Performance Evaluation of Composite Islanding and Load Management System using Real Time Digital Simulator

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Abstract— A Composite Islanding and Load Management System (CILMS) designed for managing the generation and load shedding in islanded mode of operation of an existing Industrial plant was evaluated under various operating scenarios. The closed loop performance of this scheme (with the logics built into a controller) as a composite system and the associated under/over frequency relays used for islanding was carried out on the Real Time Digital Simulator (RTDS) at CPRI. A detailed simulation of the industrial network comprising of individual generators along with its governor – turbine and exciter, generator transformers, transmission lines, circuit breakers, pot line loads and the grid was simulated on RTDS. Physical controller and relays were interfaced with RTDS and were fed with the required digital and analog signals from simulation. The output signals from the controller and relays were fed back to RTDS. Various conditions such as under/over frequency with varying $df/dt$ rates, islanded mode of operation, faults etc were studied. The results of the study helped in finalizing the revised settings for generator and load shedding, fine tuned settings of under/over frequency relays for islanding to be implemented at site. This paper discusses results of the case study of such real time performance evaluation of industrial type of controller and also highlights the importance of usage of the real time simulator facility at CPRI for such studies.

Index Terms— Real Time Digital Simulator, Islanding, Export/Import, Captive Power Plant. Load shedding

I. INTRODUCTION

RAPID industrialization has led to increased power demand and has overtaken the growth in generation and transmission networks. This has forced many industries, especially continuous process industries, to set up captive generation to meet their essential power requirements. The captive generators are generally operated in parallel with the utility (grid) supply to have a strong reinforcement. Whenever the grid is not available or grid conditions are varying widely, the captive power plant and the process industry network is to be isolated from the grid to safeguard the Captive Power Plant and the process industry. After islanding, to the extent possible, the essential loads of the process industry plant should be supplied by captive plants until grid connection is restored. If successful and timely isolation of CPP plant does not take place during prolonged disturbances in the grid, there are chances of complete blackout in the process industry plant leading to significant loss in production. Equally important is the fact that after isolation from the grid, there should be a generation –load balance within the industrial plant. Two effective ways to counteract this effect can be considered, such as increase of generation and the decrease of load demand. To increase the system generation, because of distinctive mechanical characteristics of existing generators, the achievement of the expected response within the expected time frame may not be satisfactory. As for the decrease of the load, it is often accomplished by the manual load-shedding or by the automatic tripping of some predetermined loads. Because the decisions on the manual load shedding is primarily dependent on the operators’ experience, the accuracy and performance is often affected by the limited human response. Therefore, a composite scheme which takes care of the generator/ load shedding after islanding from the main grid has become the major concern in modern industrial power system networks.

Most of the industrial plants utilize some sort of SCADA to monitor electrical parameters. With the availability of current data and enormous processing power, these systems have been used in engineering schemes for proper load management. Such schemes with a correct look up table, based on operating values and also on priority assigned by the operator for tripping of appropriate loads or generators goes long way in avoiding black outs of captive power plants.

Until now, the performance of such schemes could not be validated prior to its commission at site. Hence, after the scheme is commissioned at site, the scheme would be wired only for alarm for 4 to 5 months so that performance of the scheme can be monitored at site and settings can be fine tuned. After gaining the confidence of operating personnel, the schemes are finally wired for trip. But now, with availability of tools like ‘Real Time Digital Simulators’, the performance of the scheme can be validated under realistic conditions for
all possible scenarios that the scheme can encounter in its service time. Thus, with this type of testing not only the settings can be fine tuned, but the hardware can also be checked. The commissioning time is thereby drastically reduced and the performance guaranteed.

II. REAL TIME DIGITAL SIMULATOR

A Real Time Digital Simulator is an excellent tool for the investigation, development and integration of new and complex power system components. The user is able to study both the device itself and the response of the existing power system to its operation or misoperation. Although specific applications vary, Real Time Digital Simulators are particularly useful when actual power system devices are to be included in the test program or study. The advanced digital simulator system solves the transient model in real time, making it possible to test physical controllers in a closed-loop environment, which adds greatly to the realistic nature and quality of the testing. This so-called closed loop testing method represents an accurate and detailed way to evaluate the performance of the physical device(s) under actual operating conditions prior to their installation in the real network. Such tests help verify and optimize the physical control equipment and serve as a valuable pre-commissioning tool. In addition to evaluating the performance of the physical device, the simulator is also able to accurately represent the response of the power system to the operation of the device under test. The more precise the modeling is and the data accurate, the more reliable will be the simulation.

The simulated model interacts with the interfaced physical device through a set of input and output signals. The input signals received by the RTDS reflect the operating conditions of the physical controller, while the output signals generated by the simulator represent the response of the simulated system to the operation of the device. The exchanged signals and parameters have to be conditioned through signal interfacing modules before being exchanged.

