Ensuring Availability of Aluminium Smelters Through Island Operation Capability

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ABSTRACT

Aluminium smelters, which are supplied by **captive power plants,** can maintain their production even when disconnected from the external grid, a.k.a. **islanded** operation, provided that the captive plant can control frequency and voltage in a stable manner. This will prevent **blackout** of the plant in case of sudden disconnection or grid collapse and can also be used pre-emptively to avoid disturbances when e.g. a thunderstorm is anticipated. Increasing the **availability** in this manner can save large sums of money.

This paper presents a unique method for testing the island operation capability of a power plant in a thorough and safe manner, without risking blackout. The work presented in this paper were carried out in Captive Power Plants of a major aluminium manufacturer in India and one in Middle East, which were experiencing years of issues with island operation, and attempts to optimize had been both tedious and incomplete. The online tests conducted by Solvina gave the plant owners the best possible performance and the confidence to form the operation strategies for reliable and safe island operation ahead.

Solvina devised necessary governor changes which allowed them to be tuned. Number of tests, including simulated island operation tests, were performed on several units, one at a time. Each governor was tuned for optimum frequency response and load sharing, making any combination of units possible to run islanded. Several control issues, for example bypass control interfering with the turbine control, were identified and addressed.

After tuning, sudden load changes of around 10% of the installed capacity could be handled without causing excessive frequency deviation or other problems. This, in combination with an already installed load and production shedding system, made the power plant able to maintain production after a sudden disconnection from the external grid in a variety of operating conditions.

Keywords: *Captive Power Plant, islanded operation, blackout, Availability.*

INTRODUCTION

This paper presents a unique method for testing the island operation capability of a power plant in a thorough and safe manner, without risking blackout.

Aluminium smelters, which are supplied by captive power plants, can maintain their production even when disconnected from the external grid, a.k.a. islanded operation, provided that the captive plant can control frequency and voltage in a stable manner. However, experience shows that this is not always the case. It is not sufficient to have production capacity that covers the consumption but also the dynamic behaviour must be stable. Especially, a sudden transition to island operation can be difficult, when the captive power plant must rapidly adjust the production to the given load after having net import or export is suddenly cut off.

Ensuring that the frequency and voltage control can handle island operation is an effective way of preventing a blackout. Island operation can be initiated pre-emptively to avoid disturbances when e.g. a thunderstorm is anticipated. Balancing the import/export before disconnecting will ensure a smooth transition. After that, the frequency and voltage control of the plant will have to handle the normal load variations as well as any unexpected events. If there is a sudden transition to island operation, in case of a tie-line fault or a grid collapse, there will be no time to balance the import/export. Instead, the sudden change will have to be handled while keeping the frequency and voltage within limits. A properly implemented load and production shedding system will be the first line of defence, removing the worst of the mismatch between production and consumption. However, there will still be a significant load change for the remaining power production to adapt to.

For steam turbines, a sudden load change will put stress on the boilers, requiring a fast adaptation of the steam production to the changing steam consumption of the turbine. Gas turbines are in this respect easier to manage.

THE METHOD

When a plant grid is islanded, the frequency of the plant grid will depend on the balance between production and consumption and any imbalance will make the frequency drift up or down. The rate-of-change depends on the amount of imbalance and the amount of rotating mass in the system.

Solvina has developed a unique method for optimising and verifying the frequency control capability of power plants. The method is called Simulated Island Operation and allows for testing the island operation capability of a unit while it is still synchronised to the main grid. This way, the testing can be done in a safe manner without the risk of blackout, which would come with a live island operation test. The method uses hardware-in-loop, that is, a real-time simulator that is connected to the speed controller (governor) of the turbine and sends a simulated frequency signal to the frequency input of the governor. The simulated frequency is calculated from the balance between the consumption of the simulated island grid and the actual production of the turbine, taking into account the inertia (the rotating mass) of the turbine and generator. The governor will then act as if the unit is actually running in island operation. Figure 1 shows the setup. The simulation model can be set up to include the frequency characteristics of the loads in the islanded grid and it can also be extended with other generators of various types, as well as automatically disconnecting loads, etc.

