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Faculty of Electrical Engineering

Power Engineering Department

FILOSOFIE POUŽITÍ SYSTÉMU ŘÍZENÍ VÝKONU na příkladu Sangachalského Terminálu

POWER MANAGEMENT SYSTEM OPERATING PHILOSOPHY: in an example of Sangachal Terminal

Bachelor's Thesis

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Study program: Electrotechnika, energetika a management

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2.Analyze an example of PMS in Sangachal Terminal
3.Implementation and control of PMS network
4.Case study for overall functionality of the PMS during various operating modes

Bibliography / sources:

1.ZHU, Jizhong. Optimization of power system operation. Second edition. IEEE Press: Piscataway, NJ, 2015. ISBN 1118854152.
2.VAAHEDI, Ebrahim. Practical power system operation. Hoboken, New Jersey: Wiley, 2014. ISBN 9781118394021.

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Abstract

This thesis provides brief information about power management system and it is shown that a power management system with attentively chosen methods and technologies can provide significant advantages in power engineering.

Key Words

Power management system, load shedding, frequency control, generator start/stop, tap changer control, distribution system control.

Abstrakt

Práce poskytuje stručné informace o systému řízení výkonu a ukazuje, že pečlivě zvolené metody řízení výkonu s odpovídajícími technologiemi mohou přinést významné výhody v oblasti energetiky.

Klíčová slova

Systém řízení výkonu, vypínání elektrické sítě, řízení frekvence, generátor start/stop, ovládání přepínače, řízení distribuční soustavy.

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1. INTRODUCTION

Power management systems (PMS) provide optimised solutions for control of electrical power generation systems. These solutions include features such as load shedding, automatic synchronising, power and reactive power control. The objective is to enhance electrical power system safety and reliability. The System uses computers and networking technology for enhancing plant electrical system safety, reliability, operability, and maintainability [1] .

Plant operability shall be enhanced by providing operator assistance for safe and secure (error-free) operation of the plant electrical system. Automatic functions are provided where necessary which aid in faster recovery. PMS includes functionality to automatically and manually generate reports to reduce operator workload.

1.1. The Core Purpose for the PMS

Power management systems (PMS) have been used for a number of decades to provide comprehensive supervisory control of large industrial, marine and offshore power generation systems using multiple generators typically with the gas turbine or diesel prime movers. The core purpose of such systems is to improve reliability and integrity of power generation and distribution in critical power generation systems where loss of electrical power can have a huge cost impact on the business. This core purpose is achieved by providing reliable and fast-acting real-time automation of electrical power system operations and processes including load shedding, critical switch sequencing and control of active and reactive power levels [2].

Such power management systems utilise the latest developments in microsystem and software technology to provide reliable and flexible operation, improved operator interfacing with the plant, sophisticated data recording and many other features.

As software-based intelligent control systems become ever more capable and pervasive, it is becoming normal to expect retrieval of data from other diverse systems to be integrated together with live status data being displayed on human machine interface screens for operator interaction.

With these increasingly complex systems and an ever-increasing feature list, it can sometimes be easy to lose sight of the core purpose of such power management systems which is to maintain a high integrity power system and to avoid unnecessary power outages.

1.2. Definitions of abbreviations

HMI- Human Machine Interface
AVR- Automatic Voltage Regulator
DLE- Dry Low Emission
PMP- Power Management Panel
UCP- Unit Control Panel
SCP- South Caucasus Gas Pipeline
CB- Circuit Breakers
HMI CB- Human Interface Machine Circuit Breaker
MSR- Main Switch Room
ICSS- Integrated Control and Safety Systems
OWS- Operating Work Station
CT/VT- Current/Voltage transformer
OLTC- On load tap changer
LSR- Local Switch Room
LTPW PMP- Treatment of Produced Water Power Management Panel - LTPW
OWS/mPMP- main Power Management Panel
VCB- Vacuum Circuit Breaker
VC- Vacuum Contactor
ACB- Air Circuit Breaker
VFD- Variable Frequency Drive
GT- Generator Turbine
BOV- Blow Out Valve
HV/LV- High/Low voltage
TCS/CB- Trip Circuit Supervision/ Circuit Breaker
GPS- Global Positioning System

2. GENERAL REVIEW ON POWER MANAGEMENT SYSTEM (PMS)

Below PMS Principle functions are listed:

- Provide Power Generation control
- Maintain voltage at the generator and grid incomer connected to bus.
- Maintain frequency at the generator connected to bus when the grid is not connected
- Share the active load of connected generators and the grid by controlling the frequency set point of the generators.
- Share the reactive loads of the connected generators and the grid by controlling the set point of AVRs
- Electrical distribution network control
- Limit the circulating current between the grid incomers when connected in parallel
- Manual and auto-synchronizing of generator incomers
- Synchronizing of grid incomers
- Provide load shedding and start-inhibit function.
- Overview of the power system plus HMI interface
- System monitoring and alarm handling facility
- Trend any measured or calculated analogue value

3. ANALYZE AN EXAMPLE OF PMS IN SANGACHAL TERMINAL

3.1. Sangachal Terminal (ST)

Located 55 km south of Baku, the Sangachal Terminal is a vital link in Azerbaijan's oil and gas industry. It is an oil and gas terminal that receives, processes, stores, and exports crude oil and gas produced from all currently operated BP assets in the Caspian basin and has room for expansion. The terminal includes oil and gas processing facilities, the first pump station for the Baku Tbilisi Ceyhan (BTC) oil pipeline and South Caucasus gas pipeline (SCP) compressor and other facilities. Sangachal Terminal covers an area of about 550 hectares, which makes it one of the world's largest oil and gas terminals [3].

The purpose of this bachelor thesis is to define the philosophy for the control, monitoring, synchronizing and interface requirements for the Power Management System (PMS) associated with the Sangachal Terminal (ST) power generation and distribution system. My project describes the overall functionality of the power management system during various operating modes.

