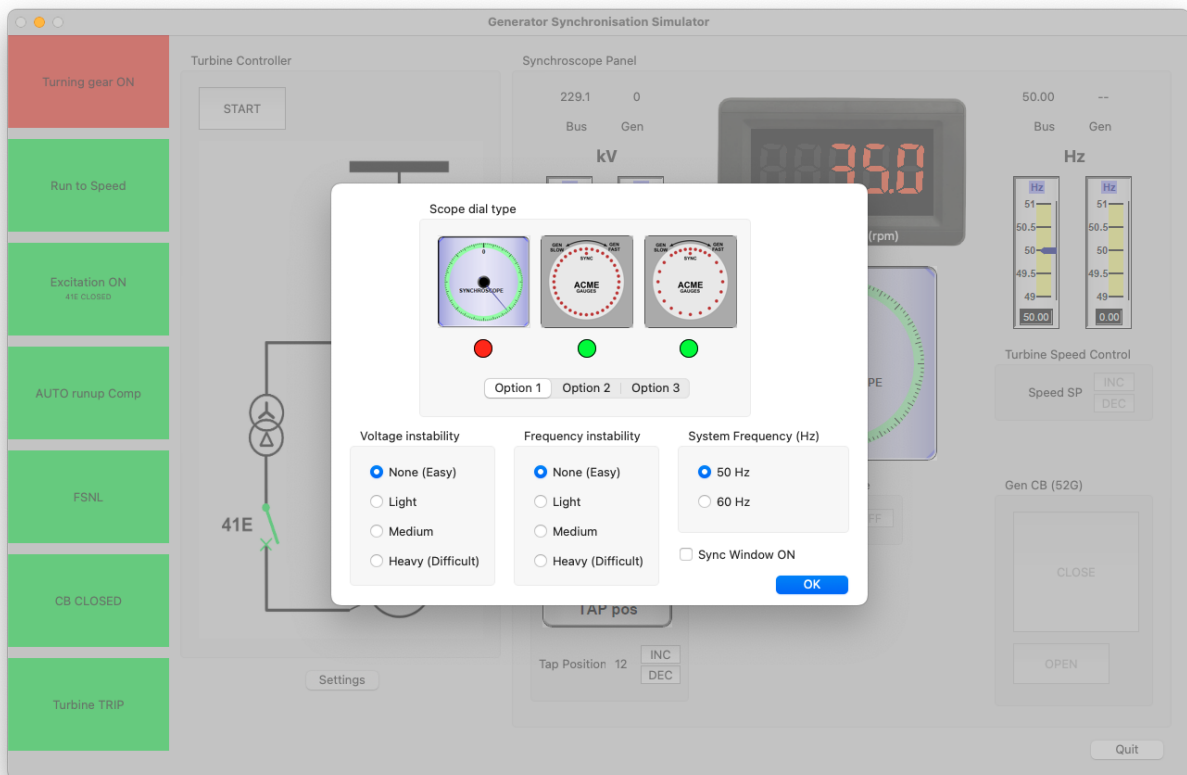


Figure 2: Settings window

When the program is first opened or by pressing the Settings button, the Settings window will appear as shown in image 2 above. Using this window it is possible to;

- Select the style of synchroscope gauge/dial you would prefer to use (Option 1, 2 or 3).
- Select the degree of Voltage instability from None to Heavy.
- Select the degree of Frequency instability, again from None to Heavy.
- Select either a 50 or 60 Hz system frequency.
- Enable a Sync Check window feature. This enforces a window of 350 to 360 degrees and will not close the generator circuit breaker if the synchroscope is outside that range. This makes it much easier to synchronise to the grid - but where is the fun in that.

Additionally if you have internet access, a message will be displayed along the bottom of the window indicating the current update status. It will display, either;

- You are running the current version of this software - everything is up to date, please continue to use this program.
- Update is available - richardspowergenerationpage.com - a new version is available for download. Click on this text and you will be taken to the download page.
- Unable to check for software update - access to the internet is not available.

3.2 Layout of the controls

The main program window consists of three separate areas, as follows;

Left panel - Turbine/generator runup status panel is displayed at the left edge of the application window.

Centre panel - SLD (Single Line Diagram) of the electric system.

Right panel - Main synchronising panel display.