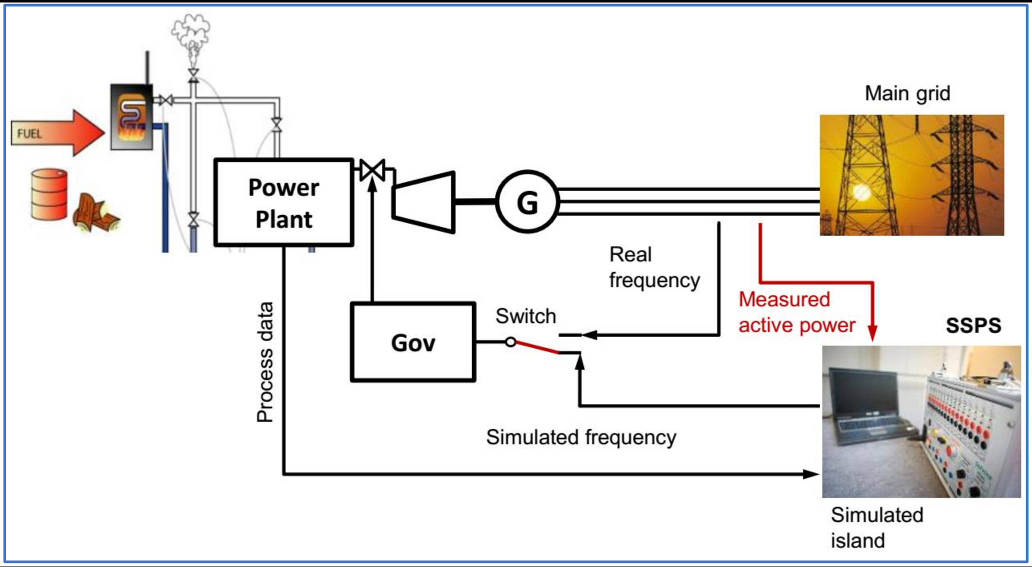

Fig. 1: Real-time simulator connected to a power plant

During a Simulated Island Operation test, the frequency controller can be tuned for best stability and minimized frequency deviation after load changes. This will optimise the capability of the power plant to maintain production despite sudden load changes in the islanded grid, such as rectifier or generator tripping. It also maximises the amount of grid export that is safe to maintain up until sudden islanding occurs, in some cases in coordination with a load and production shedding system. The ability of a unit to share the load with other units in the islanded grid can also be verified. The tests can be made to cover various operating conditions, with load levels ranging from zero up to rated load.

During the test, if the controller response is poor or anything else disturbs the operation, then the simulation is simply stopped and the power plant is returned to normal operation. In a live island operation test, this would instead have caused a blackout.

The Simulated Island Operation test requires the same action of the control valves and other equipment as in real islanded operation. For a steam turbine, the capability of the boiler and steam system to keep the steam pressure stable in islanded operation is thereby tested at the same time. For example, if the load is decreased, the steam pressure will start increasing and continue doing so until the steam production in the boiler has been reduced or other actions such as steam bypass has been taken. The self-stabilising behaviour found in pressure control mode or in manual valve operation is not there in island operation. Instead, the boiler control is much more demanding than in normal operation. These tests are therefore an excellent opportunity for also evaluating and tuning the boiler control, including the bypass valves and related equipment, and making sure that these will not interfere with the frequency control in island operation. The tests also present a unique opportunity for plant operation staff training.

For the voltage control, hardware-in-loop tests are not required. Instead, on load and off load step response tests are used to verify that the controller performance is sufficient for keeping the voltage stable in island operation. Solvina's test equipment can be used for performing this kind of tests also. With the equipment in place, this will also be a good opportunity for performing PSS (Power System Stabilizer) tests, although the PSS is normally only relevant for grid connected operation.

