Development of a simulator for alternator synchronisation

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Abstract: In situations where there are risks of damage to equipment or to personnel operating equipment, simulators play an important role in training operators. Once the operators develop a certain level of confidence over the simulator they can be further trained on the actual equipment. The paper describes the development of a custom build simulator for synchronising alternators, used to train operators at Yallourn TAFE College in Victoria, Australia.

1. Introduction:

Synchronising an alternator with another one or with the grid involves running the alternator to be synchronised at a precise speed, adjusting a number of parameters and closing the alternator circuit breaker at a specific time determined by the synchroscope. The process involves a number of tasks to be performed in a given sequence. Failure to close the breaker at the specific instant may cause severe currents to flow in associated circuits and if not properly protected this may cause damage to equipment and to personnel. Even the machine is protected severe torques and vibrations could cause mechanical failure of the machine over a number of years, considerably shortening its lifetime.

Power station and steam operations Group of Yallourn College of TAFE (TAFE stands for Technical and Further Education) runs courses in training operators for power stations. The students learn theory of electricity and obtain part of hands on experience in the laboratories and nearby power stations. The group requested Monash University to develop a computer simulation software package to train students in synchronisation of alternator to the grid. The authors undertook the project and the package was developed.

2. Basic conditions for synchronising alternators and synchronising gear at TAFE

Basic conditions to be satisfied before synchronisation an alternator to a busbar are:
Terminal voltage of the alternator (incoming voltage) should be approximately same as the busbar voltage. The difference should be less than 4%.

Incoming frequency and busbar frequency should be the same. Maximum difference should be less than 1%.
The incoming supply and busbar supply should be at the same phase position. The machine can handle 8°-phase mismatch between incoming and busbar voltages.

The phase sequence of incoming and busbar supplies should be same.

The major instrumentation in synchronising section consists of running (busbar) and incoming voltmeters, running and incoming frequency meters and synchroscope to indicate relative phase positions of incoming and running voltages. The control panel has neutral circuit breaker, field circuit breaker, line circuit breaker and the generator circuit breaker inputs. Wattmeter and VAR meter and sometimes vector meter are provided.

The ratings of the power station for which this simulation package was developed are: Nominal terminal voltage 13.8 kV, field current 750 A, rated speed 3000 rpm; machine parameters including winding resistance and reactance are also given.

3. Recommended Synchronising procedure:

Prior to starting the prime mover check whether field and alternator circuit breakers are open

1	Close line (CB) Circuit breaker	Observe line CB latches and indicating light changes
2	Close Neutral CB	
3	Check Excitation rheostat is at lowest position	
4.	Run the alternator close to the nominal speed (3000 rpm)	
5	Close field CB	Observe Filed circuit breaker latches Check field current Check the output voltage of alternator
6	Energize synchroscope	Check synchroscope moves
7	Adjust speed of the alternator to match running frequency	Check voltages of running and incoming supplies of all three phases.
8.	Adjust incoming filed rheostat to match incoming voltage to running voltage	
9	Make final adjustment to speed of incoming alternator	Observe synchroscope is moving slowly.
10	Close incoming alternator CB when synchroscope is slowly approaching 12 O'clock position.	Check synchroscope locks to 12 O'clock position

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11.	Check Watt meter to see if the alternator is motoring	Check synchroscope locked to 12 o'clock position
12	Increase alternator power output to given requirements	Check ammeters of all three phases are reading Observe alternator and bus currents loadings and voltage levels as power output is increased.

4. Mathematical Modelling.

In order to develop software to display readings of each meter, it is necessary to develop a mathematical model of the system.

The output characteristics of the alternator change according to the mode of operation, whether it is pre-synchronised or post-synchronised. The equations were developed for each case using classical electrical machines theory [1].

Under pre-synchronised conditions, alternator terminal voltage is linearly proportional to the speed and field current. Saturation of magnetic circuits is taken into account by representing characteristics by another line with different slope at saturation region.