Existing power generation in ST consists of:

- Three 22.2 MW dual fuelled gas turbine generators which were installed in phase1
- Two 21.4 MW gas fuelled gas turbine generators which were installed in phase2
- One 21.4 MW gas fuelled gas turbine generator with waste heat recovery which was installed in Phase 1.
- Two 40 MVA grid incomers were installed: one in phase 1 and the other in phase 3.

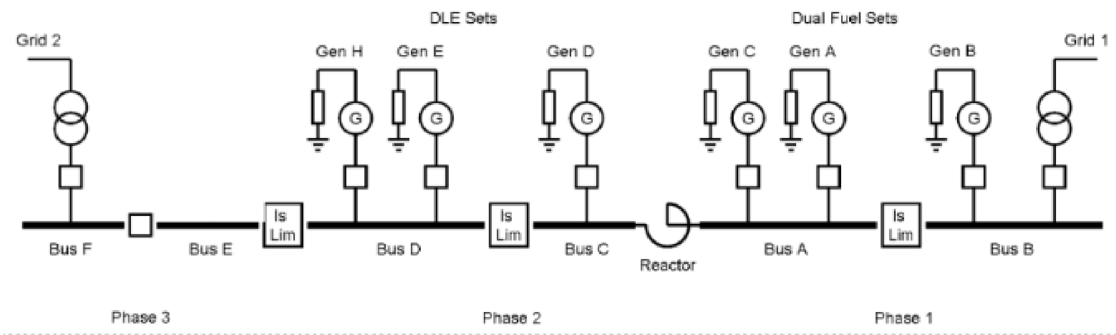

Figure 1 - Existing power generation in ST

The above generators and grid incomers are connected to a multiple section, single bus bar 11kV switchboard via incoming circuit breakers. Normal operation of the system will be with bus section breakers closed. Current limiters are provided at bus sections to limit the prospective fault currents. Current Limiting Reactor is provided between Ph1 & Ph2 to reduce the fault levels.

A 1.8 MW diesel engine driven black start generator provides start up power in case of complete loss of power at the Sangachal Terminal.

3.2. Operation

The power management panel is provided with manual controls for synchronization, generation control, associated metering and an operator interface (Human Machine Interface) computer.

The power management is provided with on and off control via a pad lockable isolator located internally to the panel. An internal Maintenance / Commissioning switch is also provided. On the front of the Power Management Panel (PMP), each generator will be provided with a Manual / PMS control selector.

The mode of operation of the power system will be determined by the position of the selector switches at the PMP / UCPs / Switchgear, as described in the Table 1.

The normal mode of operation will be with the PMP isolator switched on and each main generator selected for remote control at the respective UCP [4]. At the PMP, the PMS / Manual selector will be switched to PMS. When in this mode, the full load sharing and load shedding capabilities of the PMS will be available. If local control is selected at the UCP, the PMP outputs to the UCP will be inhibited, and the main generator will be under manual control from the UCP. Load shedding shall remain active under this condition.

If the remote control is selected at the generator UCP and manual control selected at the PMP, then PMS microprocessor outputs shall be inhibited, and PMP front panel controls/indications shall be active. These controls/indications shall include AVR raise/lower, governor raise/lower together with meters/ lamps and synchronizing commands.

PMP Selector	UCP Selector	Switchgear Selector	Operation
Isolator "OFF"			• PMS / PMP inactive.
Isolator "ON"			• PMS / PMP active.
Maintenance / Commissioning Mode			• Load shedding inactive
Manual / PMS **Set to PMS**	**Local / Remote** **Set to Remote**	**Local / PMS** **Set to PMS**	• **Normal mode.** • PMS generation control. • Manual PMP generation controls inactive. • Load shedding active. • HMI CB control active.
	Local / Remote Set to Local		• All PMS outputs to UCP inactive. • UCP generation control • Load shedding active. • HMI CB control active.
Manual / PMS Set to Manual	Local / Remote Set to Remote		• All PMS outputs to UCP inactive. • Manual PMP generation controls active. • Load shedding active. • HMI CB control active.
	Local / Remote Set to Local		• All PMP inputs to UCP inactive. • UCP generation control • Load shedding active.
Manual / PMS Set to either	Local / Remote Set to either	Local / PMS Set to Local	• HMI CB control inactive; • Load shedding active.

Table 1 - Functionality of Control Selector Switches at PMP / UCP / Switchgear

MSR1 PMP shall have the facilities for manually controlling the generator AVR and turbine governor for the all machines on the ST. It is possible to share active and reactive load manually from the MSR1 PMP. Load shedding outputs shall be inhibited if maintenance/commissioning mode is selected at the PMP.

3.2.1. Generator Start

A request to start at the PMS HMI or ICSS will initiate a turbine start and automatic synchronizing sequence. On receipt of a confirmed closed signal from the main generator incoming circuit breaker, the PMS shall act on the governor and AVR of each main generator under PMS control to ensure that the load is shared in the desired manner between the main generators and grid running in parallel and that the frequency and voltage set points are maintained when operating islanded from the grid.

If a start sequence is initiated by the PMS and during this sequence, the UCP local/remote selector is switched from remote to Local, the PMS auto sequence shall be reset as the UCP will assume control.

Note: PMS will not automatically start the generator

3.2.2. Generator Stop

When the main generator is running in parallel with existing ST generation and / or grid, provided there is sufficient spinning reserve on the affected bus, a request to stop from the OWS / PMP or ICSS will initiate the PMS to gradually off-load the selected main generator of the active and reactive load.

On reaching near zero active and reactive power, the PMS will initiate a turbine stop to the UCP which in turn will open the main generator incoming circuit breaker. The system load previously supplied by the generator ramping down will be picked up by the other connected main generator or grid supply. After a time delay, to allow the operator time to reconsider and reconnect the main generator, the PMS shall signal the UCP to stop the turbine. Both near zero power level and the time delay shall be operator configurable values.