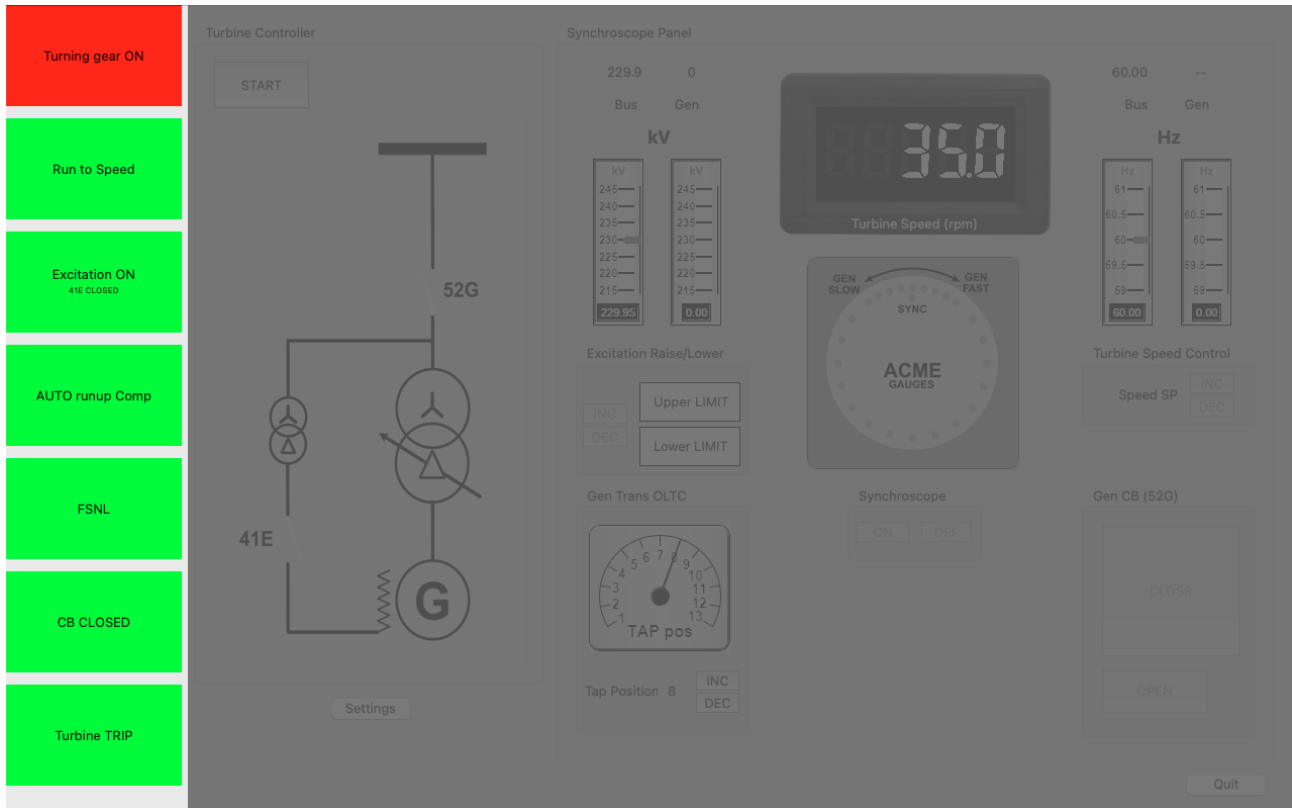


Figure 3: Left panel - Turbine runup status indication lights.

A turbine/generator runup status panel is displayed at the left edge of the application window. This indicates the current step and progress towards generator synchronisation.

- Turning gear ON
- Run to Speed
- Excitation ON
- AUTO runup Comp
- FSNL (Full Speed No Load)
- CB CLOSED
- Turbine TRIP

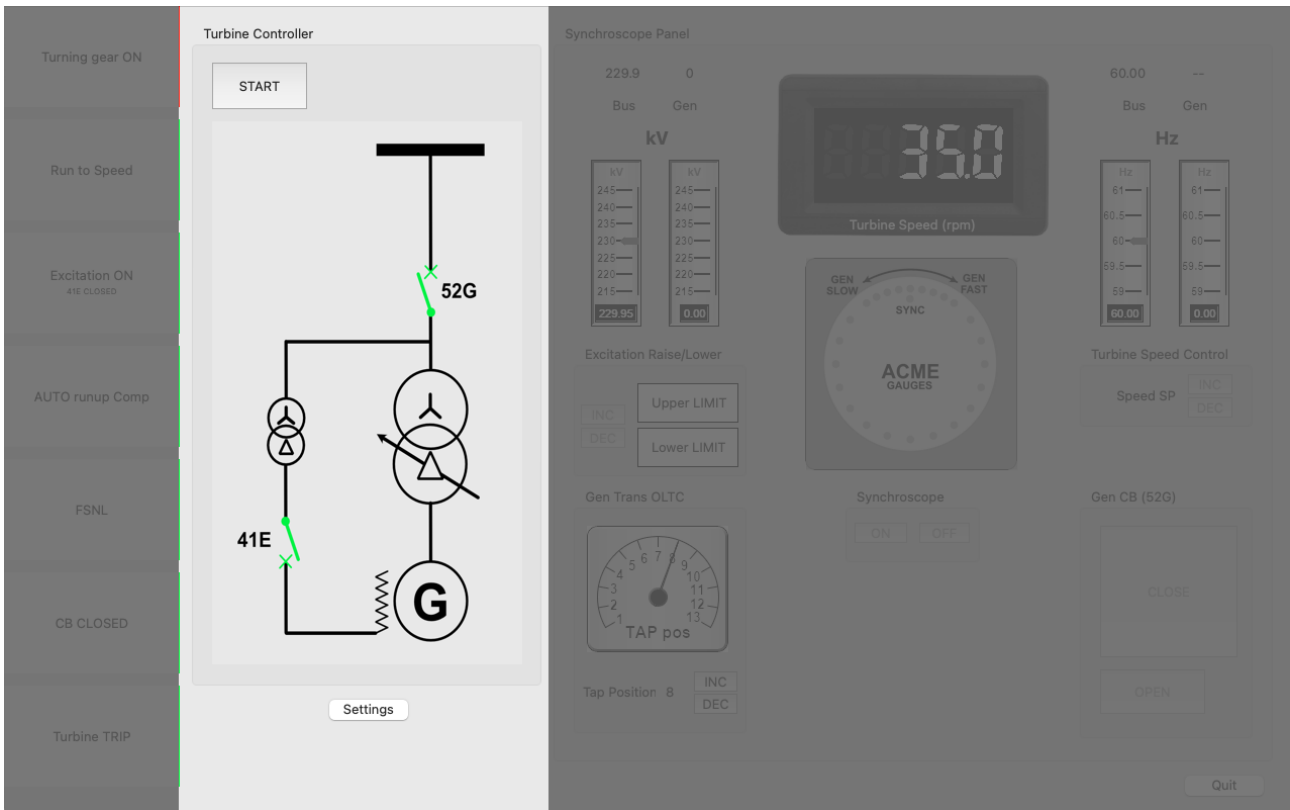


Figure 4: Centre panel - SLD (Single Line Diagram) of electrical system.

A SLD (Single Line Diagram) of the electric system is displayed in the centre panel. This consists of the following components;

- Generator (symbol G).
- Main transformer (Delta/Star configuration) with OLTC (On-Load-Tap-Changer).
- Excitation transformer.
- Excitation circuit breaker (41E)
- Main Generator circuit breaker (52G)
- Turbine Controller START button.

