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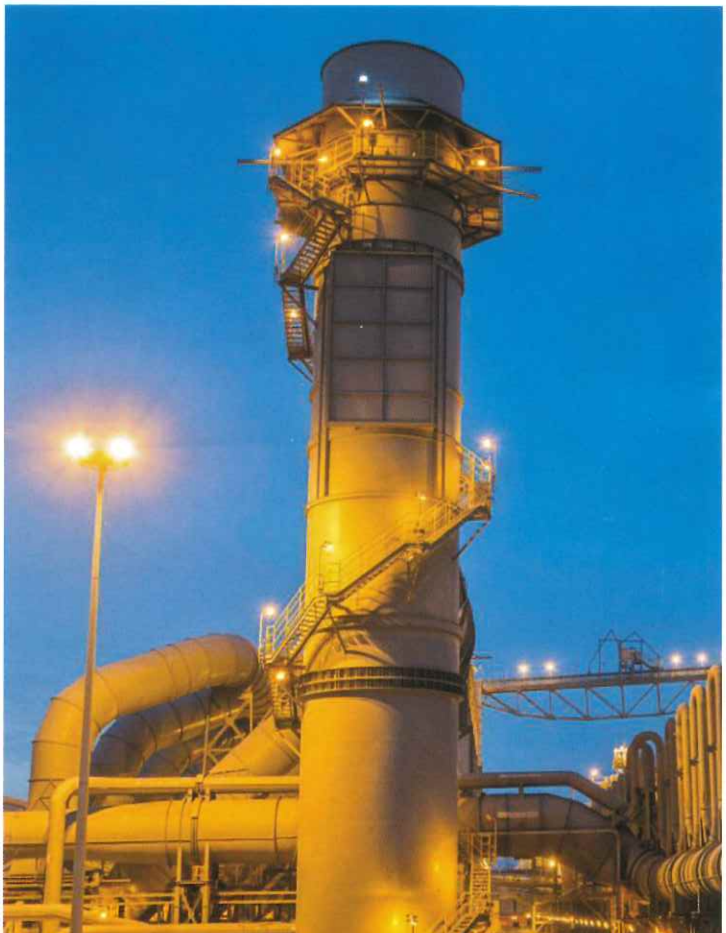
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Power system stability at Ras Al Khair, Saudi Arabia's first aluminium smelter project

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Linking an independent, major generating station to a regional electric power grid could allow instability in one system to destabilize the other. To prevent this spread of disturbances it may be necessary to separate the systems rapidly. This paper describes the detailed study required to understand load flows and voltage stability between these systems, as well as general power quality requirements.