To simplify post-synchronizing equations, we assumed infinite busbar and the resistance of the stator winding of incoming machine is negligible.

The phase current I_a under this condition is given by,

$$\therefore I_a = \frac{|E_g|\sin\delta}{X_s} - j\left[\frac{|E_g|\cos\delta - V_t}{X_s}\right]$$

Where,
 Eg = alternator generated voltage, V_t= busbar voltage, X $_s$= reactance, d= torque angle

$$Pout = 3V_t\,|I_a|\cos\theta = \frac{3V_t\,|E_g|\sin\delta}{X_s}$$

$$Qout = 3V_t\,|I_a|\sin\theta = \frac{3V_t\,|E_g|\cos\delta}{X_s} - \frac{3V_t^2}{X_s}$$

$$\delta = \sin^{-1}\left[\frac{Pout * X_s}{3V_t\,|E_g|}\right]$$

Once the generator is synchronised, the speed is locked to synchronous speed and increase of prime mover input will increase the active power exported.

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Before the machine is synchronised, increase of prime mover input increases the speed of the alternator and hence its output voltage.

The above equations were used in the software to evaluate the parameters for display in animated meters as response to operator manipulation of controls.

5. Development of software:

Initially Visual Basic was chosen as programming language. However, as faster animation was required for most analogue displays, Borland Delphi was chosen due its superior speed of execution.

As the computer screen is not large enough to display all the panels in the control desk, we had to go for a number of display windows. The software consists of eight different windows each displaying a panel: Main control display, ac drive (prime mover) panel, excitor panel, circuit breaker panel, status display panel, synchroscope panel, three phase power display panel and Three phase waveform display panel. Latter was added as an additional educational feature.

One can display any number of windows at a time, but large number of windows opened may slow down the computer. Thus depending on the size of the screen and capability of the computer, student can select the optimum number of panels opened at a time. After making necessary manipulations any panel can be closed without losing data. For example after synchronising, synchroscope panel can be closed and vector meter panel can be opened to observe power export. This resembles the actual practice in power station that when the machine is synchronised, the synchronisation panel is switched off.

When the program is executed, a flash screen appears for four seconds and during that time main program is loaded into the memory. As sown in the figure 1, any of the control panels can be selected from the main control window. Each panel resembles the instrumentation of actual control panel at the power station. The shapes of the switches and instruments were closely animated.

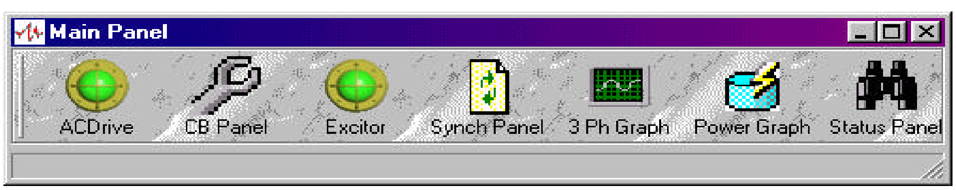

Figure 1. Main control window

5.1 AC Drive unit (Prime Mover) Panel

This panel consists of a speed indicator and a power indicator with control lever for varying the input to the prime mover. Before synchronising the alternator, the control lever raises or lowers the speed and power meter would read zero (as the alternator is not yet connected). After synchronisation, the speed will lock to 3000 rpm and power exported will vary according to the position of the control lever. Figure 2 shows the ac drive panel.

5.2 Excitor panel

Exciter panel is similar to the prime mover panel. It consists of reactive power indicator and an ammeter for excitation current. When synchronised, variation of excitor current will vary reactive power exported. These values are calculated from formulae given in section 4 and displayed in analogue meters.