EXAMPLES OF WORK

Solvina has utilized the Simulated Island Operation on more than 100 units worldwide, including gas turbines, steam turbines and hydro units. The unit size ranges from 5 to 600 MW. In the following sections, two cases of testing are demonstrated. Both these cases concern turbines belonging to aluminium smelter industries, one major coal fired CPP in India, and one large gas based plant in the Middle East.

Case 1: Steam Turbines of CPP in India

This example is from a major aluminium manufacturer in India. The plant has more than 10 steam turbines of different size, which together produce more than 1000 MW for potlines and also participate in power export to the state grid, depending on availability. For maximum grid stability, all units are set to participate in frequency control.

Before the tests, Solvina devised necessary governor changes which allowed the governors to be tuned. This was necessary since there was no control mode in the governors suitable for optimized island operation performance. A number of tests, including Simulated Island Operation tests, were performed on all units, one at a time. Each governor was tuned each for optimum frequency response and proper load sharing, making any combination of units possible to run islanded with a given load.

Figure 2 and 3 show examples of Simulated Island Operation. This is a test performed after governor tuning and shows proper governor response. The simulation is set up for one unit of several hundred MW operating as sole production in the islanded grid. In Figure 2, a load of 7 % of the unit rating is disconnected from the simulated grid, and in figure 3, 8 % is connected (red). The simulated frequency (green) immediately starts changing but is halted when the production of the unit (blue) matches with the simulated grid load. The governor then brings the frequency back to normal. After the load changes, the turbine consumes a different amount of steam than the boiler produces and the steam pressure (black) starts drifting slowly but steadily. In real life island operation, this would have required action from the operation staff or the pressure would become too high or low after a few minutes.

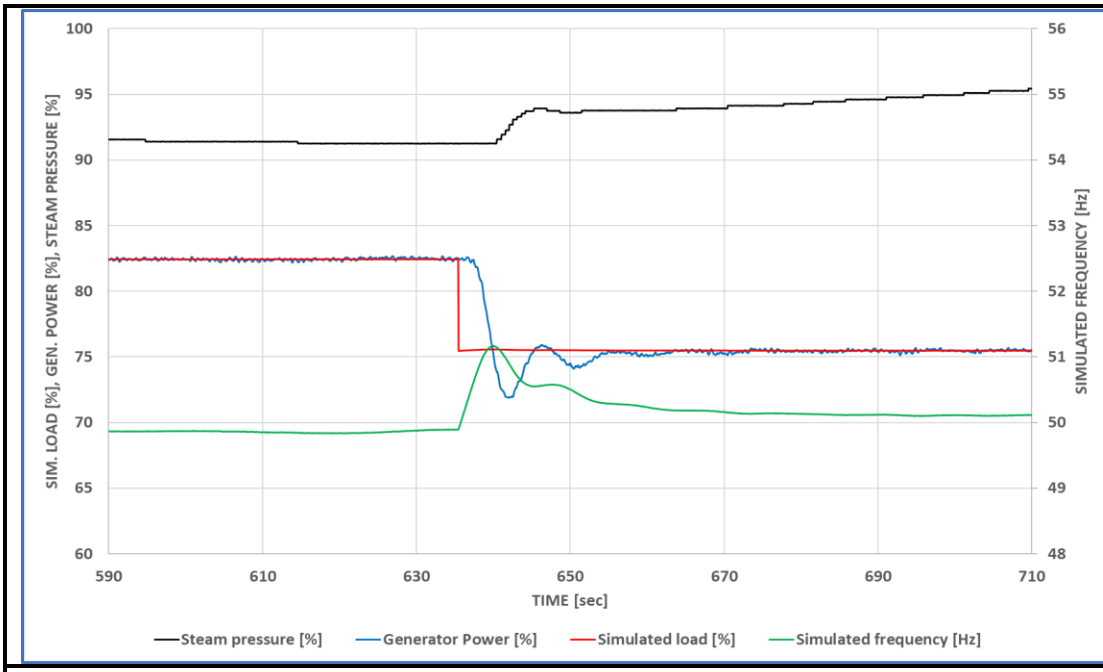

Fig. 2: Example of response to a load change in Simulated Island Operation of a steam turbine, load is disconnected.