Below the SLD is a SETTINGS button that can be used to select the type of synchroscope gauge to display, and the running voltage and frequency instability. This is explained more in section 3.1.

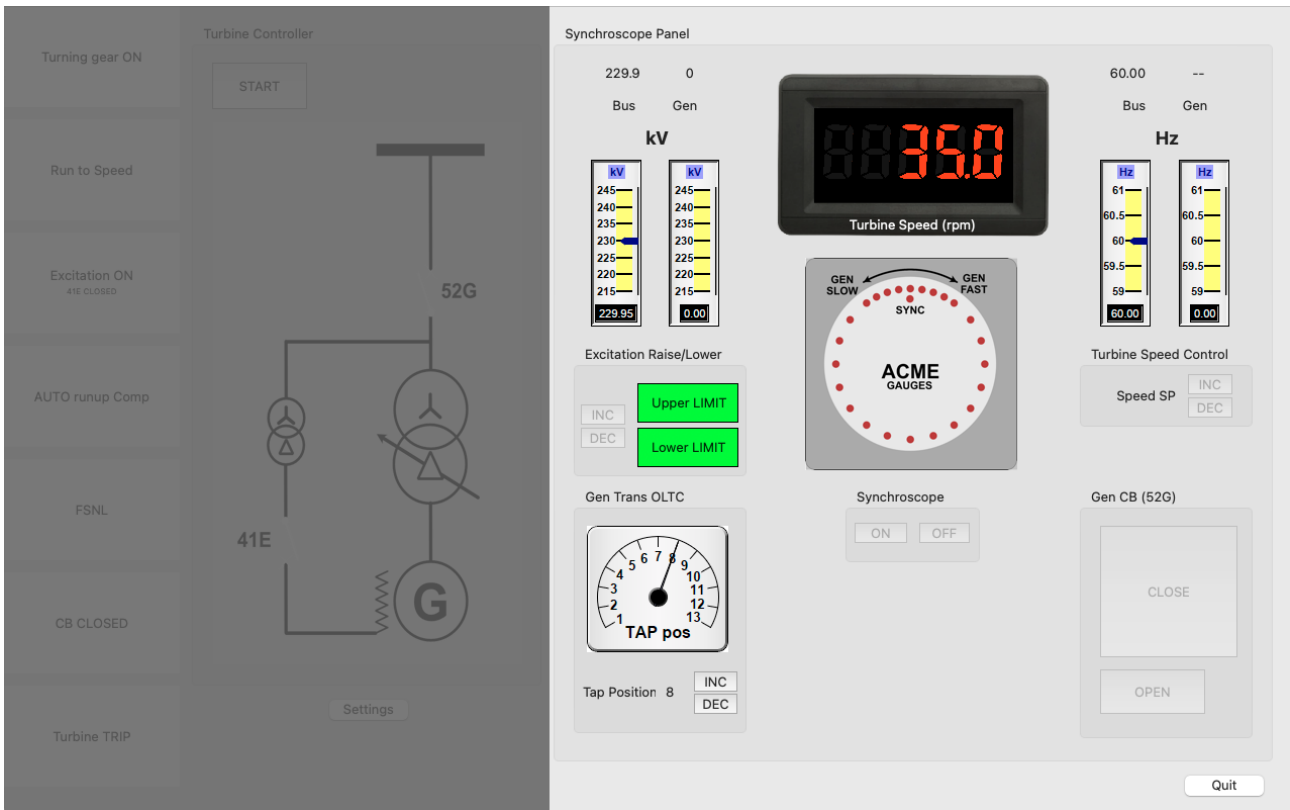


Figure 5: Right panel - Synchronising panel.

On the right side of the application window is the main synchronising panel display.

This panel can be further broken down to the individual gauges, instruments and control buttons as follows;

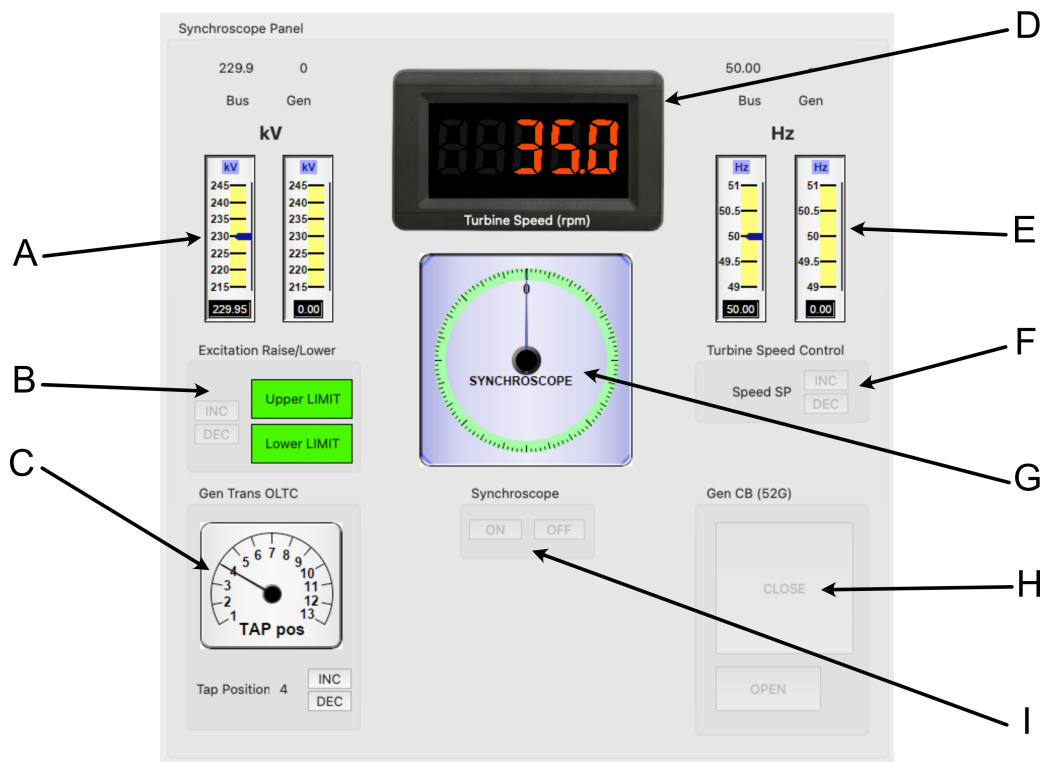


Figure 6: Detail of Synchronisation panel.