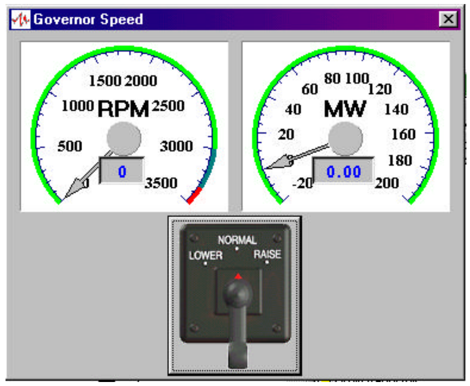

Figure2: AC Drive Panel

5.3 Circuit breaker panel

As shown in figure 3, this screen displays all circuit breakers. They can be switched ON or OFF using mouse clicks. As in all the panels, status of switches are memorised when the window is closed.

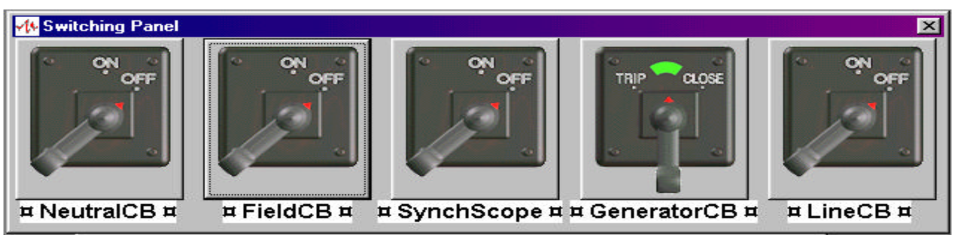

Figure 3 Circuit Breaker Panel

5.4 Status Display panel

Displays a mimic diagram of the basis components of the system with status of each breaker. When the breaker change the status, mimic diagram change the colour. The operator could immediately notice any breaker tripped. This panel is shown in figure 4

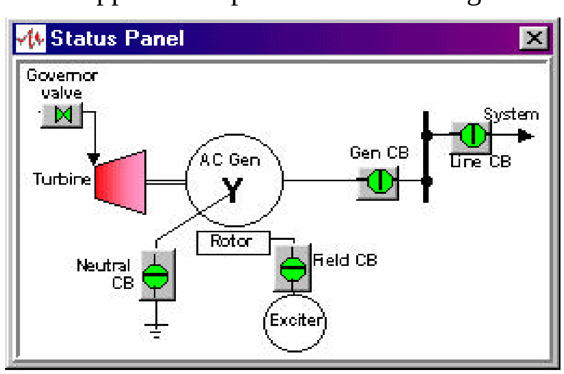

Figure 4: Status Display Panel

5.5 Synchroscope panel:

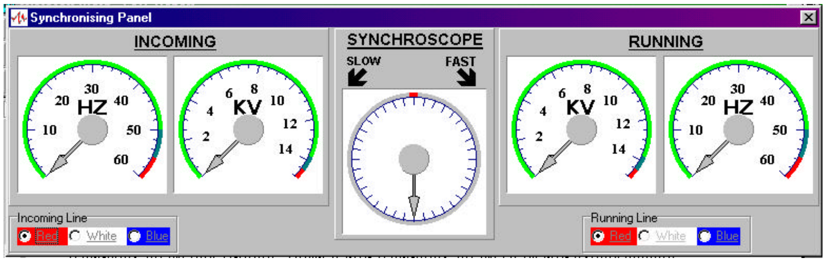

Figure 5 Synchroscope Panel

Figure 5 shows the animated panel. Incoming and running voltmeters and frequency meters with synchroscope are animated as in the power station.

Synchroscope rotates clockwise or anticlockwise depending on the speed of the incoming machine. When it reaches 12 O' clock circuit breaker can be closed to synchronise the machine, provided all the other conditions are satisfied. If the conditions for synchronisation are not satisfied the breaker will not hold. Red, white and blue radio buttons selects each phase of running and incoming supplies.