Note: PMS will not automatically stop the generator

3.2.3. Frequency Control and Generator Active Power Control

PMS shall maintain the steady state frequency for a power group at a frequency demand set point (manually adjustable) by adjusting the governor set points. With the grid incomers closed, the system frequency will be determined by the grid supply.

The active load output will be monitored by a single CT for each main generator from the main switchboard and the corresponding VT signal. The system frequency will also be measured from the applicable busbar VT signal. For grid incomers, single phase CT and three phase VT signals will be used.

In the event of a mismatch in active power sharing or an error between system frequency and the frequency set point, the PMS will act on the turbine to equalize the active powers (or the ratio of powers) of interconnected sets in a power group and to maintain the bus/group frequency.

The operator will be able to set the target active power import value from the grid. The target import value will typically be set to minimum to prevent unnecessary import charges, but remain available to support load fluctuations.

MW export through the grid to be monitored and operator adjustable alarm to be provided. MW to be calculated in PMS using CT/VT input from the 110kV side of Grid.

The operator will be able to set the minimum load to be picked up by each generator and grid incomer. If the load decreases to below minimum loading level, an alarm will be initiated. The operator will be able to set maximum load that can be put on each generator and grid incomer.

Note: To safeguard against possible damage or premature wear to turbine bleed-off valves, the turbine manufacturer recommends engines should be run above the bleed-off valve close point. This occurs when the generator is loaded to around 9-11MW as determined by the engine controller which is also influenced by the ambient temperature. To alert the operator of situations when the generator is running with the bleed-off valve open, the generator UCP shall send an alarm to the PMS and ICSS. [Hold: Interface will be decided in the execute phase of this project]

A 4-20mA generator capability signal will be sent from the UCP to the PMS to change the base rating (active power) of each main generator automatically depending on ambient air temperature, fuel type, turbine wear, and fouling. The PMS will only accept a signal in the range 20-35MW, operator configurable in the event that the generator capability signal is lost, the PMS will default to an operator-configurable base-rate value.

3.2.4. Generator Reactive Load and Voltage Control

The PMS will utilize the same CT and VT signals of the active power to monitor reactive load and voltage. Bus voltage on each side of the reactor will be independently controlled by the generators on each side.

In the event of a mismatch in reactive load sharing or an error between the main switchboard voltage and the voltage set point, the PMS will act on the generator AVRs to normalize the reactive loads of interconnected sets and to maintain the system voltage at the main switchboard.

The main switchboard voltage set point will be manually adjustable. When operating in parallel with the grid, the system voltage will be maintained by control of on-site generators within their VAr limits, and MVAr import will be controlled by tap-changer control of grid incomer transformers.

When the generated VArs reach the limiting value on either side of the reactor Grid Transformer tap-changers is to be reverted to Voltage control and compensate the VArs from the grid. As the On load Tap-changer (OLTC) will change the tap on each of the grid transformers, the voltage drop and hence the VAr flow through the reactor will be minimum. A dead band is to be provided for the VAr control of generators to prevent hunting. The operator will be able to set the target MVAr import value from the grid. AVR control of onsite generators will provide fine-tuning to achieve the target MVAr import.

3.2.5. Generator Load Sharing

When two or more generators are connected to the system, the PMS will control the generation system such that real power (MW) and reactive power (MVAr) will be shared equally between the generation sets connected [5].

When generators are connected in parallel with the grid, the PMS will control the generation system such that active power (MW) and reactive power (MVAr) will be shared equally between the generation sets connected, import and export power of the grid will be maintained at pre-set levels set by the operator.

Note: The target MVAr value shall be calculated to share the reactive load evenly between the Interconnected generators on each side of the reactor.

Alternatively, the generator can be controlled to a set point (base-load), which is a pre-set specified by the operator from the HMI, while other generator sets operate in sharing mode.

DLE sets are automatically selected for base-load control. When running in parallel with non-DLE generators, DLE machines will run only in Base load mode. When the

DLE sets are islanded, one set will share any fluctuations in system load while the rest of the sets will be base load.

The machines are base loaded in order of priority as below.

1. Gas turbine generator with waste heat recovery unit.
2. Gas turbine generators.
3. Dual-fuel gas turbine generators

The highest priority machine (1) will take precedence when base loading and will be the last to break away from base load mode. It will be possible for the operator to change the base loading priority of the machines. If these base load targets cannot be reached due to the minimum or maximum loading of the sharing sets, then the targets will be relaxed to ensure the stability of the full system.

When the connected load reduces the defined spinning reserve below the set point for a period of time, the PMS shall initiate a low spinning reserve alarm, repeated at ICSS. This alarm will alert the operator to increase the generation capacity by starting another main generator or restricting further load increase within the available capacity. The value of spinning reserve and period of time shall both be operator configurable.

An excessive spinning reserve alarm shall be initiated when the spinning reserve exceeds the set point for spinning reserve for a set time. Both the set point and time will be operator configurable values. The operator will then have the option of shutting down one of the main generators.

3.2.6. Generator Synchronising & Distribution System Synchronising

1) Generator Auto Synchronising

Under normal operations, generator automatic is synchronizing, and generator circuit breaker closure forms part of the ST main generator(s) start sequence. The automatic synchronizing equipment and circuit breaker closure logic to achieve this are vested within the associated UCPs. Hence any location which can initiate a generator auto-start will inherently execute generator auto-synchronize and circuit breaker closure.

2) Generator Manual Synchronising

Each ST generator has manual synchronizing controls on its associated UCP. The operator is able to perform manual synchronizing for all the ST generators from MSR1 PMP.

3) Distribution System Synchronising

The Power Management Panel at MSR1 shall be able to perform auto-synchronisation and manual synchronization for 11kV bus sections and intertie circuit breakers as necessary. The normal mode of operation of the electrical system is for all bus-ties of the generation bus to be closed, although there will be occasions when the system is split and operated as separate busses/power groups.