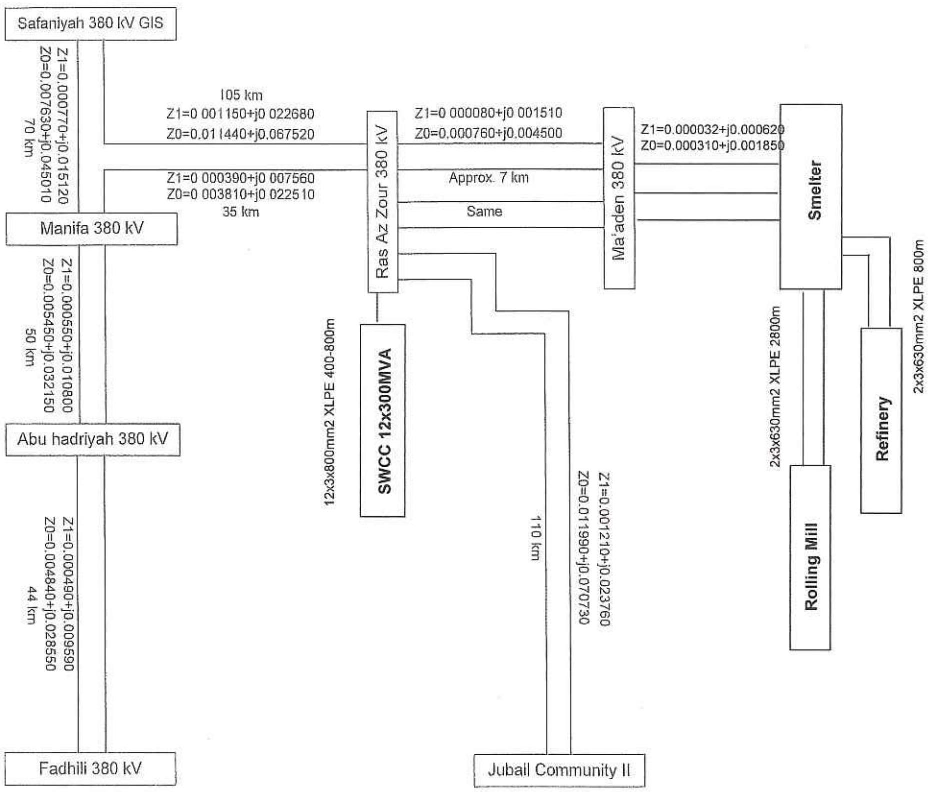


Fig. 1: SEC grid setup

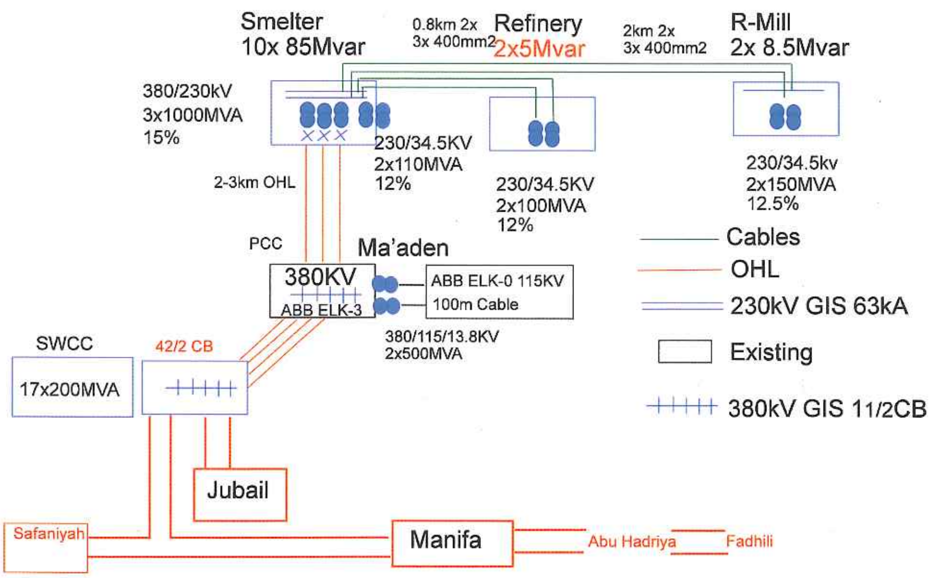


Fig. 2: MAC 380/230 kV configuration

Overview of the project

This industrial project is located at the Ras Al Khair complex in the north-eastern region of Saudi Arabia. It comprises an aluminium smelter, a major generating station including a desalination plant and a water distribution system operated by Saline Water Conversion Corp. (SWCC), an alumina refinery, a phosphate plant (Ma'aden Phosphate Company, MPC) and a rolling mill – all fed by a local new power plant connected to the SEC grid (Saudi Electric Company).

The Ma'aden project, Phase 1, is a 740,000 tpy primary aluminium smelter with two potlines, each consisting of 360 pots. Ma'aden plans to extend the smelter in the near future to six potlines delivering 2.2 million tpy of primary aluminium, making it the world's largest single site smelter.

The smelter is connected to the SEC Ma'aden substation by three 380 kV transmission lines in parallel, each of which is connected at the smelter's 380/230 kV stepdown transformers. The 230 kV switchgear at the Ma'aden smelter will supply not only the smelter but also the external alumina refinery and the rolling mill via 230 kV cables.

The smelter has two potlines, each with an ultimate load of 650 MW. Power factor correction and harmonic current filtering will be done by filters connected to the tertiary winding of each of the five voltage regulating transformers feeding each potline. The auxiliary load will be 85 MW and will be fed by two 100 MVA 230/34.5 kV transformers. Loads supplied from the smelter's 230 kV switchgear are estimated to be 115 MW for the rolling mill and the 90 MW for the alumina refinery.

The smelter will initially be fed directly by the SEC Ma'aden substation, which in turn will be connected by two SEC 380 transmission lines from Jubail. These lines will later be connected to the SWCC Ras Al Khair 380 kV substation. Two 380 kV lines, one each from the SEC substations of Manifa and Safaniyah, will be connected to Ras Al Khair 380 kV substation at a later date. The power for the plant will be supplied by the SWCC combined-cycle gas turbine power plant and by the 380 kV SEC regional transmission system.

The SWCC power station will have a nominal capacity of 3,000 MW and will also supply a large desalination plant and a water distribution system. About 1,000 MW will be fed to the regional SEC grid. The Ma'aden substation will additionally power the MPC phosphate plant, having a load of 150 MW connected via 380/115 kV link to the SEC Ma'aden 380 kV substation. This plant will have two 85 MW generators to supply its own load.