5.6 Three phase power (Vector meter) Panel

This animates instantaneous real and reactive power exported by the alternator (real power in X-axis and reactive power in Y-axis. Safe operating area is animated and if the operating point moves out of safe operating area alarms are activated.

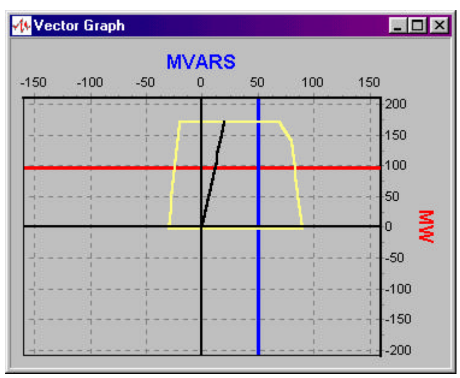

Figure 6: Vector meter animation

Alarms are set to indicate over speed, over voltage and overload conditions. When alarm is activated a red band will light up in the main window. Whole program would shut down (trip off) in major faults including speed exceeds 3300 rpm or if field CB is opened with generator CB is closed or main CB is opened. This simulates tripping off of the power station in major faults.

5.7 Three phase voltage waveform Display

This is not a component of power station. It is added as an educational feature to demonstrate how incoming voltages move with respect to busbar voltages and lock in when the alternator is synchronised.

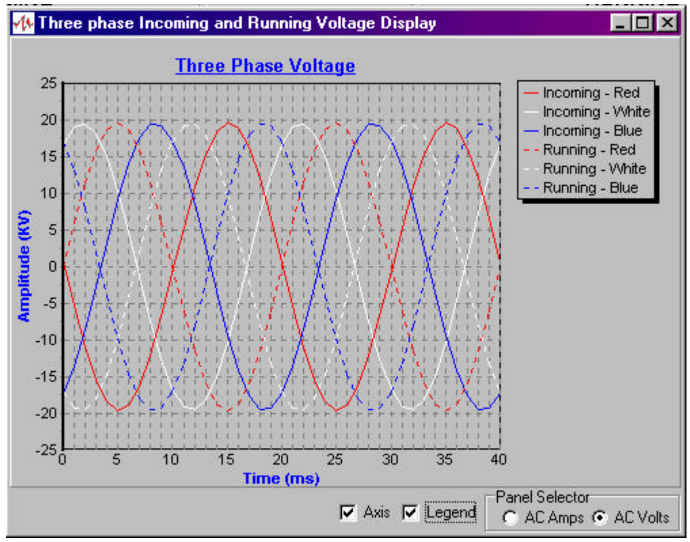

Figure 7. Waveform display panel

6. Limitation of simulation programs:

Though simulation programs are very useful in training personnel at initial stages, there are a number of limitations. For example errors due to wear and tear of machines, vibrations at particular frequencies of power stations, disturbances due to noise etc cannot be easily simulated. Another problem would be that the simulator-trained operators might take the operations too lightly when they are on actual equipment.

Thus once a certain amount of confidence is achieved the operators should be trained on actual equipment.

7. Future developments:

Authors intend to incorporate an assessment program to monitor performance of operators on simulation package to issue “licence” to get training on actual equipment. This feature would record major and minor faults during the operation and store them in a database.

Incorporation of sound clips to simulate more closely actual working atmosphere is also considered. With new operating systems two or more monitors can be used to open more panels to simulate exact control panel in the power station is not a hard task. This would enable to simulate situations of different power stations with the same package. More and more panels would be developed to simulate different control panel requirements and educational needs.

8. Conclusion:

Development of a simulation package for synchronising alternator to a busbar is developed. The package together with other commercial packages is successfully being used in TAFE College for training operators. The modular approach of the package offers more flexibility so that user can patch his or her own control panel. This package can be used in ergonomic design of panels by simulating and trying various configurations. Students and staff of the

TAFE College are very happy with the simulator and they hope to expand this idea to simulate other functions of a power station.

9. **Acknowledgement:**

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