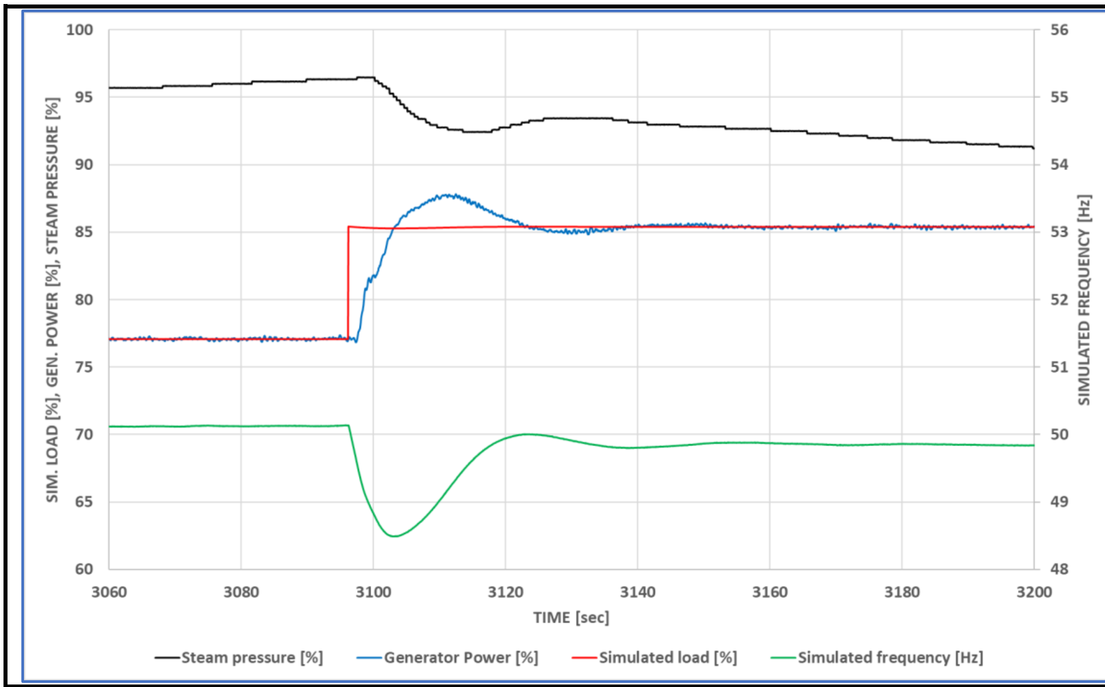

Fig. 3: Example of response to a load change in Simulated Island Operation of a steam turbine, load is added.

After tuning, the tested unit could handle sudden load changes of around 10% of the rated load without excessive frequency deviation or other problems. This, in combination with an already installed load and production shedding system, will make the power plant able to maintain production after a sudden disconnection from the external grid in a variety of operating conditions. In general, 10 % of rated load is a fairly typical value when it comes to steam turbines.

During the tests, several control issues could be rectified. For example, the bypass control would in certain condition open the bypass valves despite that the steam pressure was well within limits. This interfered with the frequency control of the governor and would in some cases severe oscillations. This problem would have been very difficult to identify and solve without the Simulated Island Operation tests.

A common problem in steam turbine is the non-linearity of the control valves, that is, each % of valve opening sometimes gives a very different response in MW depending on where this change takes place on the valve curve. This was found in this case here also, but not to a worse extent than that it could be handled by the frequency control. This phenomenon accounts for the somewhat different dynamic behaviour between Figure 2 and Figure 3, where the former shows a faster response. We have however seen examples where the valve linearity is so poor that the valve curves of the governor will have to be adjusted to get the desired frequency control performance.