The power plant has a connection agreement with SEC that will include the ability to use power from the SEC grid when required. However, in case of grid disturbance and for emergency operation, the power plant will also be able to feed the smelter operating in island mode, i.e., isolated from the grid.

The next two diagrams show a simplified outline of the Ma'aden Aluminium Company (MAC) 380 kV/230 kV configuration and how MAC can be fed from the external grid.

Power system and power quality concerns

Study of the installed SEC grid in the Eastern province together with plans for the planned MAC extension, revealed that the smelter load and the way of operation had a significant impact on the SEC grid, as well as on consumers in the MAC region. Therefore many possible feeding grid operation scenarios had to be described, assessed and evaluated.

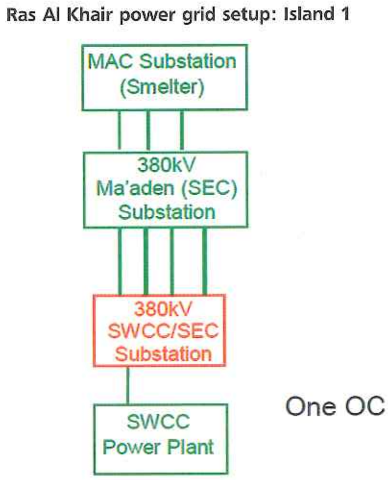
The outcome of this study was a detailed description of the network so as to better understand load flows and voltage stability as well as general power quality requirements.

Load flow case studies

- Smelter first metal including the smelter's first potline start considering five operation points. In this case, the SWCC power plant does not exist yet and the power supply comes from the grid.
- Smelter completion and SWCC power plant installation. In this case the power plant is already providing power to the smelter and SEC external grid. The smelter has the two potlines working at full rating.

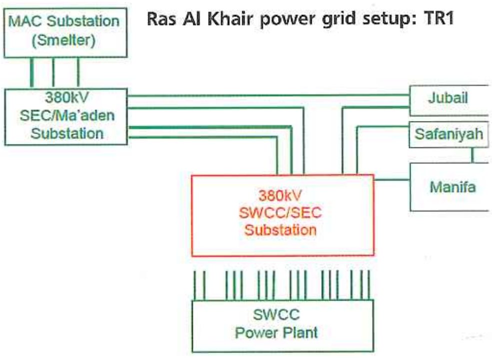
This phase extends the previous evaluation, considering the intermediate cases between both scenarios. For the proposed scenarios, the existing voltage levels and the adequacy of the reactive power will be investigated. The regulating tap changer located at the smelter will also be investigated and will provide information about the regulating capacity of the transformer and the maximum range of regulation.

- Ras Al Khair power grid setup: Island 1. The smelter is in island, not connected to the external grid. The SWCC has only one open cycle power generation unit (OC) in operation, supplying power to the smelter that has a load according to the supply capability of the generation groups.

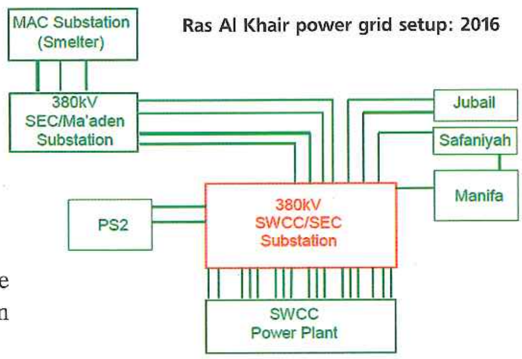


- Ras Al Khair power grid setup: TR1. The Transition (TR) case studies evaluate the influence of SEC grid connection transitions. The smelter plant is considered at full rate for all the cases, with both potlines in operation.

The first case, TR1 considers the external grid conditions as shown in the figure below:



- Ras Al Khair power grid setup: 2016. The case study evaluates the impact of the system foreseen in 2016, where PS2 (a new power grid system) will be connected to the RAK substation. Information about the overhead lines connecting PS2 and RAK, as well as the load and/or generation profile of PS2 system, should be submitted by the client prior to the start of the studies.



Voltage stability studies for power plant according to SEC requirements

The SEC grid code requirements document includes different points that should be evaluated and verified prior to the connection of the SWCC power plant to the SEC grid.

The system will be evaluated according to the following considerations:

- In normal operation of the SWCC and smelter power plant, as described in the full smelter plant case with the two potlines in operation, the SEC grid is fully connected and the SWCC power plant is in normal operation condition. The smelter will include its dynamic model.
- According to the results of the load flow studies, the generators will control the voltage at the RAK substation and the tap changer transformers will control the voltage at the generator busbar voltage level. In case the client requests an alternative operation procedure this should be settled before installation work. Otherwise the above conditions would be valid.

