REDUCING VULNERABILITY OF AN ELECTRICITY INTENSIVE PROCESS THROUGH AN ASYNCHRONOUS INTERCONNECTION

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Summary
This paper presents the results from a study conducted for M/s Hindalco Industries Ltd. to find out the ways and the means to reduce vulnerability of its electricity intensive smelting process. The industry’s power system is interconnected with the Northern Regional Grid of India which experiences rather frequent disturbances and operates within a wide frequency range.

It has been found that an asynchronous connection of the industry power system, which includes its captive power plant, to the Grid in association with an intelligent load management scheme, is one of the most suitable means to tackle its stability, frequency excursion and power flow related problems. With the proposed frequency stabiliser being placed between the Grid and Hindalco Plant 1 busbar, the industry shall be in position to operate its generating units at near rated frequency of 50 Hz, irrespective of the operating grid frequency and at the same time avail continuous support from the grid under normal or emergency operating conditions.

The pay-back period of such investment for the industry has been estimated to be just over three years.
Keywords : Aluminium, HVDC, Back-to-Back, Stability, Asynchronous, Grid disturbance

1. Introduction
Processes like aluminium smelting where electricity is the basic input get affected greatly in the event of disruption in power supply. The aluminium smelting process is very susceptible to disruption due to possible solidification of molten metal leading to damage to carbon electrodes and consequent production loss. The production loss is mainly due the fact that it takes sufficiently large time to resume the process. In view of vulnerability of the process, most of the aluminium smelting industries in India have set up their own captive power plants (CPP). In most of the cases the generation capacity of these CPP matches with the electricity requirement of the industry. Despite self-sufficiency, these industries/CPPs kept connected with the grid for greater reliability of power supply to the process as also for emergency support in the event of an outage of a CPP generating unit(s).

2. Hindalco Industries Ltd.
M/s Hindalco Industries Ltd. owns and operates an aluminium plant at Renukoot, District Sonebhadra in the State of Uttar Pradesh, India, with an operation capacity of approximately 210,000 tons per annum. Presently there are seven pot-lines, 3 in Plant 1 and remaining 4 in Plant 2, which is located about 1.5 km away from Plant 1. These Plants receive most of their input power from the fossil fuel based captive power plant (CPP) at Renusagar, located about 30 kms away, which has 6 generating units in operation. Generally, all the six units are continuously operated at uprated output between 69 to 75 MW. The plant is connected with Northern Regional Grid of India at Rihand Hydro-electric Station (Pipri) of UPSEB via Hindalco 132 kV bus by ~3 km long lines.

In addition to this, two co-generation units (5.6 + 31.4 MW) have also been commissioned at Hindalco while 2 more generating units (each ~75 MW) are scheduled to be commissioned in
Dec ’97 and Feb ’98 respectively at Renusagar. One more pot-line (# 8) is also scheduled for commissioning in Dec ’97.

For this study, 5 generating units at Renusagar and 7 pot-lines at Hindalco were considered to define the present scenario.

3. Operation Mode
Generally, the generating units at the Renusagar CPP are operated in synchronism with the grid.

During normal operating conditions, there is limited power exchange (of the order of 10-30 MW import) taking place between Hindalco and the grid. In future scenario an export of 30 - 90 MW is foreseen.

On one hand the connection with the grid supports the industry during disturbance in their system, on the other transfers the Grid disturbances. Due to the synchronous connection with the Grid, the operation frequency of the CPP units depends upon the grid frequency and thus this plant is forced to operate at sub-optimal frequency (below 48 to above 51 Hz) for significant duration of the time, every day.

4. Disturbances
It has been noted from the past records that the grid has not only been experiencing frequent disturbances, many of them major ones, but also unfortunately, has increasing trend.

In order to meet any major eventuality following the grid disturbances, the industry has an arrangement to isolate and island Hindalco Power System along with the captive power plant at Renusagar from the grid by using under frequency and df/dt relays. However, the experience has shown that these islanding schemes are not fail-safe and on several occasions could not help survive the islanded system.

A grid disturbance on April 13, 1996 resulted in total power failure at Hindalco as the CPP could not sustain itself following islanding which led to solidification of molten metal in the pot lines and the industry had to suffer a huge loss. In order to avoid the occurrence of such events, the present study has been conducted.

As per the information available, 40 disturbances were experienced by Hindalco power system in 1996, out of which 39 originated from the Grid and one from the Renusagar. Islanding failed on 9 occasions, 22 times the islanding was successful and on another 9 occasions islanding was unsuccessful and led to the trip of one or more of Renusagar generating units. April 13, 1996 incident was one of the last 9 occasions.

5. System Performance
In order to assess the problem and work out a solution, a number of studies were performed including load flow, system security, short circuit, transient stability, relay co-ordination, automation needs, etc. Many of these studies have been performed by using ABB’s Power System Simulation & Analysis Software, SIMPOW®.

5.1 Synchronous Connection
It was found out that for a single contingency there were no limitations/ restrictions on the steady state power flows. With regards to system security on disconnection of various elements without any fault, the system was found stable for most of the cases except that it was unstable if it went in islanded mode not coupled with proper load shedding/ management. The same was valid when any unit is tripped while the system was running in isolation.

While evaluating the stability behaviour of the CPP machines, it has been seen that when a 3 phase 8 cycles fault is applied at the Rihand 132 kV bus, the system is generally stable (Figure 1) but the frequency excursion during the disturbance can be as low as 46.8 Hz (if pre-disturbance frequency was 47.7 Hz) or as high as 53 Hz (if pre-disturbance frequency was 51.8 Hz). Also, the voltage at Hindalco and Renusagar drops to ~5 and ~15% respectively. In these conditions, some of auxiliaries of generating units trip out and creates further problem.
Further, if the fault duration is longer than 8 cycles, the system itself was found to be unstable. During a 3 phase 0.5 second fault (corresponding to the back-up protection setting at Rihand), speed of machines increases by about 7% (Figure 2).