To evaluate the bypass control, a load reduction similar to that which will occur when entering island operation was tested. Just like in Figure 2, the steam pressure started building up and after a few minutes the bypass valves started opening automatically. There was no significant disturbance of the frequency control in this case, but it was found that the automatic bypass control was far too slow to handle the pressure build-up and manual intervention was necessary.

The tests of these units took several weeks, which made it possible for multiple shifts of control room personnel to experience the dynamic behaviour of the boiler during island operation, thus preparing them for handling a real-life island operation situation.

Case 2: Gas Turbines of Aluminium Smelter in the Middle East

Another recent example is from a major aluminium plant in the Middle East. The plant has more than 20 gas turbines and also a number of steam turbines. In this case, it is only the gas turbines that will participate in frequency control while the steam turbines run at base load.

Gas turbines are by nature easier to control than steam turbine and can change relatively freely between different loads since there is no boiler to consider. However, gas turbines still have their difficulties. For example, the type of gas turbine used at this plant changes the fuel injection between primary and secondary nozzles at a certain temperature in order to minimize NO_X emissions. At some of these changes, there are large transients in the turbine power. Let us consider a sudden load reduction of 20 MW on a 120 MW gas turbine unit, set to operate as the sole production in an islanded grid. In Figure 4, the response is smooth and predictable, while in Figure 5, there is a severe dip in the turbine power due to a combustion mode change. Nevertheless, the frequency control handles the situation and stabilises the frequency well. Typically, islanded gas turbines can handle load changes of up to 20-30 % of rated load.

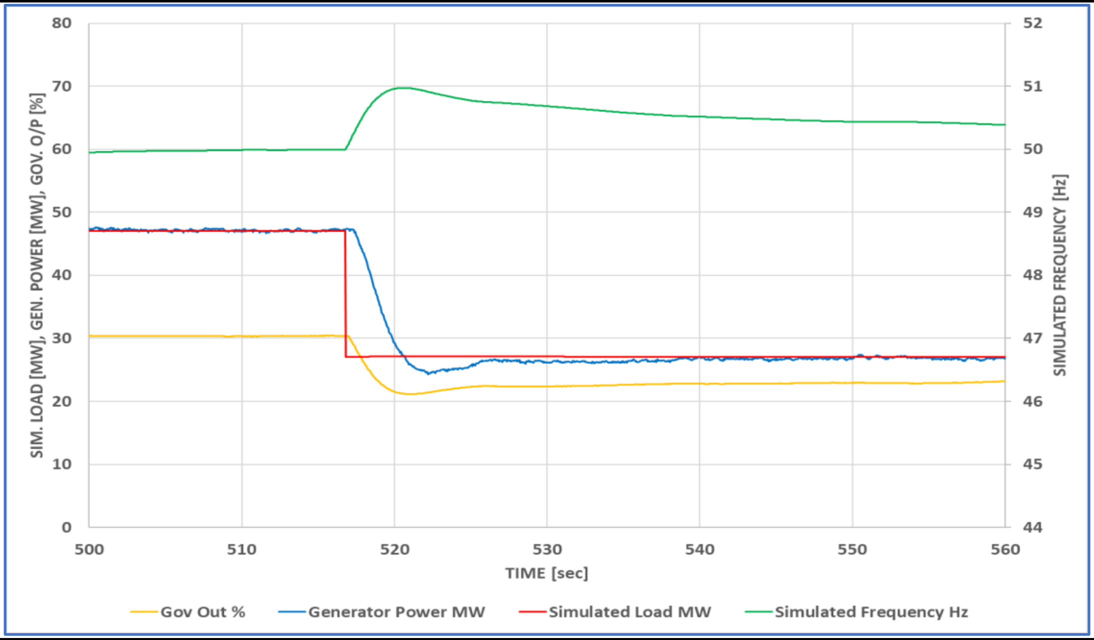

Fig. 4: Example of response to a load disconnection in Simulated Island Operation of a gas turbine, without combustion mode change.