The study will investigate several events that would cause deviations of voltage at the busbar: loss of a load unit, and loss of a generator unit.

Resulting from the simulations, recommendations will be provided to avoid the loss of coordination between both control systems.

Transition into island mode operation and load shedding scheme

The studies proposed below serve to analyse possible improvements in the electrical performance of the systems connected to Ras Al Khair substations and to protect against voltage dips in the external grid (SEC). Given the existence of a new cogeneration, the study will be focused on determining if switching to islanding operation is suitable for the installation. This study requires the analysis of the following issues:

- Is the system capable of operating separately from the grid?
- If the separation from the external grid occurs, when exactly will it be most convenient and suitable to carry out the transition to island mode?
- How should the separation process from the grid (and consequent actions) be controlled so that the production is disturbed as little as possible?

Islanding the Ma'aden and SWCC system from the external grid (islanding operation) is not desirable for reasons of economy,

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Ras Al Khair smelter 380 kV outdoor GIS incomer from SEC grid

Ras Al Khair PL 1 rectiformer station, 400 kA 1750 VDC

risk, reliability or impact on equipment. Therefore these switch-offs should be limited to the essential minimum and should be delayed as long as possible. However, the switch process to islanding will imply higher risk the longer the plant is connected to an external faulty system. Thus the best solution will be obtained if the system is switched to islanding mode when:

- There is a real problem in the external grid
- 'All possible times' for the external system to recover have been given
- There is an acceptable level of certainty that the switch to islanding mode and subsequent islanding operation will be successful.

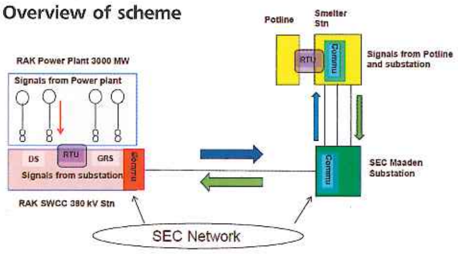
In order to be able to quantify the preceding statements, the dynamic operation of the installation must be known exactly both during the disturbance process and during the subsequent switch to islanding mode. This underlines the importance of the proposed transient stability study, which will mainly analyse the dynamic performance of the SWCC and Ma'aden Aluminium smelter plant subject to three-phase faults of various duration in the external grid. The study will specifically analyse following aspects:

- Determination of the units' stability limit time
- Analysis of the switch process to islanding operation
- Voltage collapse and frequency collapse
- Joint power / frequency control of generation units in islanding operation
- Generator and interconnection protections.

Monitoring system of the MAC feeding grid

The outcome of the various studies was that, in order to react fast and to keep the smelter connected to the grid as long as possible during grid disturbances, a monitoring system has to be installed. This power monitoring system consists of power monitoring units (PMU) installed at many feeding lines and substations so as to have an overview of the grid power flows and voltage fluctuations. Thus

Overview of scheme

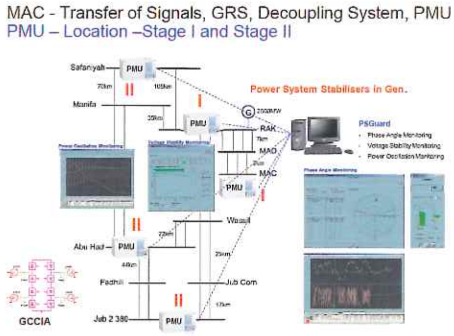


the SWCC power plant control system will be able to react rapidly to control the power flow and voltages.

The power monitoring units provide the basis for accurate monitoring of the power network with a one microsecond time stamp accuracy. Measured values and abbreviations used:

- Phase Angel Monitoring (PAM)
- Power Oscillations Monitoring (POM)
- Voltage Stability Monitoring (VSM)
- Line Terminal Monitoring (LTM).

With all these data available, the high-speed and accurate power monitoring system can then provide signals to damp power oscillations, to decouple feeders and loads, and to control grid voltages, and so to stabilize the grid.



Power flow monitoring system which was evaluated and partly installed

Statement by Karl Cunningham, Alcoa Power: "By analysing and learning about the complete power system we could develop and select the most advanced monitoring and control system to provide us with the highest network availability and reliability. ABB supported us from the beginning of this long journey and managed to fully satisfy our need."

Conclusions

All scenarios of disturbance should be considered, also possible situations during partial realization of new network elements. The control system requires power monitoring units at key points to provide an overview, and the ability to react rapidly to disturbances according to agreed criteria.

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