To restore a split system to being fully interconnected, the PMS will have the facility to group synchronize the separated busses and automatically close the appropriate bus-tie or interconnector CB.

4) Grid Incomer Synchronising:

Manual synchronizing of the grid incomers will be available from the PMS. In this mode, PMS will raise and lower the voltage and frequency of the 11kV bus. When PMS is not available, the grid incomer can only be closed only on to a dead bus.

3.2.7. Tap changer Control

PMS will control the import of MVArs from the grid by controlling the grid incomer transformer tap changers to the set Grid Var set point target. It will control the system voltage thru the tap changer control when no local generation is available. If the maximum Var capability of the generation is reached the Grid Var target shall be relaxed by the PMS. When both grids are in parallel, the PMS shall adjust the taps to ensure there is minimum circulating MVAr.

Taps will be controlled either automatically via voltage regulator in the Siemens' panel or manually by the operator by using tap raise or lower switches. Siemens panel will have Auto/Manual/Remote (PMS) tap changer control selection. When selected auto, the taps will be controlled by a voltage regulator. When selected Manual, the operator can change tap by using raise and lower controls at the Siemens Control panel. When selected remote, the controls are transferred to PMS.

At MSR1 PMP, an Auto/Manual selector switch will be provided. When selected auto, the PMS will control the voltage regulator by PMS driven relay contacts. When selected manual, the operator will be able to change taps by using the tap raise/lower switch mounted at the MSR1 PMP.Following tap changer indications and alarms will be available at PMS as a minimum:

- tap changer in the remote position, i.e., control available from PMS.
- OLTC group alarm

3.2.8. Distribution System Control

1) Normal Operating Mode

Under normal operation, the control of VCBs, VCs, and ACBs throughout the ST power system is available from the MSR1 and MSR2 PMP HMIs. Apart from the load shed and start to inhibit signals, it will not be possible to control any process drives from the PMS.

2)Loss of PMS Control

On the loss of any fiber optic communication link, the distribution system control will be performed manually from wall mounted control switches located adjacent to respective switchboards. Panel mounted generator control switches on the MSR1 PMS such as voltage raise / lower, frequency raise / lower remain operational with the ST PMS out of action.

3.2.9. Load Shedding

Load shedding by frequency relays is the most commonly used method for controlling the frequency of power networks within set limits and maintaining network stability under critical conditions [6]. In the event that the system demand exceeds the connected generators and the grid incomer capacity, the PMS will automatically shed pre-determined loads and maintain system stability. The load shedding will be independent of whether PMS control or manual control is selected. The load on the system will be calculated as the summation of the generator outputs.

Feeders nominated for load shedding will be assigned a priority by means of a shedding matrix. Feeders with the lowest priority will be the first to be shed, and those with the highest priority will be the last to be shed. The load shedding priority will be manually changeable to suit varying process conditions.

In order to protect the variable frequency drives, load shedding of the VFDs will be carried out by a signal to the VFD. The VFD supply circuit breaker will then be tripped by a signal from the VFD. Load shedding will occur when one or more of the following conditions exist:

1) Under Frequency

If the frequency of the system drops below a pre-set limit for a period of time, the load shedding scheme will be activated, and loads are tripped according to the load shedding matrix[7]. In this instance, the feeders will be tripped sequentially with a delay between each stage to allow the frequency to recover. If a selected load does not trip, then the next lowest priority load will be shed with no time delay, and an alarm shall be raised to highlight the failure.

The 'under frequency shed point', 'under frequency trip time delay' and the frequency recovery time will all be manually adjustable. Under-frequency shedding is disabled when the grid is connected.

2) Gradual Overload

If an overload appears on the system for a period of time, load shedding will be initiated. PMS will shed feeders of least priority sufficient to restore the load to below the power group capacity. In the event of further trips being required, they will be initiated after a manually adjustable time delay. If a selected load does not trip, then the next lowest priority load will be shed with no time delay, and an alarm will be raised to highlight the failure. The value of overload and permitted period of time will be automatically varied by the PMS. The permitted overload will be based on integrating timer, i.e., higher the overload the shorter the duration it will be sustained.

3) Fast Acting Load Shedding

In the event of a sudden loss of generating capacity resulting in a negative spinning reserve, the PMS will calculate the difference between the remaining available generators and the grid capacity connected to the system and the connected load.

When the remaining main generators are under PMS control, the base rating of each machine (determined and sent from UCP) at that point in time is used in calculating the available capacity.

When the remaining main generation consists of one machine under PMS control and one or more under manual control, the available capacity is calculated as the load drawn from the machines running in manual plus the base rating of the machine running in auto.

Loss of a generator will be detected by the PMS by continually monitoring the generator and turbine master trip relays as well as the generator circuit breaker status [8]. If the connected load exceeds the available capacity, the PMS will simultaneously trip sufficient feeders to remove the overload.

The above sequence will be performed with the minimum delay to prevent system overload and instability. In the event of further trips being required, they will be initiated after a time delay, which will be manually adjustable. If a selected load does not trip, then the next lowest priority load will be shed with no time delay, and an alarm will be raised to highlight the failure.

When the last generator connected to the 11kV Main Switchboard trips resulting in a dead busbar, the PMS shall not trip any of the outgoing feeders.

4) Step Load Acceptance Shedding

In the event of loss of generation, but with the resultant load on the remaining connected generators being below the combined generation capacity, the fast-acting load shedding would not apply.

However, the PMS will calculate the load step that could be imposed on each of the remaining generators as a result of the loss of generation on a section of the bus.

The potential load step would exceed the given load step capability of any of the generators; the PMS will simultaneously shed sufficient feeders according to the load shed priority matrix with no time delay to limit the load step to within machine capability. The ‘Maximum Fast Acting Step Load MW’ is a user-defined set point. Step load acceptance is not required when the generators are in parallel with the grid. In the event that insufficient load has been disconnected and further shedding is required, this will be initiated automatically.