A Busbar and Generator Voltage indication.

- B Generator Excitation control (Increase/Decrease).
- C Gen Transformer OLTC (Increase/Decrease).
- D Turbine speed indication.
- E Busbar and Generator Frequency indication.
- F Turbine speed control (Increase/Decrease).
- G Synchroscope.
- H Generator CB CLOSE button.
- I Synchroscope ON/OFF buttons.

3.3 Starting the turbine and Synchronising

When the program is first loaded the display window will look as shown in image 7 below. The turbine will be rotating at or near 35 rpm, which is the turning/barring speed for this machine.

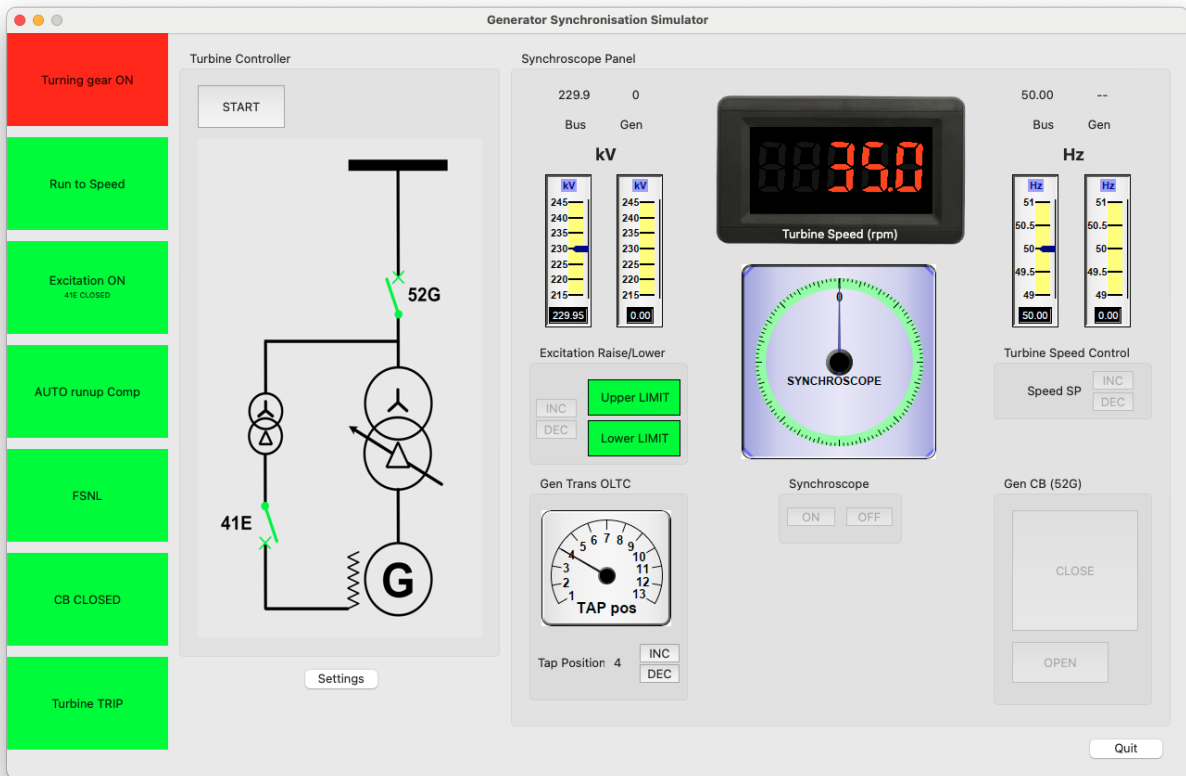


Figure 7: Initial view when program opened.

1. Push the Turbine Controller START button

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 approximately 2950 rpm (3550 rpm if 60Hz machine has been selected).

Turbine speed can be monitored using the speed indicator located above the synchronoscope (item D on the layout picture - page 10).

2. At a turbine speed of 2900 rpm (3500 rpm if 60Hz machine has been selected) 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) and the excitation circuit breaker (41E) will indicate closed on the SLD (Single Line Diagram) of the electrical system.

Also at this time the Generator voltage indication (item A on the layout picture - page 10) will start to show the generator terminal voltage.

3. Turn on the synchronoscope (item I on the layout picture - page 10). The following will occur;
 - the synchronoscope needle will start to rotate (probably anti-clockwise).
 - you now have control of the Excitation raise/lower buttons (items B on the layout picture - page 10).
 - you now have control of the Generator main CB (item H on the layout picture - page 10).
4. Adjust the Generator Transformer OLTC (On Load Tap Changer) and Excitation Raise/Lower controller (items C and B respectively on the layout picture - page 10) to match the Generator voltage to the Busbar voltage.

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

5. At a turbine speed of approximately 2950 rpm (3550 rpm if 60Hz machine has been selected) 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 F on the layout picture - page 10).

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 E on the layout picture - page 10) 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 or 60 Hz depending on selection).
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 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 synchronism causing possible damage. If too late then the force to pull the rotor into synchronism 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.

9. Once the Generator CB is closed and the machine synchronised to the Busbar your score will be displayed (see Figure 8). 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.