5.2 Islanding
Following islanding, the frequency starts to drop, because of non-availability of any spinning reserve in the islanded system of Hindalco. The machines slow down to unacceptable limits if no load - generation management is undertaken. It takes more than 5 seconds when the frequency drops by 5%.

While studying the effect of load shedding, the simulation results showed that the machines speed starts to recover and settles to a new state. The oscillations on the lower side are arrested and the system remains stable. It was seen that CPP machines shows stable behaviour if the load shedding is effected within one second.

The situation would change in the future scenario when CPP will have additional machines and would export to the grid under normal operating conditions.

5.3 Asynchronous Connection
The industry can run its CPP generators at nominal frequency irrespective of the grid’s operation at off-nominal frequency if it has a asynchronous connection with the grid through a frequency stabiliser or back-to-back HVDC link. Further studies were conducted to find out the impact of such connection on the stability and overall performance of the Hindalco’s
It has been seen that in such mode of asynchronous operation, the impact of grid disturbance is reduced substantially. When comparing the simulation results for 3 phase 0.5 seconds fault at Rihand 132 kV bus (Figure 3) it was seen that:

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<thead>
<tr>
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<th>Synchronous connection</th>
<th>Asynchronous connection</th>
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</thead>
<tbody>
<tr>
<td>Frequency first increases by</td>
<td>7 - 10%</td>
<td>drops by</td>
</tr>
<tr>
<td>Rate of change of frequency is around</td>
<td>6 Hz/Sec</td>
<td>0.5 Hz/Sec</td>
</tr>
<tr>
<td>Voltage at Hindalco changes by around</td>
<td>95 %</td>
<td>1%</td>
</tr>
<tr>
<td>Renusagar machines outputs transiently increases to</td>
<td>150 - 200 MW</td>
<td>75 - 80 MW</td>
</tr>
<tr>
<td>After the disturbance Renusagar machines oscillate for a duration and are</td>
<td>longer</td>
<td>shorter</td>
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Because of the stabilised parameters of voltage and frequency in the CPP the station auxiliaries would continue to be in service and operate under optimal mode without any apprehension and risk of tripping of units which were normally taking place due adverse voltage / frequency excursions.

Based on the simulation results, it is amply clear that frequency stabiliser acts as a buffer against the impact from any of the grid disturbance on Hindalco Power System and thus helps the Hindalco Industries complex to maintain all its operating parameters at optimum level.

The frequency stabiliser practically insulates the Hindalco system from the grid and Renusagar machines would not experience the impact of large disturbances which the grid are normally subjected to and continue to supply the Hindalco load. Thus the production loss and excessive strain on the machines due to under frequency operation of Renusagar will be minimal.

Also, from the simulation results, it has been seen that the system behaviour in both pre-defined present and future scenarios is similar and therefore frequency stabiliser's importance and utility in future scenario remains the same as in the present scenario.

The other major impact of providing frequency stabiliser between the grid and Hindalco power system is in appreciable reduction of fault currents not only in Hindalco network but also at Rihand power station. The following table shows the approximate fault current magnitudes (with 8 units at CPP) with and without frequency stabiliser (FS):

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<thead>
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<th>With FS</th>
<th>without FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hindalco 132 kV</td>
<td>12 kA</td>
<td>27 kA</td>
</tr>
<tr>
<td>Rihand 132 kV</td>
<td>19 kA</td>
<td>29 kA</td>
</tr>
</tbody>
</table>

### 6. Economical Aspects

To evaluate the economical aspects of installing a frequency stabiliser, following has been considered:

Cost of investment would include cost of a 100 MW frequency stabiliser and cost of capitalised
losses (35 years, 12% return) in the station. For recovery of cost, following components were evaluated considering 1996 grid disturbance data:

1. loss of opportunity cost (sale price - marginal production cost) because of lost aluminium production due to tripping of CPP unit(s) following a grid disturbance and/or non-availability of power from the grid in islanding.
2. cost of restarting a solidified pot line caused due to a black-out of longer duration, considering one pot line solidifying in four years.
3. cost towards maintenance of turbine blade failures which are caused mainly due to operation in low frequency regime and cost of increased electricity import from the grid.
4. unloading of CPP machines at high frequency and cost of increased electricity import from the grid.

A pay-back period of just over 3 years has been estimated considering above costs while adopting NPV (net present value) concept.

7. Conclusion
It has been recognised that the problems with being synchronously connected with the Grid are two fold;

1. Sustaining the major frequency and voltage excursions in the Northern Grid by the Renusagar machines at CPP which is not healthy and leads to turbine blade failures, excessive heating, shortening of life, etc.
2. Sustaining the post islanding conditions by the Hindalco Power System.

The first problem could be eliminated by providing an adequately rated frequency stabiliser which will provide necessary isolation from the Northern Grid while allowing controlled power flow in asynchronous mode. A rating of 100 MW is decided considering the normal power flow requirement in future scenario.

The second problem which can occur even when the frequency stabiliser is used, can be tackled by providing a state-of-the-art intelligent load management scheme.

The present paper demonstrates that the interconnection with the grid through an asynchronous link (i.e. an HVDC back-to-back or a frequency stabiliser) makes the aluminium smelting process and its associated CPP immune to all the quasi steady state grid parameter variations as well as majority of grid disturbances.

8. Acknowledgement
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