5) Start Inhibit

The PMS will provide a start inhibit signal to the configured loads to ensure that sufficient spinning reserves are available at all times and also that the system cannot be overloaded.

6) Grid Incomer MVAr Limit Load Shedding

Load shedding is initiated when a Grid Incomer MVAr import is above the pre-set MVAr Load Shed Trip Level for the duration of the present MVAr Load Shed Trip Time. A single load is shed when the timer expires. After the pre-set MVAr Load Shed Recovery Time the grid MVAr import is compared with the pre-set MVAr Load Shed Recovery Level. If the MVAr flow has not reduced sufficiently, another load is shed.

3.2.10. Circuit breaker Discrepancy

A circuit breaker status discrepancy alarm condition is initiated based on the discrepancy between 52a and 52b contacts of the breaker, which will affect the PMS logic and outputs in accordance with the Table 2 until discrepancies are cleared.

To avoid spurious indication of CB discrepancy during CB auxiliary contact change-over, the initiation of a discrepancy alarm will be subject to a user-configurable time delay of up to 10 seconds.

CB Status in Discrepancy Condition	PMS Action
11kV Generator & Grid incomer	☐ Critical Alarm to ICSS ☐ Disable raise / lower V / Hz outputs of the affected generator - Generation stays at last point of control ☐ Disable raise/lower tap changer outputs of the affected Grid incomer - Stays at last point of control ☐ For load shedding logic the generator CB state is determined by the power drawn and grid incomer is assumed closed to avoid unnecessary trips ☐ Back-up load shedding is provided by other load shed logics
MSR1 & 1A 11kV bus ties	☐ Critical Alarm to ICSS ☐ Disable raise / lower V / Hz outputs of all generators & tap changer control grid connected to the effected bus ☐ Generation stays at last point of control ☐ For load shedding logic - status of bus tie is assumed closed, to avoid unnecessary trip ☐ Back-up load shedding would be provided by PMS
Other feeder	☐ Alarm ☐ Where applicable - Assume open to avoid issuing unnecessary load shedding commands

Table 2 - Affects of circuit braker

4. IMPLEMENTATION AND CONTROL OF PMS NETWORK

1) Current Limiting System

In order to keep the ST system fault levels within the capability of the switchgear, three withdrawable current limiting devices (Is-Limiters) are installed in the ST MSR1 & 1A 11kV switchboard line-up, adjacent to the bus-tie circuit breakers. The control logic for blocking the operation of Is-limiters and activation of selectivity criteria is failsafe and vested within the Is-Limiter control panel.

The Is-Limiter logic operates independently from the ST PMS to ensure functionality remains active when the PMS is out of service.

2) Load Flow across Bus-Tie

PMS shall limit the load flow by controlling generation and OLTC. The load flow across bus-tie breakers will also be limited by protection trip from the associated breaker protection relay. The PMS will then initiate load shedding if the isolated buses get overloaded.

3) Black Start Generator Breaker Trip

In order to prevent back feeding to the ST 11kV system, if there is no Grid and main generation available with the ST Black start generator breaker closed then PMS shall trip the 11kV feeders to 1S-ESW81012. This will be effective regardless of whether PMS ‘control’ is selected.

5. CASE STUDY FOR AVERALL FUNCTIONALITY OF THE PMS DURING VARIOUS OPERATING MODES

5.1. Typology

The main Power management panel (PMP) is located in the Main Switch Room MSR1. This shall be the main control point with overall system control and monitoring for the integrated electrical system. MSR1 PMP panel will include an HMI and manual controls for synchronization and generation control and serial links to ICSS.

Further PMPs as below are provided for various phases of development.

- Phase1 PMPs located in local switch room LSR1 and LSR2
- Phase2 PMP located in local switch room LSR6
- Phase3 PMP located in local switch room LSR7
- PMPs located in the main switch room MSR2.
- LTPW PMP located in local switch room LSR8
- Elevated flare PMP located in local switch room LSR10

There will be a stand-alone PC work station at MSR2. The outstations are connected to the MSR1 main control station in the star topology. Communication diagram is shown below.

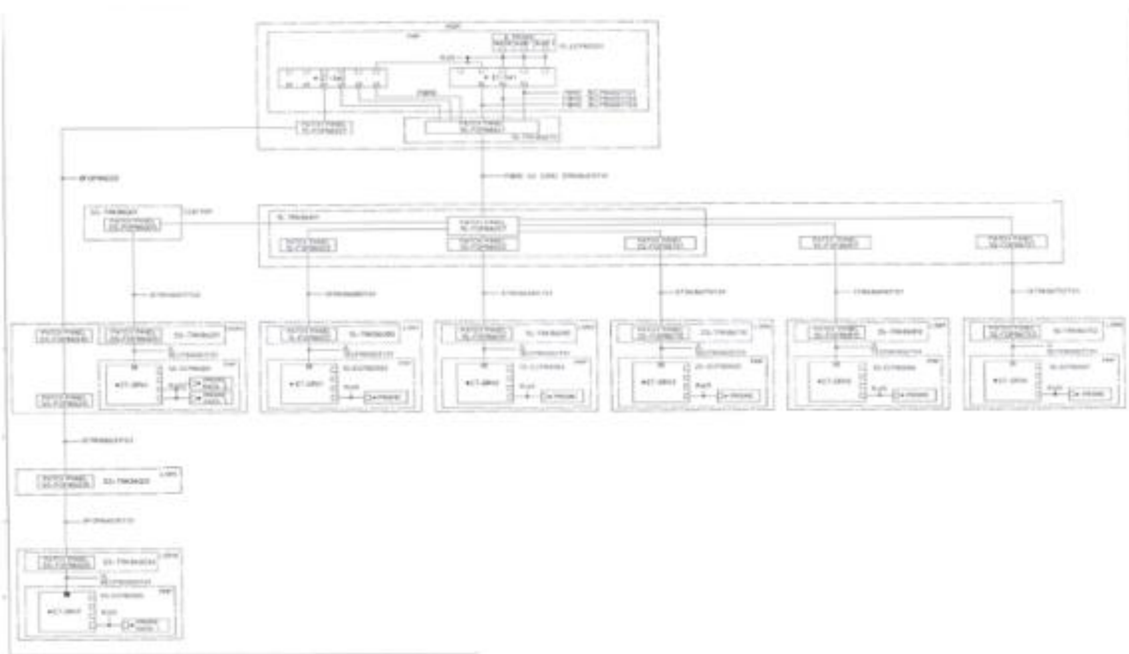

Figure 2 - Communication diagram

5.2. Communications link failure

There will be a stand-alone PC work station at MSR2. The outstations are connected to the MSR1 main control station in the star topology. Communication diagram is shown below.

