Electrical Modernization with Power Management System Implementation for Distributed Power Generation

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ABSTRACT

When power demand is foreseen to rapidly increase in near future, the need to upgrade the electrical system/ equipment becomes apparent. When operation must proceed while any change is in progress, the revision is very difficult. Parallel operation of electrical equipment of various vintages and ratings is inevitable for some extent of time. The special considerations and review on the monitoring, metering and control of new master PLC controller called power management system (PMS) are discussed. Electrical distribution system design and equipment modification and upgrade which improve system operability, enhance reliability and contribute to safety are described. Furthermore, hazard is evaluated for electrical design of a system upgrade. The primary technique for the hazard evaluation was a hazard and operability study, which is a brainstorming approach conducted by a multidisciplinary team. The approach simulates creativity of the team member to generate new ideas. As a result of this study, numerous and qualitative recommendations have been made to electrical design the safety and operability problem out of the major power system upgrade. Among the recommendations are suggestions on protection and control strategy, materials of construction, process material releases, alternative design options, and maintenance of this power system upgrade.

Keywords: Power management system, Brown field, Load shedding, Safety and operability study, Energy analysis

1. INTRODUCTION

The electrical generation, distribution and utilization system, which evolved from supplying a 10MW load in 2007 to a 50MW load in 2015, has undergone significant changes as per production development plan. The existing electrical power system and generation was planned to have a major upgrade. The system upgrade was basically focused on augmentation in the generating capacity of plant's central power. This was required in view of plant load increase in upcoming years forecasted.

Avoiding process unit operations required the onsite design team to complicate modifications into the existing distribution system. The design, commissioning and start up of the new electrical equipment provided a series of challenging opportunities to the design team. The scope of this electrical renewal project required the new equipment to be integrated with existing facilities with minimum unit shutdown time.

Several new substations were installed in the midst of operating units. The sequence of work often had to be changed to take advantage of unplanned process unit outages. Operating units dictated that hazardous location classifications were observed, while the work was in progress. While the old 40kAIC switchgear was still connected, there were severe restrictions on the configuration of the new 50kAIC switchgear. Detailed plans were required for the transfer loads from the old system to the new system. Final transfer of power and control was undertaken in 30 stages. Each transfer required that new operating procedures were written and that a flow of information was established to operating personnel on the current electrical system configuration. It was of critical importance to keep the operating unit personnel informed since not all of the changes were implemented at the same time. Constant communication kept operations personnel informed of the complex sequences of changes in the power system. All of these activities spanned a 27 months period and occurred without injury to personnel and with no damage to equipment. Major changes in the electrical systems, as the one initiated by this project, required a thorough and detailed safety review of the design, construction, commissioning and startup of the equipment [1].

The key facility of system upgrade is implementing of a new master PLC control system called as power management system (PMS), which requires major modifications and upgrades to be made to the

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existing distribution system. All new systems are equipped PMS. Apart from features for main distribution the communication network included, the PMS system is take main role to perform automatic generation control with active/reactive generation and grid load sharing, frequency/voltage control, initiation of automatic generator synchronization, automatic reverse synchronization of group generators with the grid, automatic synchronization of inter-tie feeder circuit breakers, automatic dynamic contingency on-line load based rapid load shedding under sudden generation source tripping (due to sudden grid or generators tripping), automatic dynamic contingency on-line load flow based rapid grid islanding or generator shedding under sudden bulk load circuit breaker switching off (leading to excess generation and excess grid export), load or demand side management, start inhibit of loads according to generator spinning reserve available, event recording and parameter trending, and display of alarms [2-5].

2. BACKGROUND

The project is intended to cater for the additional loads, which are forecast. It includes new generating units, installation of new 50kAIC switchgear for replacing existing 40kAIC switchgear, re-rating of existing equipment to accommodate the increased load forecast. Introduction of a new PMS system is one of the very important parts of the project. The main electrical scope for the project consists of following parts:

- Installation of three gas turbine generators (GTG).
- Installation of the new 50kAIC switchgear (50-HV-02) as the main intake switchgear and relocation of connection of power grid (EGAT) from old 40kAIC switchgear (50-HV-01) to new main switchgear.
- Installation of new 50kAIC switchgear (LPG -HV-01) for replacing old 40kAIC switchgear (LPG SWGR).
- Installation of current limiting reactors (CLR) to limit the short circuit current to old main switchgear
- Installation of earthing transformers for significant change in plant's system earthing
- Installation of new PMS system for control and monitoring of power generation.