¹However 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.

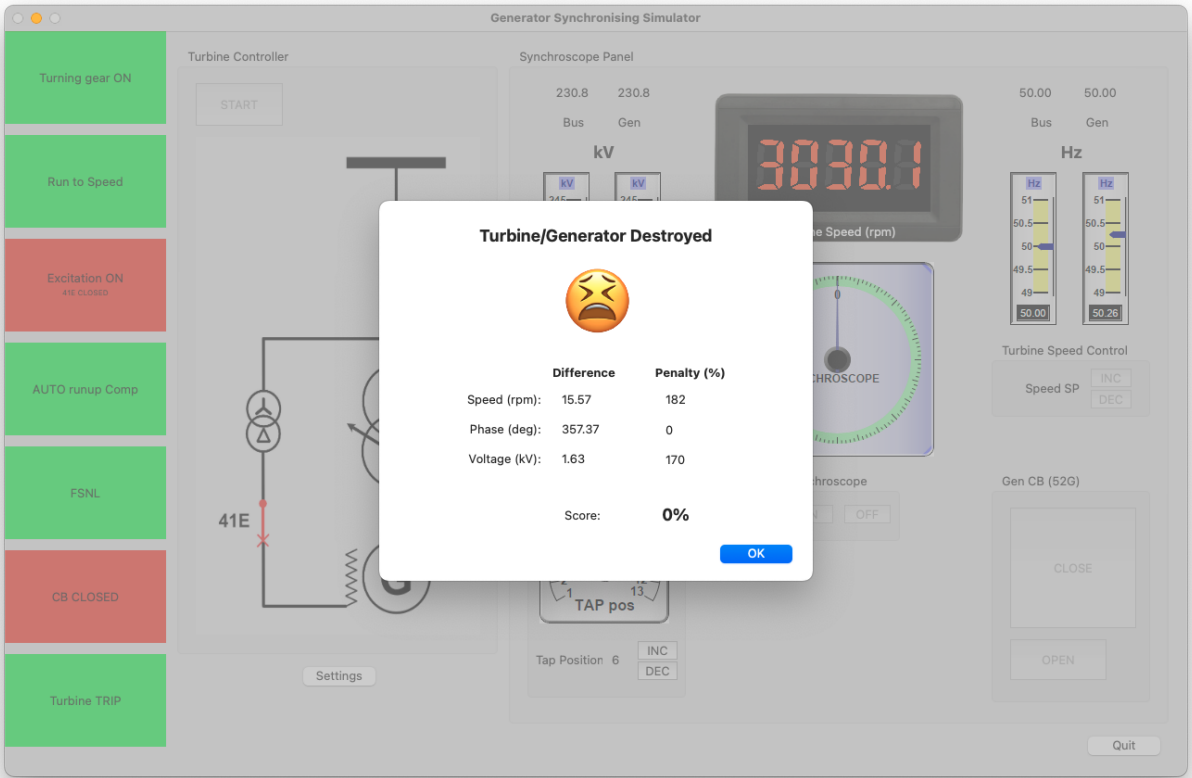


Figure 8: Not a good result

4 Change Log

4.1 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 9: 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 realistic 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.

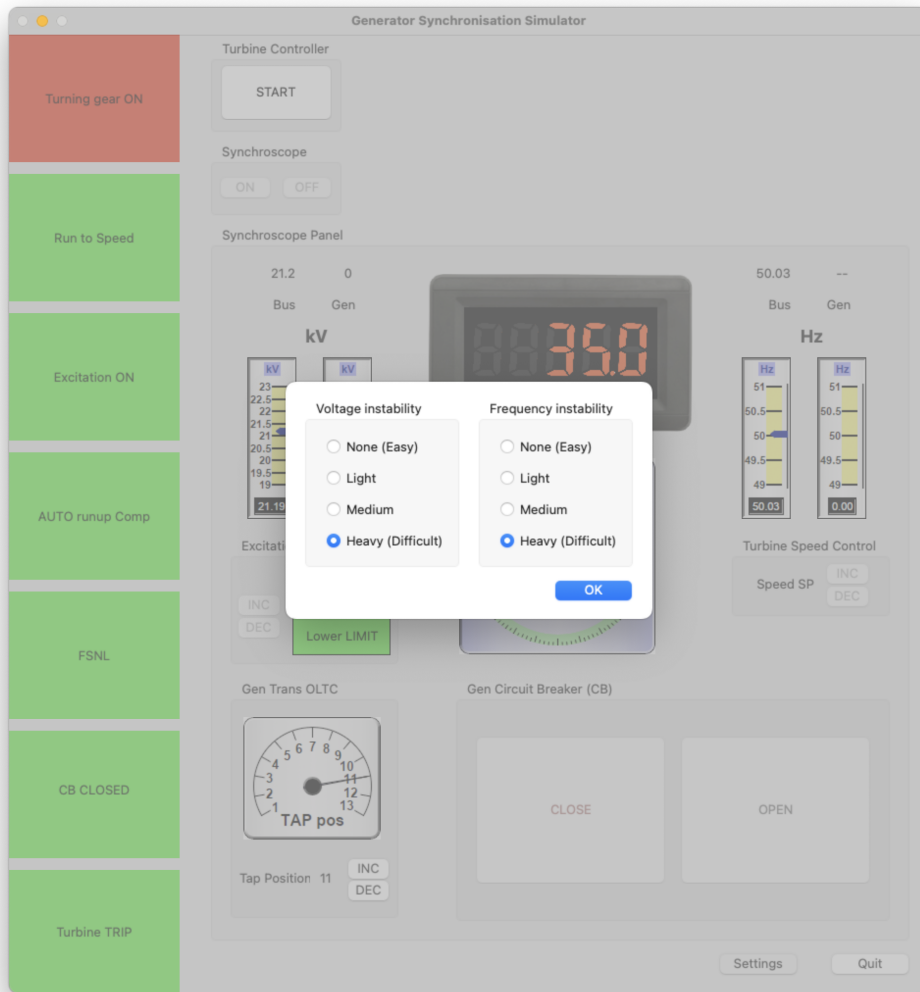


Figure 10: Voltage and frequency instability settings

4.2 Additions to v1.4

Code compiled as 64 bit application under macOS.