For load shedding, PMS relies on data from remote PMPs located in outstations LSR1, LSR2, LSR6, LSR7, LSR8, LSR 10 and MSR2. Loss of communication link between MSR1 PMP and any of the outstation PMP will result in the loss of load shedding, load sharing, generator priority loading calculations due to insufficient data for PMS and remote control of breakers. Therefore, upon loss of communication, all load shedding outputs and start inhibit from PMS will be disabled. The electrical system will be protected from overload by protection relays.

If the system is split electrically, then the PMS load shedding/start inhibit functionality will remain operational in each of the separate parts of the system [9]. Generator control from MSR1 PMP will remain operational during the loss of communications to a remote outstation. As tap changer controls are all hardwired to MSR1 PMP the loss of communication will not affect grid incomer's transformer tap changer control.

At the Master controller level at MSR 1, the system shall be dual redundant such that any single failure of an Ethernet switch or a master controller or a cable will have no impact on the PMS performance and shall result in no data loss.

5.3. Remote access and monitoring

The process of monitoring includes the examination of power system conditions. Operators need to examine the prevailing system conditions to establish whether the system is operating within the acceptable physical and operational limits [10].

ST PMS will have provision to be connected to network infrastructure for remote monitoring and remote troubleshooting capability. But the PMS shall not be connected to the network infrastructure.

PMS systems will run either MacAfee or Symantec anti-virus software, which will be free issued by company. The Supplier will also provide disaster recovery procedures.

5.4. Interface signals

5.4.1. Interface signals between PMS and ICSS

Following interfaces exists with the ICSS to give the status of selected equipment.

1) Three serial links from MSR1,
2) One serial link from MSR2,
3) One serial link from LSR8.

All signals within the PMS Holding Register will be available for transmission across serial link to the ICSS. The content of the holding register of the upgraded system shall be identical to the existing holding register.

Note: PMS shall include a protocol converter for ICSS communication using Modbus RTU.

5.4.2. Interface signals between PMP and each Generator UCP

The following interface signals exists between the PMP and each Generator UCP.

- Governor Raise/Lower
- AVR Raise/Lower
- Start/Stop GT
- PMS available/fault
- Control selection (Local/Remote)
- Turbine tripped
- Generator capability signal
- AVR in manual
- Synchronising signals
- Open/close generator circuit breaker
- Common Alarm
- Fuel Selection/On Liquid Fuel (Ph1 only)
- Start Sequence Incomplete
- BOV continually open signal (hold)

5.4.3. Interface signals between PMP and HV/LV Switchboards

The following interface signals exists between the PMP and HV/LV Switchboards.

- Load shed/close inhibit of selected feeders.
- Open/close generator circuit breaker (in MSR1) via UCP
- Open and Close distribution feeders and incomers on the HV and LV system
- Open and Close bus sections and inter-ties
- Generator, Grid Supply Incomers, and Bus bars VT signals
- CB status/Tripped/Available signals of generators, distribution feeders, incomers, bus sections and inter-ties
- Gen and Grid Supply CT signals
- Transformer Alarm signal of Transformer feeders
- Auto Transfer On/Off Status and Auto Transfer Trip Selected indication of Bus sections
- kW/kVA/kVAr Analog Outputs of distribution feeders
- Trip circuit supervision and common alarms of HV and LV Bus sections
- kW/kV Analog Outputs of Grid Supply incomers
- kW Analog Output of Generator incomer

5.4.4. Interface signals between PMP and Current Limiters

The following interface signals exists between the PMP and Current Limiters. Current limiter status signals as below are required by the PMS to initiate load shedding. These will be hardwired.

- Is-limiter tripped
- Is-limiter not ready
- Main supply missing
- Aux. supply missing
- Is-limiter blocked
- Is-limiter service position.

Status signals from the Is-limiters will be displayed on the relevant graphics and alarm pages.

5.4.5. Interface signals between PMP and 110kV Grid Supply

The following interface signals exists between the PMP and 110kV Grid Supply.

- Status of CB, disconnectors, earthing switches
- 110kV ST CB Tripped indication
- 110kV Sangachal Substation CB Status and Tripped indication
- OLTC remote Control Raise/Lower from PMS
- OLTC group alarm
- Tap-changer remote control selected indication on PMS
- 4-20mA Analog Inputs/Outputs for voltage and current
- 4-20mA Analog Inputs/Outputs for indication of tap changer position

5.5. Operating Work Station (OWS)

A separate desktop HMI PC is provided in MSR1 with the desktop keyboard. At the HMI, the operator shall be able to monitor power system & PMS status and perform functions such as - starting/stopping of generators, switching circuit breakers, interrogating trend or log files and adjusting system pre-sets. Trip selection of circuit breakers forming part of a secondary selective transfer scheme will be made manually at each switchboard. The circuit breaker selected to trip on transfer will be indicated at the HMI. It will also allow commissioning engineers to set up dead bands and pulse size etc. to match the generator performance. The dual LCD display screens of OWS at MSR1 shall be upgraded. The associated PC will be upgraded to a server grade PC. Make & model of the monitor and PC shall be agreed with company in the execute phase.