When physical controllers are tested, it is very common for large number of signals (both analogue and digital) to be interconnected to and from the simulator. Thus the RTDS is provided with large numbers of flexible, accurate, high speed inputs and outputs (I/O’s). Exchange of analogue and digital signals with externally connected devices is accomplished using a host of high speed, high precision and optically isolated, specially designed communication modules, which connect directly to the processing elements, ensuring well coordinated exchange of data between the simulator and the physical equipment. Figure 1 shows an overview of Real Time Power System Simulator, installed at CPRI. Many of the performance evaluation studies carried out on RTDS for various utilities have helped in obtaining information that could not have been discovered by any means other than by the real-time power system simulator.

Fig. 1 - Overview of RTDS at CPRI

III. ISLANDING SCHEMES

The power system is never in a completely steady state. There occur frequently some kinds of transition states, such as changes in consumption and production, faults or various switching operations. As the power systems are nowadays operated closer to their limits, these disturbances may lead to frequency or voltage collapse in the network or loss of synchronism of the generating units. In such disturbed conditions of the grid, if plant generators are not successfully isolated from the grid, they also sink with the grid.

The type of disturbances can be categorized as follows:

(a) Grid collapse leading to loss of utility supply
(b) Loss of grid supply due to tripping of the circuit breaker either at the plant end or at the grid side required to isolate a fault
(c) Wide fluctuations in frequency or grid voltage or both.

The time frame for Grid isolation is generally within few seconds for most of the disturbances, giving sufficient time margin for isolated CPP generators to stabilize and feed partly or fully the plant loads after isolation. Various criterions used in islanding schemes (in operation) are:

(1) dF/dT along with underfrequency for Specified Time
(2) dF/dT along with overfrequency for Specified Time
(3) Pure Underfrequency or pure Overfrequency
(4) Directional overcurrent with undervoltage
(5) Pure undervoltage
(6) Overvoltage with reactive power inflow
(7) Reverse power with underfrequency

After successful grid isolation, there should be means for controlling the islanded operation. The control of the frequency and the voltage in an isolated industrial network with captive generation is problematic, for an island network is seldom a stiff one. If the island operation is likely to be of long duration, load shedding facility should be activated else leads to blackout of the plant. Whenever the plant was importing power from the grid, it is essential that after grid separation, the generators supply additional power to meet the plant loads. If adequate generation is not available, load shedding is to be resorted, to achieve load-generation balance within the
plant and thereby prevent a system collapse. The amount of load shedding depends on various factors such as – extra margin available in the CPP's to take up further load, response time of governing system, inertia of the generators, power that was imported from grid before islanding etc. Thus the generator/load shedding scheme is to be custom designed for site specific conditions.

Having designed the Islanding and load management system, its performance is to be evaluated under realistic operating conditions for all possible contingencies and export/import scenarios that can be encountered in the site.

IV. SYSTEM SIMULATION

A typical industrial plant power system network considered in the study is shown in Fig 2. The industrial plant comprised of eight numbers of steam generating units and is connected to the nearby utility grid at 220 kV level. The total Generation of the plant is about 810 MW, 270 MW in complex A – comprising of four generators each with rated capacity of 67.5 MW and 540 MW - comprising of four generators each with rated capacity of 130 MW in complex B. The total plant load (smelter loads) is about 710 MW. The loads are in blocks of 110 MW each (two no.’s) with an auxiliary load of 30 MW connected at Bus C, and 387.5 MW with an auxiliary load of 14.5 MW connected at Bus A.

Under normal condition with full generation in operation supplying the entire plant load, the plant operates in export mode, supplying excess power to the grid. The plant also imports power from the grid during shortage of generation within the plant.

Individual Captive power plant generators are modeled in detail with their sub-transient, transient, steady state reactances and time constants on d & q – axis. The excitation system, speed governor/turbine systems have also been modeled in detail with their appropriate gains, time constants and limits, as existing at site. The governors of generators are modeled to operate in constant MW mode when in synchronism with the grid. Once islanding is confirmed i.e. grid circuit breaker opening is sensed, the governor operation is changed from constant load mode to droop mode within 100 milliseconds with a dead band of 40 RPM in their characteristics. The turbine mass models of generators in both the complexes are of high pressure type. The utility grid is modeled as impedance based on the fault level (about 10200 MVA).

Transmission lines are modeled with actual line lengths, positive & zero sequence impedances. Power transformers are modeled with their leakage impedances, magnetizing impedance, appropriate voltage ratios and vector groups. All loads are modeled as constant impedance loads at appropriate voltage levels. Generator circuit breaker, tie line circuit breakers, and breakers connecting the load are all modeled as time controlled switches. The opening and closing operation of these breakers are controlled by the CILMS which is being interfaced with the RTDS.