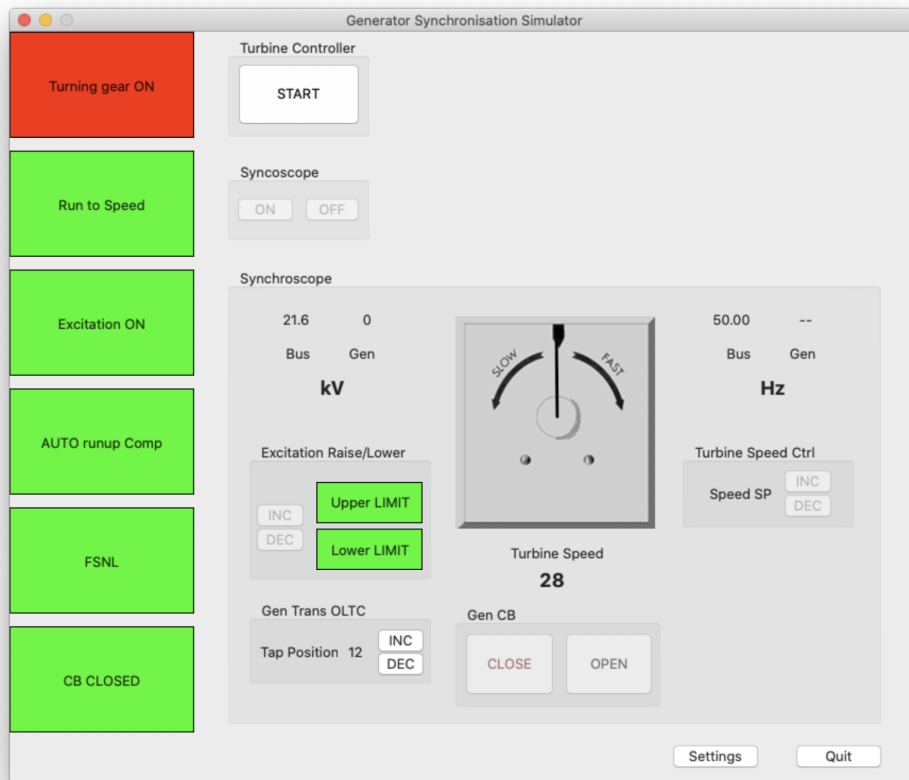


Figure 11: Synchroscope dial has reverted to earlier version as v1.2 upgrade components were not 64 bit compatible.

4.3 Additions to v1.5

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

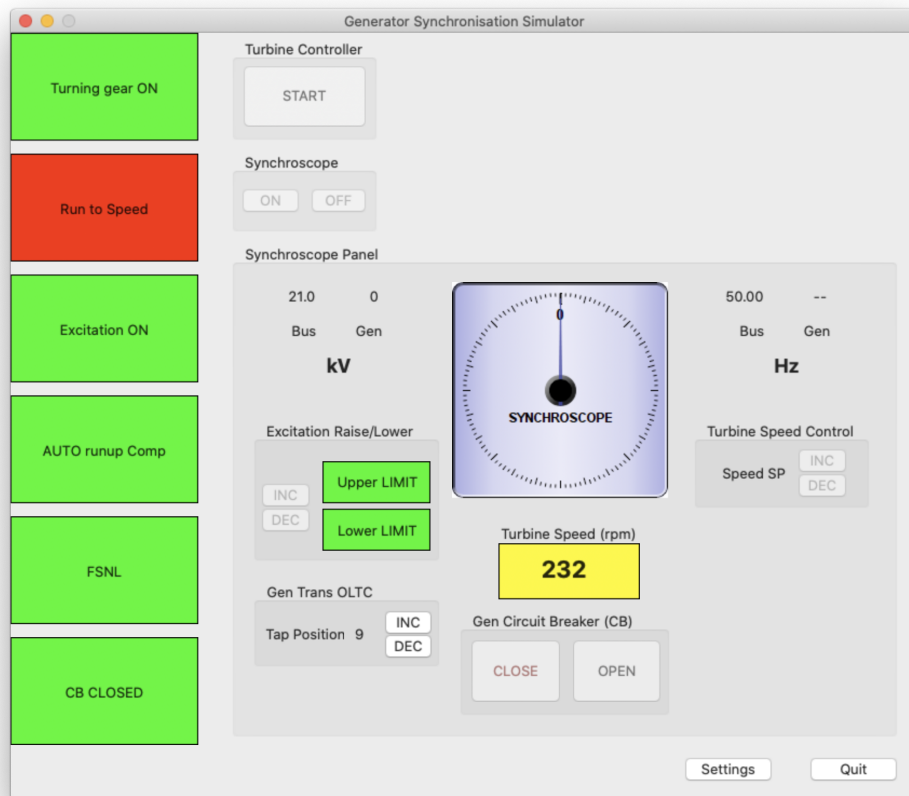


Figure 12: Synchroscope dial has been improved again.