The OWS will provide a graphical display of the power generation and primary distribution in single line diagram form. Each OWS will also display PMS status, power system status and allow distribution control and manual change of user-configurable operator parameters and the load shedding matrix.

Data will be displayed as graphics pages; typically the following pages will be provided:

- Active single line diagrams
- System load and spinning reserve

- Load shedding matrix
- System status and alarm messages
- System set points
- Main generator set points
- Main generator vector display
- User-configurable preset table
- Hard-coded configurable table
- Function logic diagrams

Alarm pages will be selectable or appear as alarms occur. The colors used for OWS alarm graphics and banners are shown in the table below and shall match with the existing alarm color ST PMS HMI.

State	Meaning
Flashing Amber	Alarm active and unacknowledged
Solid Amber	Alarm active and acknowledged
Flashing Magenta	Alarm previously active and unacknowledged
Solid Magenta	Alarm previously active and acknowledged
Solid Grey	Discrepancy / indeterminate state
No Colour	Alarm not active

Table 3 - Alarm colors and meanings

The colors used on graphic pages will be consistent with existing ST PMS HMI and are shown in the Table 4.

Notwithstanding whereby a circuit breaker status discrepancy occurs, display graphics will accurately indicate the true status of all circuit breakers at all times. Each circuit breaker can be operated in three possible configurations.

- CB available in the service position (remote control)
- CB not available in the service position (local control)
- CB not available in the withdrawn position (during maintenance)

Description	Symbol / Text
Busbars & connected equipment - de-energised / not conne cted	Red
Circuit breaker status	Green / Red / Grey
Monitored analogue values	Yellow
MVAr Lagging	Green
MVAr Leading	Red
Preset analogue values	Cyan
Alarm data – active	White on Amber
Alarm data – previously active	White on Magenta
Alarm data – inactive	Grey

Table 4 - Alarm colors and meanings

Circuit breaker status information will be based on three separate inputs from each circuit breaker: open, closed and available. The open and closed inputs will be conditioned with position limit switches such that the circuit breaker status will always be reported as open when operated in the withdrawn position as shown in the Table 5.

SIGNAL	Status	DESCRIPTION
CB AVAILABLE AR	0	NOT AVAILABLE for PMS control
	1	AVAILABLE for PMS control (In service, PMS control selected and all protection reset)
CB CLOSED LS 52a	0	CB OPEN
	1	CB CLOSED IN SERVICE
CB OPEN 52b LS N M	0	CB CLOSED IN SERVICE
	1	CB OPEN, or Withdrawn and/or Maintenance Switch in Maintenance
LS contact sense is shown for CB inserted in service position.		

Table 5 - Signal status and descriptions

The following three tables illustrate how the circuit breaker status will be indicated when operating in each of the three possible configurations.

OWS DISPLAY:- NORMAL OPERATION; PMS CONTROL			
AVAILABLE	1	IN SERVICE / PMS CONTROL	
CB OPEN	1	0	DISCREPANCY
CB CLOSED	0	1	
CB	GREEN	RED	GREY DISCREPANCY
CIRCUIT	GREEN	RED	GREY

Table 6 - Circuit breaker in normal operation

OWS DISPLAY:- LOCAL OPERATION			
AVAILABLE	0	IN SERVICE / LOCAL CONTROL	
CB OPEN	1	0	DISCREPANCY
CB CLOSED	0	1	
CB	GREY UNAVAILABLE	GREY UNAVAILABLE	GREY DISCREPANCY
CIRCUIT	GREEN	RED	GREY

Table 7- Circuit breaker in local operation

OWS DISPLAY:- CB WITHDRAWN; IN TEST			
AVAILABLE	0	WITHDRAWN / PMS or LOCAL CONTROL	
CB OPEN	1	0	DISCREPANCY
CB CLOSED	0	1	
CB	GREY UNAVAILABLE	GREY UNAVAILABLE	GREY DISCREPANCY
CIRCUIT	GREEN	GREEN	GREY

Table 8- Circuit breaker in CB withdrawn

5.6. System monitoring

The entire system will be continuously monitored for correct operation and provided with a local and remote watchdog alarm facility. Alarms will have a clear meaning and assist the operator with relevant information. Alarm handling and data display content will be developed during the execute phase of the project. Typical alarms to be provided at the PMS will include the following:

- TCS / CB status discrepancy common alarms/ Urgent operator intervention required
- Switchboard common alarms
- Microprocessor failure
- Load sharing mismatch
- PMS switched off
- PMS in maintenance/commissioning mode
- Load shedding operated (with reason)
- Start inhibited (with reason)
- Failed to load shed
- PMS Common Alarm
- Insufficient generation for a motor start (if applicable)
- Busbar load flow high/excessive
- Voltage boost required
- Inability to execute a command (with reason)
- Busbar power flow approaching system rated value
- Insufficient spinning reserve
- Generator minimum continuous load alarm
- Excess spinning reserve
- Circuit breaker status discrepancy alarms

5.7. Additional PMS features

5.7.1. Commissioning mode

Commissioning mode can be selected from any of the ST PMPs. This mode of operation allows the operator to manually force both inputs and outputs to prove the correct operation of the system. It is primarily provided for the manufacturer's test engineers to prove the various interfaces with the PMS. It is not normal practice for the operators to have access to this mode of operation and its access will be password protected. When selected to commissioning mode the test engineer disables all outputs to prevent inadvertent operation of the system. Sharing, shedding, inhibiting, synchronizing, generator start/stop, distribution system control and tap-changers control will all be disabled under this mode of operation.

5.7.2. Speed of response

PMS shall be provided with operator configurable parameters to vary the speed of response for active and reactive load mismatch to ensure that active power, frequency, reactive load and voltage excursions are quickly corrected without overshoot or hunting and with a minimum dead band. The mark-space ratio (pulse on/off times) for PMS outputs to the generator AVRs and governors shall be operator configurable values.