A. Existing Power Supply System

Existing configuration is as shown in figure 1. The existing system received incoming power supply from power grid at 115kV. The voltage level was brought to 6.6kV via 115/ 6.6kV transformer. The capacity of existing transformer was 25MVA. Four of GTG each of rating 2.8MW were installed for in-house generation. Generators along with the power grid were connected to 6.6kV bus of old 50-HV-01.

The main switchgear was two-section switchgear with bus coupler normally closed. The short circuit rating of the switchgear was 40kA/ 3sec with make capacity of 100kA. Various loads were supplied from main switchgear. The main loads were old LPG SWGR and other loads outside the plant, which were supplied via 6.6/ 22kV transformers with overhead lines.

B. Brief Scope of the Project

To cater for the increased power requirements up to 2015, new three generators were planned for addition on the network, which they were rating of 4MW each. Two of them were connected on old 50-HV-01. New 50kAIC switchgear call 50-HV-02 shall be introduced in the upstream. The third generator along with EGAT was connected to new 50-HV-02. Owing to increased fault current at old LPG SWGR, this shall be replaced with the new switchgear (LPG-HV-01) with higher short circuit rating meeting the new requirement. Earthing arrangements were changed in view of requirement from the generator manufacturer. To limit short circuit current on old 50-HV-01, currents limiting reactors (CLR) were introduced.

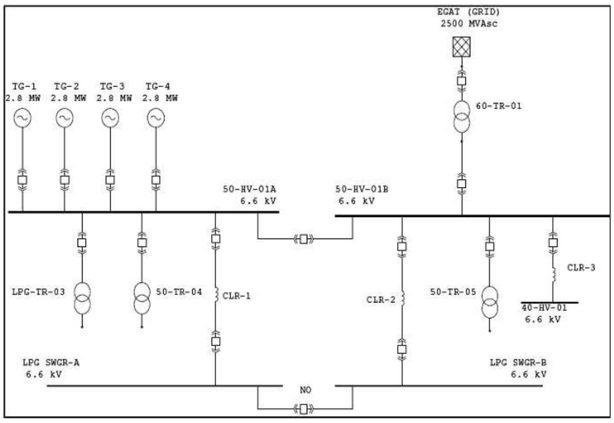

Fig.1: *Existing configuration*

C. Operating Configuration

The new operating configuration was bus coupler at new 50-HV-02, which was in the normally closed configuration, whereas the bus coupler at old 50-HV-01 was kept in open condition. The basic configuration for the new system is shown in figure 2.

The existing four generators along with two new generators were connected to old 50-HV-01. One new generator and power grid were connected to new 50-HV-02. In order to remain within the fault rating of old 50-HV-01, CLRs were connected between 50-HV-01 and 02.

As part of the new system earthing philosophy, earthing transformers were installed at each bus section of 50-HV-01 and 02. The switchgears for the new system were operated by communication network, whereas control modes for all the generators (existing and new) were controlled via the PMS, which

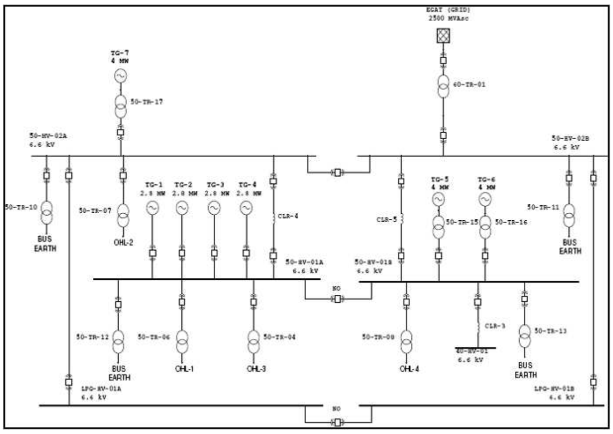

Fig.2: *Final configuration*

transmitted signals to each gas turbine control panel. The PMS system shall include the functionality required for islanding and load shedding schemes based on spinning reserve as well as dynamic system. In addition, it also initiated synchronization via the PMS.