4.4 Additions to v1.6

Improvement as follows;

- turbine speed response improved when using buttons Increasing/Decreasing turbine speed.
- cute but annoying emoji's added to results display

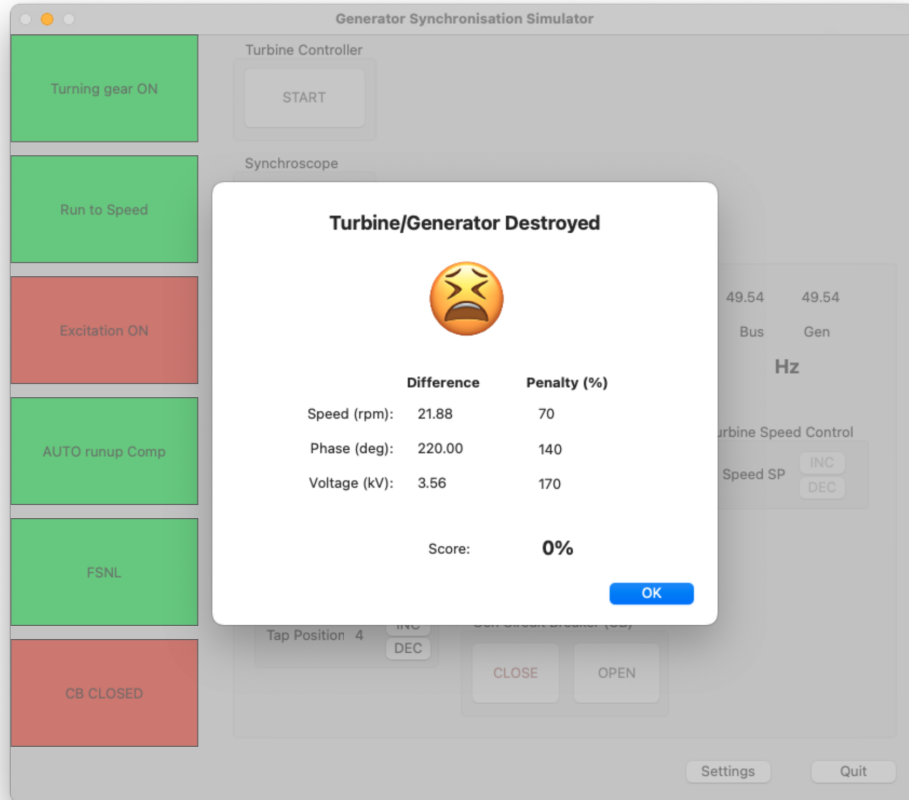


Figure 13: Emoji added.

4.5 Additions to v2.1

Improvement as follows;

- Running volt and frequency modified with new curves to give a more realistic feel.
- Revamp of main screen with more analogue representations of measured values.
- Turbine overspeed trip added to prevent just increasing speed forever.

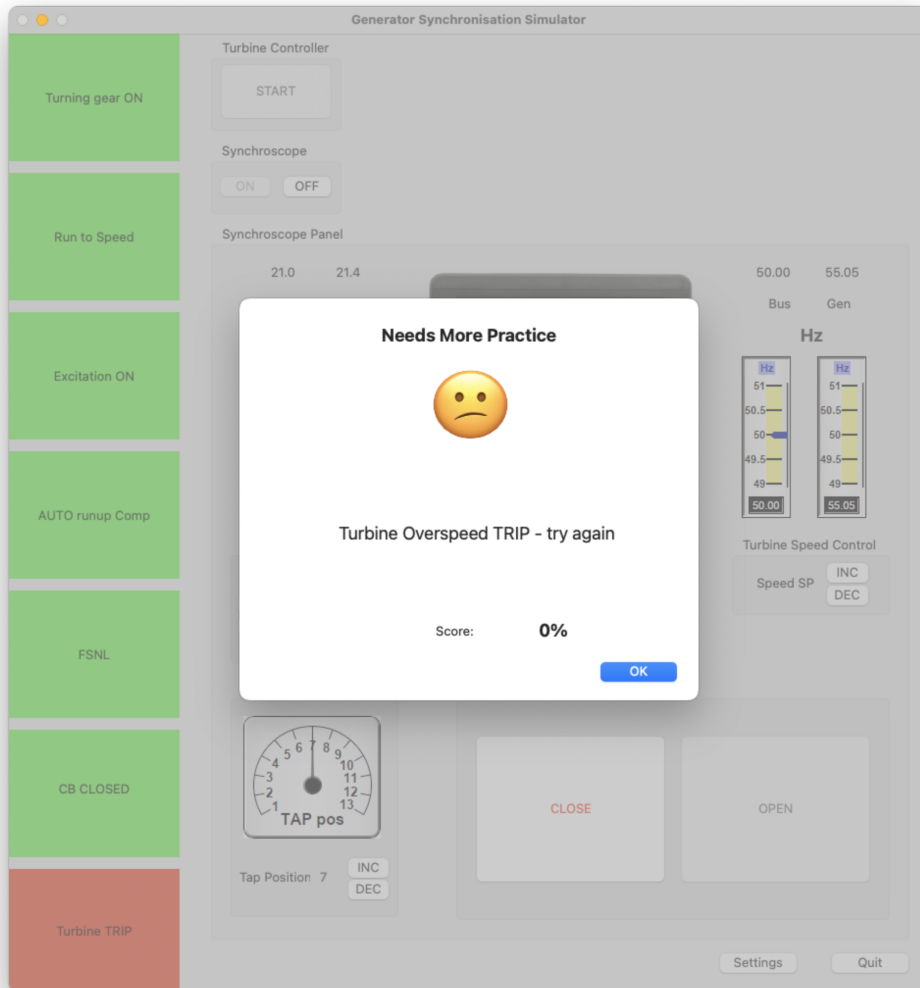


Figure 14: Turbine Overspeed TRIP.

4.6 Additions to v2.2

Improvement as follows;

- Compiled to run in Windows (64-bit INTEL & ARM).