5.7.3. Trending of analogue values

An operator configurable facility with the capability to trend any measured or calculated analogue value shall be provided. The time resolution of individual trends will be operator configurable, with a maximum resolution less than 200ms.

5.7.4. Inability to execute command

An alarm shall be displayed on the OWS should an operation be attempted for which the conditions have not been met. Examples of such conditions would include followings:

- Inhibit stopping a generator if that could result in a generation overload
- Prevent the out-of synchronism closure of a circuit breaker
- Further adjustment in bus voltage or frequency would result in operating out of tolerance

5.7.5. System Time Synchronisation

The PMS shall be time synchronized from an external GPS based clock time source from the telecom system.

6. CALCULATIONS

With the monitoring of my Supervisor and Teacher I calculated Short Circuit Current and the Maximum Current at the beginning of the Short Circuit.

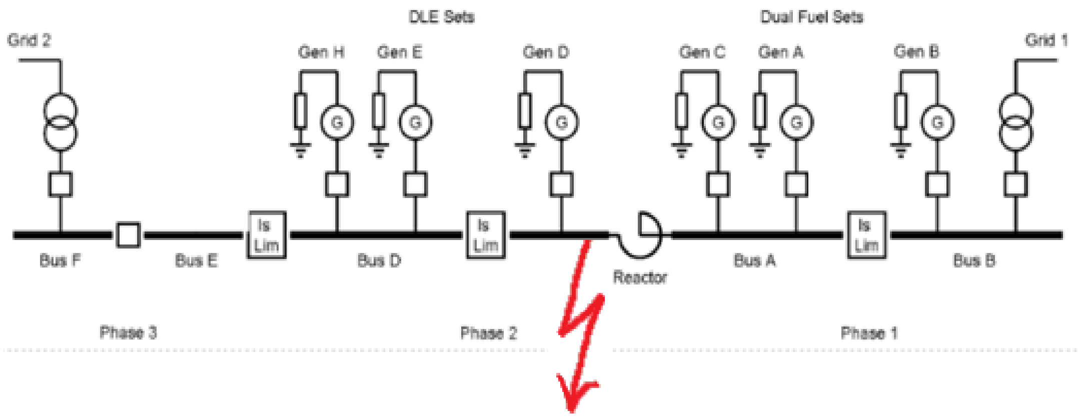

Figure 3 – Place where short circuit occurs

From the image above we can observe that we have 2 grid incomer Transformers 6 Generators and a Reactor. Lets assume that Short circuit (S_c) occurs between Generator D and Reactor. To find a S_c current we divided scheme into 2(left and right) parts from the origin where S_c occurs.

Base Power	27.75 MVA
Base Voltage	11.5 kV

	G1(H)	G2(E)	G3(D)	G4(C)	G5(A)	G6(B)	T1(gr2)	T2(gr1)
S_n (MVA)	27.75	27.75	27.75	27.75	27.75	27.75	40	40
$\frac{Uk}{X''d}$	11.8%	12.2%	11.7%	12.1%	12.1%	11.9%	7.5%	7.32%

	Reactor
Z(imp)	0.127Ω

First we need to find Relative reactance for each generator and transformer with the formula which is mentioned below.

$$Recalculated\ relative\ reactance(RR) = \frac{\text{Uk}}{X''d} * \frac{\text{Base Power}}{S_n * 100}$$

	G1	G2	G3	G4	G5	G6	T1	T2
RR Ω	0.118	0.122	0.117	0.121	0.121	0.119	0.052031	0.050783

Relative reactance for Reactor is calculated with the formula which is written below.

$$Reactor\ RR = \text{Z} * \frac{Base\ Power}{(Base\ Voltage)^2} = 0.026648\ \Omega$$

We need to consider the fact that each component of left part are in parallel connection with each other as well as the right part except the reactor which is in serial connection with the right side components.

$$Left\ Part\ total\ Reactance \qquad \frac{1}{L_T(RR)} = \frac{1}{G1(RR)} + \frac{1}{\text{G2(RR)}} + \frac{1}{\text{G3(RR)}} + \frac{1}{T1(RR)}$$
$$= 0.022504\ \Omega$$

$$Right\ Part\ \ Reactance \qquad \frac{1}{Right(RR)} = \frac{1}{G4(RR)} + \frac{1}{\text{G5(RR)}} + \frac{1}{\text{G6(RR)}} + \frac{1}{T2(RR)}$$
$$= 0.049058\ \Omega$$

$$\text{Right Part Total Reactance} \qquad Right_T\text{(RR)} = \text{Reactor RR} + \frac{1}{\text{R(RR)}}$$
$$= 0.026648 + 0.022409 = 0.049058\ \Omega$$

$$Total\ Reactance\ R_T = \frac{Right_T + L_T}{Right_T * L_T} = 0.015427\ \Omega$$

After finding Total Reactance we can easily calculate S_c Power and S_c Current.

$$S''_c\ \text{Power} = \frac{\text{Base Power}}{R_T} = 1798.8006\ MVA$$

$$S''_c \text{ Current} = \frac{S''_c \text{ Power}}{Base\ Voltage * \sqrt{3}} = 90.414706\ kA$$

To find a Peak Short-circuit Current:

$$I_{peak} = k*\sqrt{2} * I\ S''_c = 216.72405 \text{ kA}$$

Where factor k=1.7 for HV systems.

7. CONCLUSION

This paper has shown that a dedicated power management system with carefully selected methods and technologies can provide significant advantages when compared with alternative power management solutions. With careful project management, including the use of well-structured functional specifications, test plans and the use of real-time simulation it is possible to successfully put power management systems into service, on both new build and brownfield sites, with minimum disturbance to new build plant commissioning or interruption to plant processes respectively. When implementing systems for brownfield sites, it is essential to plan for interfacing with legacy control systems. This can be achieved relatively easily with careful planning and selection of a flexible power management system architecture.

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