3. SAFETY AND OPERABILITY EVALUATION FOR ELECTRICAL DESIGN

The systematic approach was also proposed to review the safety, reliability and operability of the electrical system design from both technical maintenance and operational viewpoints for the project of major power system modification and upgrade.

With common backbone of hazard and operability (HAZOP) analysis, it is electrically based and concentrates on proper electrical system design, operability, maintainability and technical fit for purpose as well as safety as presented in figure 3. This paper also explains the process of the systematic approach of Electrical Engineering Safety and Operability Review (EESOR), which will be more effective than the usual technical reviews, as an overall assessment of fitness for purpose, although technical reviews should be retained for the requirements of specialist topic. Review results and recommendations obtained from systematic approach are beneficial for the project to identify a number of critical actions, which need to be resolved to ensure the overall integrity of the post modified and upgraded electrical power system and that the project can be safely executed [6-8].

The EESOR study was carried out by a multidisciplinary team consisting of the EESOR facilitator, project engineer, electrical discipline engineer, construction engineer, maintenance engineer, safety engineer and engineering consultant, see figure 4. The majority of the team members were already involved in the design and analysis of the power system upgrade project. The results of the EESOR study were in the form of design deviations, their causes and potential consequences. The EESOR study was successful in identifying and examining many types of

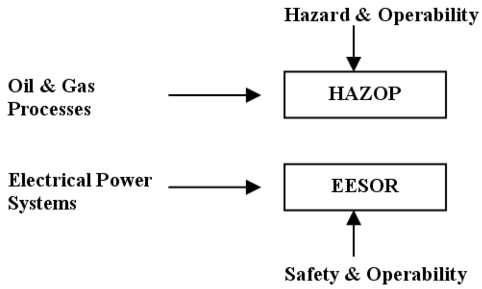

Fig.3: *Plant safety study*

risks, sources of non-optimum system reliability, and improvements in the project design. The strongest contributions of the EESOR study in system reliability were in power control and protection strategy, equipment rating, alternative design options, operation and maintenance [9-10].

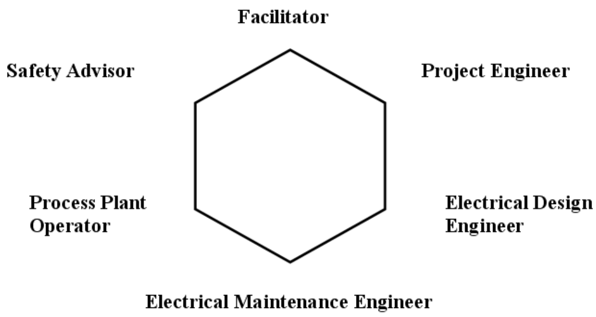

Fig.4: *Typical EESOR review team*

4. THE PROCEDURE OF ELECTRICAL ENGINEERING SAFETY AND OPERABILITY REVIEW

The EESOR process is a formal framework for searching and systematic examination of electrical engineering designs, which it is shown in figure 5. The objectives of EESOR study are:

- To assess and minimize the type of potential hazardous to people around or in electrical installation.
- To provide a critical review of system design and equipment through limitations and their effects on operability and security system.
- To analyze key tasks set for operations, assess facilities, instruction and recommend measures to avoid operator error.