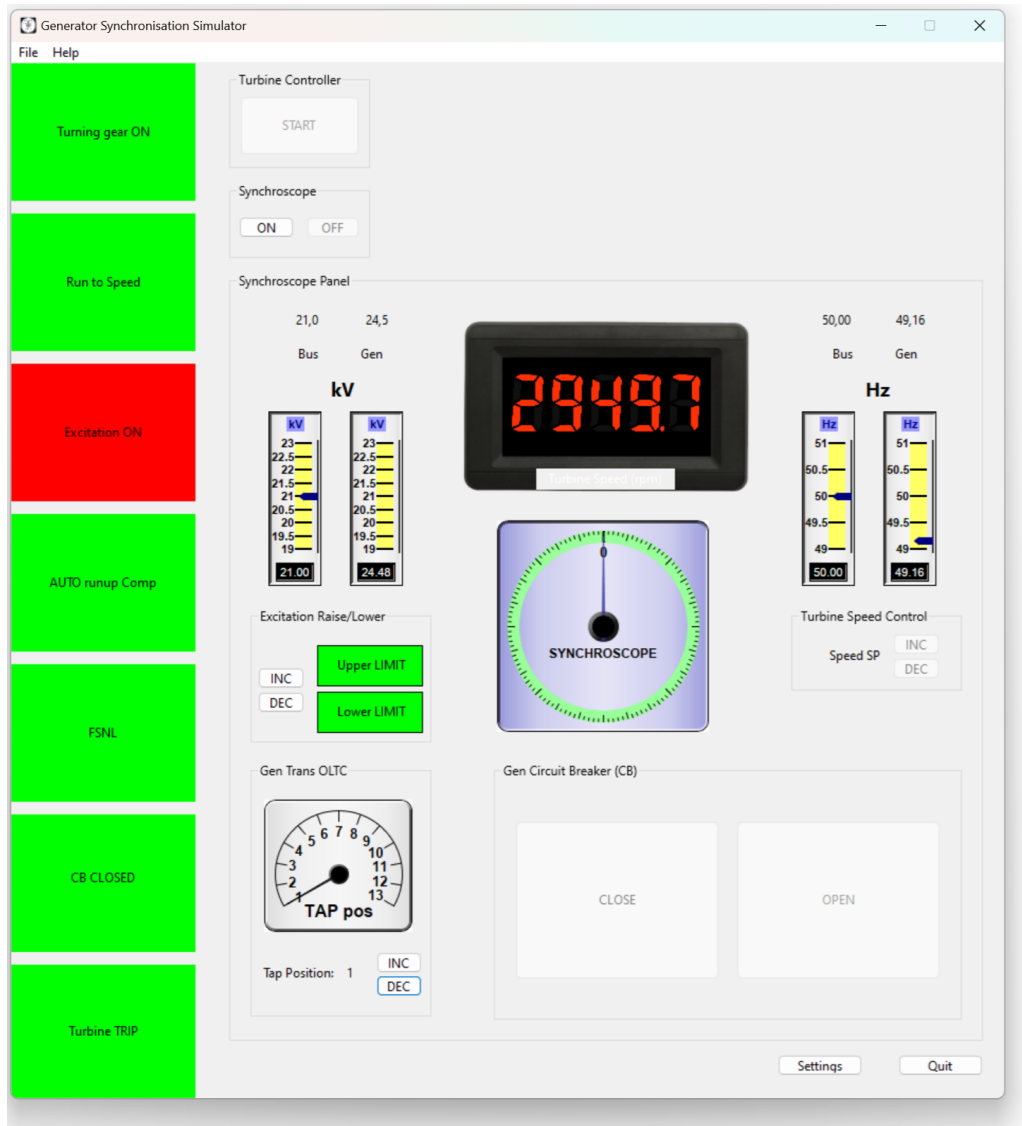


Figure 15: The application running in Windows.

4.7 Additions to v3.0.1

Improvement as follows;

- 50Hz and 60Hz system frequency options added.
- SLD of generator, transformer and busbar.
- Update of the Settings window to include;
 - Option of 3 differing synchroscope faces to use.
 - Automatically check if a newer version is available for download and display at bottom of About window.
 - Sync Check Window enable button added.

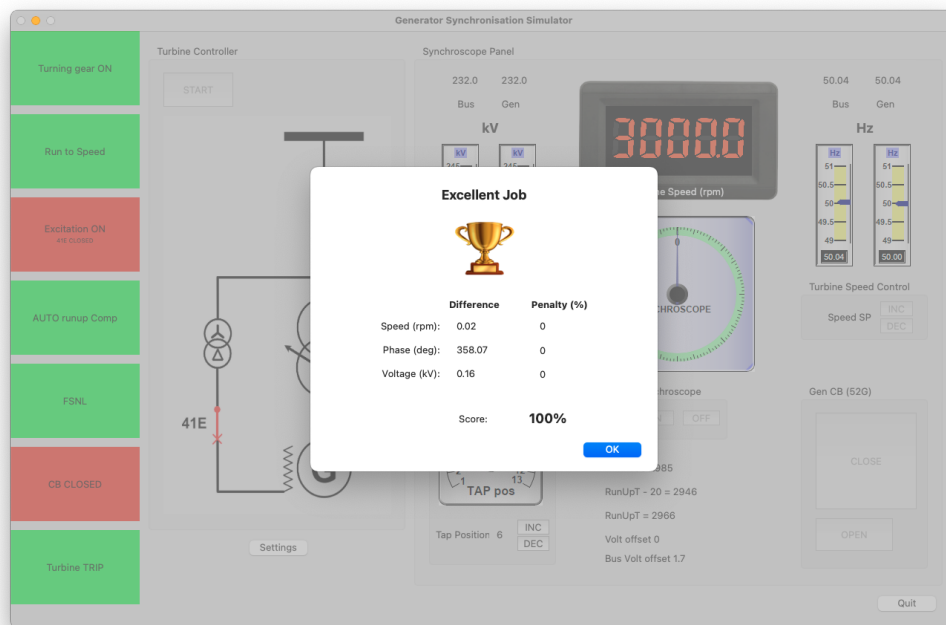


Figure 16: If you manage a perfect synchronisation on the toughest settings.