The validation of the simulation on RTDS is carried out by comparing the snapshot power flows (MW & MVar), bus voltages with those recorded at site. The signals from the simulated network are interfaced with the actual controller and physical relays through a set of input and output signals required for decision making in the controller. The protective device functions that were used for islanding the industrial plant were under frequency (UF), over frequency (OF), rate of change of frequency (±df/dt relay) along with underfrequency, rate of change of frequency (±df/dt relay) along with overfrequency, under voltage (UV) and directional overcurrent relays.

The various signals that were interfaced from the system simulation were the 220 kV bus voltages, line currents in both the interconnecting lines, status of all generator and load circuit breakers, active powers of all CPP generators and loads, frequency error signals etc. Fig 3 shows a schematic diagram of the signals exchanged between the CILMS, RTDS and Relays.

![Schematic diagram of the signals exchanged between the CILMS, RTDS and Relays](image-url)

The digital inputs represent the status of various circuit breakers and analog inputs provide the bus voltages, power
outputs of various generators, power consumption of load and power flow on lines. The bus voltages and the line currents obtained from the simulation were amplified to the levels as that of the CVT’s and CT’s using power amplifiers, which also form a part of the RTDS.

V. CASE STUDIES

The islanding and islanded operations of the Industrial system were studied by simulating the dynamic behavior of the typical system connected to grid shown in Fig 2. The contingencies in the grid that result in an islanding operation have been simulated on the RTDS by changing the voltage and frequency of the source representing the grid.

Following are the cases which were simulated on the RTDS on the grid side:

1. Over Frequency with df/dt more than 1.5 Hz /sec
2. Over Frequency with df/dt less than 1.5 Hz /sec (Normal OverFrequency)
3. Under Frequency (UF) with df/dt more than 1.2 Hz /sec
4. Under Frequency with df/dt less than 1.2 Hz /sec (Normal UnderFrequency)
5. Fault at the grid side creating undervoltage of less than 0.3 p.u. (Directional Overcurrent + Under Voltage)

The analog inputs (bus voltages) to relays1 and 2 sense the changes in voltage and frequency. When these values exceed the set values a trip signal is given to the tie line breakers on the plant side to trip, thereby isolating the plant from the grid. All the above cases of islanding operation are studied, both under import and export conditions of the grid. The various import / export conditions are created by curtailment of Load/ CPP generator units within the industrial plant.

Having confirmed the status of the grid circuit breaker having opened i.e. the industrial system successfully islanded, the CILMS takes over the function of performing the load-generation balance in the plant. A lookup table built into the controller logics for generator tripping (if the plant was in export mode prior to islanding) and load shedding (if the plant was in import mode prior to islanding), sends trip signals to appropriate generator/load circuit breaker for tripping thereby maintaining a perfect generation - load balance.

Few case studies of importance which formed a part of the study for arriving at the fine tuned settings and checking their validity are discussed below:

(a) Case 1: Over Frequency with df/dt more than 1.5 Hz /sec: In this case as the total generation in the system was about 735 MW and load 582 MW, there was an export of 152 MW. Fig 4(a), 4(b) and 4(c) shows the behavior of generators and loads when the frequency of the grid suddenly increases to 51.5 Hz with rate of change of frequency of 1.55 Hz.

As seen from plots, with existing settings, there was a maloperation of tripping of one of the loads at Bus C.

(b) Case 2: Same as Case1 but with revised settings. Fig 5(b) clearly shows that there was no tripping of loads, but only one generator at Complex B has tripped.

(c) Case 3: Under frequency with df/dt less than 1.2 Hz /sec: In this case as the total system generation was about 613 MW...
and load 632 MW, there was an import of 19 MW. Fig 6(a), 6(b) and 6(c) show the behavior of generators and loads when the frequency of the grid suddenly changes to 47.8 Hz with a rate of change of frequency of 1.1 Hz. As seen from plots, with existing settings, there is a tripping of one of the generators of Complex A, followed by tripping of one of the loads connected to Bus C.

(d) Case 4: Same as Case 3 but with revised settings. Fig 7 clearly shows that there was no tripping of loads.

VI. CONCLUSION

The CILMS and the associated relays used for islanding and managing the generation-load balance of a typical industrial system was tested using realistic signals derived from the simulated system on the RTDS. This extensive testing helped in validating the existing settings of the frequency relays adopted for islanding and also correctness of the settings of generation/load shedding lookup table built into the CILMS. Based on the test results, the time delay settings of the over/under frequency and df/dt relays were reduced to ensure successful islanding. Likewise, the settings in the lookup table for generator trippings and load shedding were revised and recommended for implementation at site. Performance of the actual system after implementation of the revised settings have been encouraging.
There is a good scope of future work in afore said study. The response of different types of governors could be studied at instance of islanding. The system response and frequency settings of the islanding relay will differ from case to case basis. But with various such studies a trend of settings can be figured.

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REFERENCES

[2] Prabha Kundur, Power System Stability and Control,