5. SYSTEM UPGRADE DESIGN

Due to the project was implemented in brownfield operating areas. The design including construction, commissioning and startup of the new electrical equipment provided a series of challenging opportunities to the design team. The scope of the project

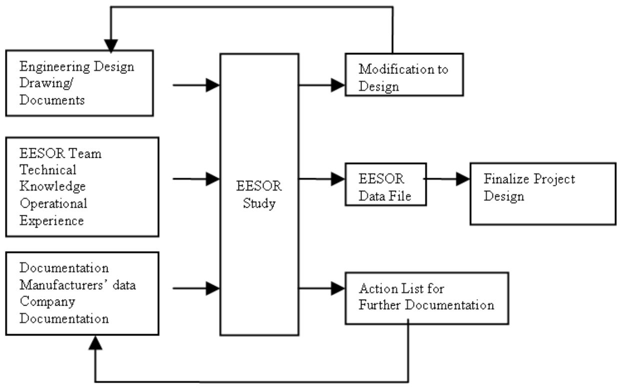

Fig.5: *EESOR study - Input & Output*

required new equipment to be integrated with existing facilities with minimum operation unit downtime. No injuries to personnel, no damage to equipment and no unplanned shutdowns were anticipated and considered during engineering design. Several new equipment, new operating systems and modification works to the existing systems were installed and executed in the midst of operating units. The sequence of work was foreseen, that it may often have to be changed to take advantage of unplanned process unit outages. Operating units dictated that hazardous location was observed while the work was in progress (such as work near energized conductors). While old 40kA switchgear of 50-HV-01 and old LPG SWGR were still connected, there were severe restrictions on the configuration of the new 50kA switchgear of 50-HV-02. Detailed plans were required for the transfer of loads from the old system to the new system. Each transfer required that new operating procedures were written and that a flow of information was established to operating personnel on the new electrical system configuration. It will be of critical importance to keep the operating unit personnel informed since not all of the changes were implemented at the same time. Constant communication kept operations personnel informed of the complex sequences of changes in the power system. All of these activities were planned to span about twelve months period and expect occurrence without injury to personnel and with no damage to equipment.

Based on above concerns covered during engineering design, the following points are summarized with respect to the existing electrical power distribution system constraints.

- The old 50-HV-01 switchgear's short circuit current rating (of 40kA/3s)was likely to be exceeded with new gas turbine generators and additional loads hooked up since the existing system available short circuit current level is already at approx. 80% rating.
- It was evident that without any adoption of short circuit limiting, old 50-HV-01 with the 3 new firm generator connections were very close to its fault rating with no margins available even after considering a higher %Z of 11% (normal being 8.35%) for the 5MVA generator transformers. The rating was exceeded with additional new generators to be installed for non-firm loads. This was mainly due to almost 50% of short circuit current contribution was from power grid.
- There was no space for extension of old 50-HV-01. If the switchgear extension was necessary, a new switchgear room or building would be required;
- The maximum power transfer across any portions of the old 50-HV-01 switchgear bus / bus section circuit breaker shall be limited to a maximum of 20MW. The total non-firm load growth estimated was at some 50MW. This non-firm load growth capacity shall be arranged to equally split between the two bus sections as much as possible.
- The maximum supply capacity of the power grid, existing in-plant generation, and new firm plus non-firm generators (based on 5 numbers of 4MW GTG) were 20MW, 11.4MW and 20MW, respectively. Under normal operation, the supply from the power grid shall be kept close to zero. It was thus unlikely that there was a case where both grid and generation were required to operate at their maximum power flow at the same time. To limit the power transfer across old 50-HV-01 bus section, the existing and new generation capacity of some 31.4MW shall be split to hook up at both bus sections of old 50-HV-01 at approximately equal capacity.
- From the above arrangement of supply and load split, it was unlikely that the old 50-HV-01 rating of 2500A posed any problems from unsatisfactory load transfer across its busbar sections. This aspect had been checked in selection of scheme where importance was given to appropriate split of load and generation between the two 50-HV-01 bus sections to ensure no parts of the switchgear rating were exceeded under normal or credible generation outage scenarios.
- There might be some advantage in considering the 22kV or intermediate 11kV voltage hook up option provided the power grid 115kV intake was transferred to this new higher voltage rating switchgear. Without transferring the grid to the higher voltage there was no reduction in fault level at old 50-HV-01 even after hooking new generators to the new higher voltage switchgear. Thus without grid intake transferred from old 50-HV-01 switchgear, there was no advantage in considering the 22kV or 11kV new generation hook up option. The higher voltage scheme was likely to be costly with the need for the new main grid intake transformer and redundant

inter bus transformers to the old 50-HV-01 switchgear. However, with power grid intake reconfiguration, it may offer a sound system for future huge load implementation prospect.