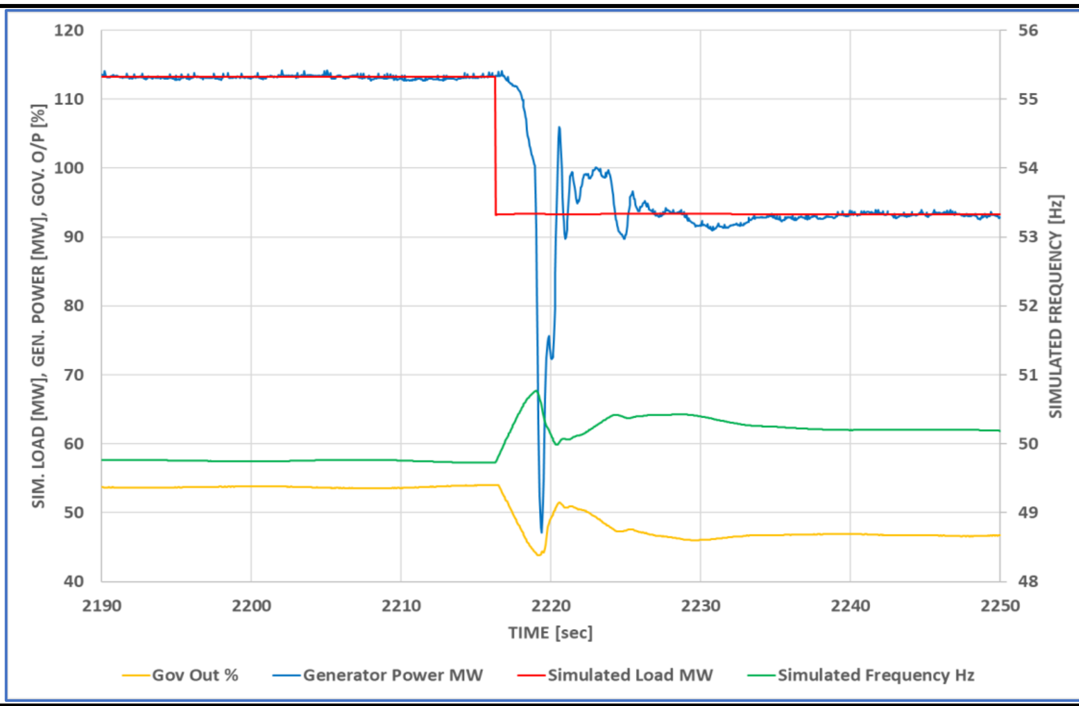

Fig. 5: Example of response to a load disconnection in Simulated Island Operation of a gas turbine, with combustion mode change.

CONCLUSIONS

The plants referred to in this paper had experienced years of issues with island operation, and attempts to optimize had been both tedious and incomplete. The online tests conducted by Solvina gave the plant owner the best possible performance and the confidence to form the operation strategies for reliable and safe island operation ahead.

The online islanding tests have resulted in optimally tuned plants and a clear picture of the performance to be expected in a real islanding situation. Vast cost savings have been gained already in the test phase due to fast execution, minimized production losses and avoided trips. The following benefits from the tests are obvious:

- Control logic could be evaluated and optimized in a fast and accurate way.
- Obvious faults and errors could be corrected, in logics and hardware.
- Bottlenecks could be identified and taken in consideration, like steam pressure drop.
- Tuning in the whole load range was managed.
- Several trips could be avoided by using the online method instead of full scale live tests.
- The behaviour constitutes a great input to the design of loadshedding systems and protection.

Out of the 100+ plants that have been tested since year 2000, a big fraction is captive and co-gen plants with regular need for islanding. A common feedback from these plants is a vastly improved islanding success rate and stable operation.