6. STUDY AND EVALUATION RESULTS

The EESOR identified a number of actions, which need to be resolved to avoid jeopardizing the project schedule and to ensure that the project can be safely managed [11]. The areas of improvements, e.g. risk areas have been identified and recommendations are detailed in the EESOR worksheets. Some main issues raised in EESOR study are as follows.

A. Main issues raised during safety analysis

- Project specific electrical safety rule needed to be developed to manage all electrical safety aspects associated with the brown field nature of the project. This was particularly important due to the number of concurrent activities i.e. during normal operation, during transition and demolition phases of the project.
- The sequence of activities for construction, testing and commissioning was required to be made available in advance. This should be included in the overall implementation plan of the project.
- Verification was required for short circuit capacity of existing main switchgear for all phases of the project in view of addition of new GTGs on this board.
- Confirmation was required for the adequacy of the existing electrical equipment (termination boxes, cables etc.) due to higher short circuit (SC) levels after the addition of generators and loads on the system.

B. Main issues raised during system security and operability analysis

- Adequacy for existing rectifier of substation needed to be checked in view of additional battery bank planned.
- Requirement of sequence of activities and ensure for all the phases of the project, equipment rating was not exceeded.
- Requirement of optimum power factor after the new loads and sources were added to the system.
- In case of momentary paralleling of the two sections of existing main switchgear, the SC rating of the board was going to be exceeded. This was not acceptable. However; this restriction can be overcome by reducing the SC contribution on the board by reducing the number of sources such as generators. For the identified cases, instructions/ procedures needed to be developed as part of the power generation, operation and control philosophy.
- During detailed design the various islanding scenarios needed to be addressed and for each scenario the load shedding priorities needed to be defined.
- Refurbishment of the spare current transformer (CT) was required to ensure that existing CT were for the new and requirement of any new CT was verified in line with the requirement of GTG and unit transformer. This included X class CT for differential protection.
- Confirmation was required for under frequency / over frequency settings of GTG. Co-ordination of equipment protection and system frequency needed to be carried out for operating condition. This shall be carried out by transient stability study.
- Relay co-ordination study with its implementation plan was required for the transition phases of the project.
- A hardwired under frequency load shedding scheme was required with relevant priority as a back up of power management system.

C. Main issues raised during operator task analysis

- Planning for on site training should be prepared with identification of the resources.
- Handover procedure consisting of as built drawings, documents, vendor drawings manual was required during each phase of the project.
- Implementation plan should include the manpower requirements for project and normal operation after addition of new systems. Type of resources,which were required for the various phases of the project, needed to be decided.
- Switching procedure should be included for each phase of the project.

Referring to above concerns covered during engineering design, the following considerations are given during project planning.

- System expansion and provision of capacity and configuration to accommodate foreseeable future load additions.
- Monitoring, metering and control to be improved.
- Limiting earth fault current flow to acceptable limit on the 6.6kV system by utilization of bus earthing transformer.
- Balancing load flow while maintaining a match between equipments interrupting rating and available short circuit current.
- Optimizing substation operability and reliability by the use of power management system (PMS).

The details of study results are given below.

A. System Expansion

Operating units were polled about their expectations for future electrical requirements. Appropriate provisions were made in the electrical equipment design and configuration to accommodate at least seven years' growth.

B. Two-section Substations

The design basis established during conceptual design was to incorporate two-section substations from the 6.6kV system through to the 380V level for critical operating units. This would permit de-energization of a transformer and its associated primary system for repair or routine maintenance without requiring shutdown of operating units. Routine maintenance of secondary breakers could also be performed without a process outage.

C. Operator Safety

Each substation design incorporated enhanced operator safety features. All 6.6kV switchgears were equipped with full insulation. No life parts of bus bars were opened for danger. The switchgears were qualified as classification IAC according to IEC 62271-200 with regard to its mechanical strength in the event of an internal arc. The secondary and bus tie breakers were equipped with synchronizing check relay to electrically block breaker closing should the two sources be out of synchronism. At the 6.6kV level, breakers were equipped with a closed door electrical rack-in system to enable the operator to stand at a safe distance from the breaker while racking the unit. Both electrical and mechanical interlocks were provided to assure proper sequence of operations.

D. Monitor, metering and control

PMS was designed for monitoring, metering and controlling to the system. PMS included features for power distribution communication network, load sharing, synchronizing, load shedding, event recording and parameter trending, and display of alarms [12-13].

E. System earthing

Existing system earthing of 6.6kV power system utilized individual neutral earthing transformer of 50A for each generator and grid transformer neutral which had inherent drawback from its varying earth fault currents from 50A to 250 A which was dependent on the number of the on-line power sources and affect effective earth fault protection. To ensure earth fault relaying sensitivity was maintained even with the minimum generation in operation, bus earthing transformers connected to each of 2 old 50-HV-01 bus sections were implemented to the system.

F. Load flows and interrupting capacity

Load flows on the existing system were greatly out of balance thus limiting switching flexibility. The 40kA switchgear rating also placed severe restriction on the new system configuration. The new system was installed with 50kA rated switchgear. The current limiting reactors were installed to limit fault current to old 40kA switchgear.

G. Power plant operation and control

The existing problem was of frequent power system instability during disconnection from power grid due to ineffective isochronous operation of power plant with existing master controller (LSP). It was determined to use simple speed droop operation for each GTG. New PMS was installed and interfaced with existing LSP panel to control and monitor all the new and existing power generation and import /export power control with grid supply.

H. Load shedding system

Load shedding functionality of PMS as illustrated in figure 6 was implemented to the system.

Load Shedding Scheme	Purpose of Scheme	Status for Initiating Load Shedding Operation
Fast Load Shedding	To remain the in-plant power generation operation while the reserve of plant is rapidly decreased.	• Sudden generation tripping. • Grid tripping (Islanding). • Bus Inter Tie Tripping.
T5 Overload Load Shedding	To avoid overload of the gas turbine generator, which is caused by slow increment of plant electrical load from remote location.	• All GTG T5 control mode The signal is got from GTG via communication network.
Overload Underfrequency Load Shedding	To avoid overload conditions during GTG's islanding running.	• Bus Underfrequency* * Analog input from frequency transducer receiving from each system bus of the 6.6kV switchgear. PMS shall automatically start slow load shedding scheme if the bus frequency fall down at below or equal to 49 Hz setpoint.

Fig.6: *Load shedding functionality of PMS*

7. RELIABILITY IMPROVEMENT OF DISTRIBUTED POWER GENEARTION BY DESIGNED PMS LOAD SHEDDING

One of system reliability improved by implementation of PMS was system load shedding. The existing load shedding system had low sampling rates, which can result in slow shedding of load under generation or grid trip. Stability of the generation and distribution systems depended on fast operation of load shedding functions, to reduce system load to acceptable levels within critical fault clearing time and sudden islanding by trip out of grid during importing power. Faster load shedding was therefore to be employed to ensure power system stability in this system upgrade. The concluded load shedding priority is defined in figure 7. Figure 8 to 10 shows recovery time of under-frequency load shedding (UFLS) shed as priority table executed by PMS is 565ms, which is much faster than the existing load shedding of 1 sec [14].

8. APPLICATION FOR BACKUP OF PMS LOAD SHEDDING

The load shedding system for upgrade electrical distribution system is mainly managed and controlled by PMS system. Hard-wire underfrequency load

Priority	Sheddable Loads			Load 2015 (kW)	UFLS Stage
	Descriptions	Panel	Feeder		
1	Load-A	40-HV-02	L02/L19	1800	1
2	Load-B (OHL-2)	50-HV-02	M3	8900	
3	Load-C (OHL-1)	50-HV-01	L01	9000	2
4	Load-D (OHL-3)		L03 / L18	2300	3
5	Load-E (OHL-4)		L17	8400	4
6	Load-F, G, H	LPG-HV-01 B	N15,16,17	1800	5
7	Load-I, J, K	LPG-HV-01 A	N3,4,5	1800	6
Total Sheddable Loads				34MW	

Fig.7: *Load shedding functionality of PMS*

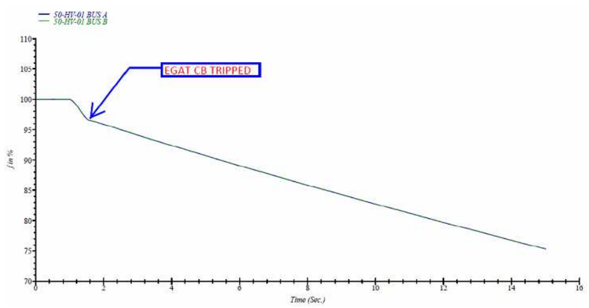

Fig.8: *Frequency response when grid tripped*

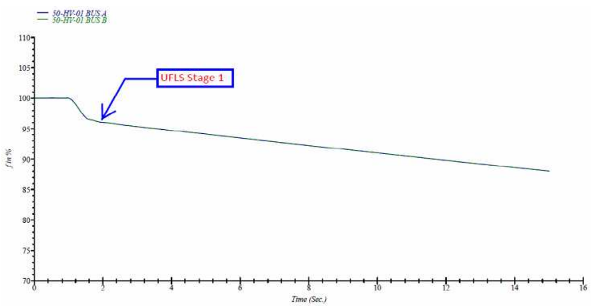

Fig.9: *Frequency response when UFLS stage 1 operated*

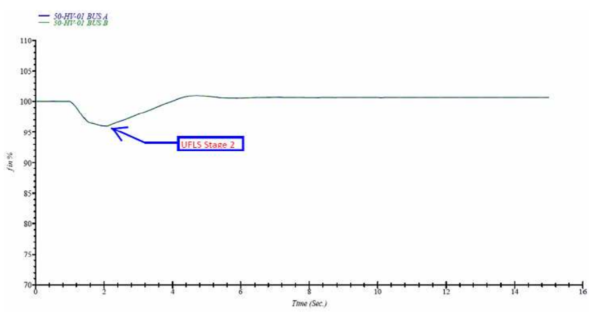

Fig.10: *Frequency respond when UFLS stage 2 operated*

shedding (HWUFLS) is designed and implemented for backup of PMS load shedding and will take operation during PMS failure.

Instead of using another PLC software to perform function of load shedding during PMS failure, HWUFLS operated by underfrequency relays during system facing of abnormal system frequency. The underfrequency relays are those typically installed at switchgear, which the relays have definite time and rate of change of frequency (df/dt) settings. HWUFLS prevents power system from cascade outage by its shedding command when system frequency falls below predetermined value or rate of change of power system frequency.

Proper frequency setting & sequences of HWUFLS are resulted by transient stability study. The study was carried out to ensure final setting adopted satisfy the requirements of all scenario in terms of both speed and coordination between each stage to ensure it able to operate and trip designed loads without unnecessary/ unintended load shedding. The classification of operational conditions for a plant network or an external network is given in figure 11.

Class.	Type	Voltage (per unit)	Frequency (per unit)	Description
OC1	Steady State	0.95≤U≤1.05	0.98≤f≤1.02	Normal operational conditions, equipment is able to perform all primary functions continuously
OC2	Sustained	0.90≤U<0.95 1.05<U≤1.10	0.95≤f<0.98 1.02<f≤1.03	Abnormal operational conditions without loss of generation or load
OC3	Deviated	0.70≤U<0.90	0.92≤f<0.95 1.03<f≤1.10	Transient conditions to be operated for a limited time span
OC4	Degenerated	U<0.70		Loss of generation and load if cause is not eliminated immediately

Fig.11: *Stability criterion for plant network*

This criterion is used as basis for all under/over frequency relay setting, i.e. grid, generators and load shedding.

To prevent total plant blackout, HWUFLS has to initiate load shedding prior to system frequency dropping to generator underfrequency setting (45Hz, 0.1 sec). The logical scheme of HWUFLS has been illustrated in figure 12.

Co-operation and working sequence between PMS load shedding and backup HWUFLS is as shown in figure 13 to 14.

9. CONCLUSIONS

The upgraded electrical distribution system fulfills requirements which directed the original design. Features to reduce employee exposure to potential electrical hazard were incorporated. Flexibility of operation was achieved along with means to protect operators from inclement weather and switching errors. A supply of electrical power was available for all critical loads as long as the public utility or the co-generation

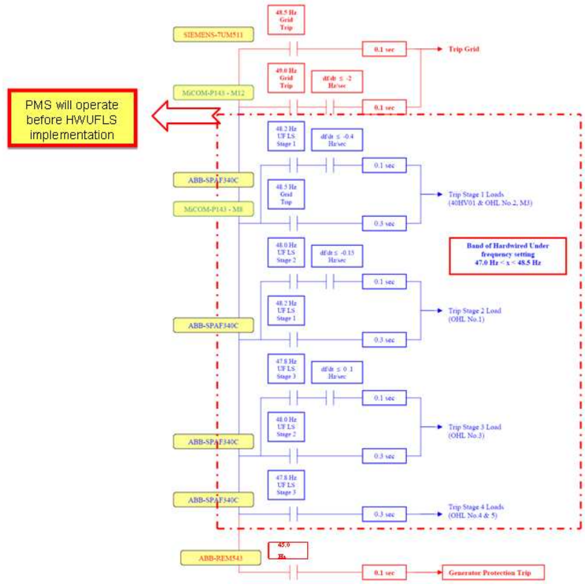

Fig.12: *Logic scheme of HWUFLS*

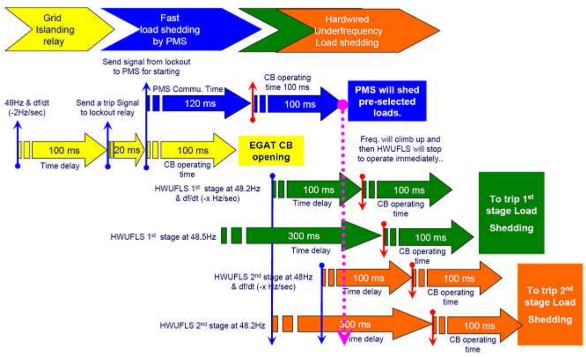

Fig.13: *Working sequence of PMS load shedding and backup HWUFLS (1)*

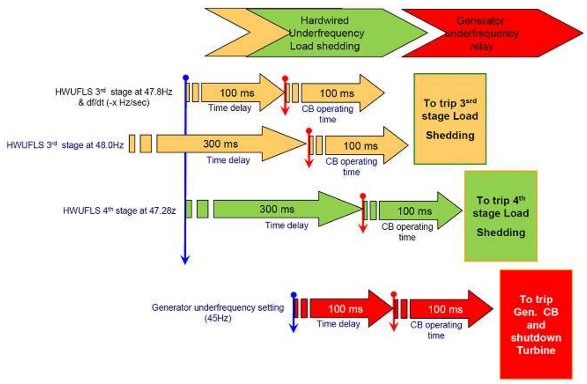

Fig.14: *Working sequence of PMS load shedding and backup HWUFLS (2)*

units remain in service and no two parallel circuits were simultaneously down. Maintenance need was definitely be reduced. The ability to serve evolving process operating units was inherent in the final system. System reliability can significantly be improved via implementation of PMS. To ensure rapid load shedding can be achieved, incorporation of new load shedding functionality/ calculation as part of the master PMS was implemented.

An EESOR review result contained detailed significant findings / conclusions in the form of worksheets and includes the main recommendations to avoid or minimize problems identified by the EESOR team. With engineering good practice and result of EESOR review, it made project confident that the upgraded electrical power generation and distribution system were able to fulfill requirements which directed to the original design. Construction time can be reduced during all potential problems were concerned. This can reduce project cost up to 10% approximately. Features to reduce employee exposure to potential electrical hazards were incorporated. Flexibility of operation was achieved along with means to protect operators from inclement weather and switching errors. A supply of electrical power was available for all critical loads as long as the public utility or the co-generation unit remained in service and no two parallel circuits were simultaneously down. Maintenance needs were definitely reduced. With the ability to serve evolving process operating units was be inherent in the final system.

10. ACKNOWLEDGEMENT

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