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Marsh Specialty

Al Mourjan for Electricity Production Company

Deep Dive Report Oct 2022

Rabigh 2 Independent Power Plant, KSA

8th of March 2023

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Following: A Deep Dive session of the plant on 8th of March 2023 and discussions with the site personnel

Revision History

Revision	Date	Comments
1.0	Feb 2021	First issue following February 2021 Deep Dive session Human Elements
2.0	Sept 2021	Second issue following Sept 2021 Deep Dive session AIM-EM
3.0	Mar 2023	Third issue following Mar 2023 Deep Dive session – AIM-RE

Contents

Section One

Introduction

This report has been prepared following a one-day Deep Dive session at the site and discussions with management and technical specialists on 8th March 2023. This was the third session for Deep Dive. This is the third visit to site for conducting the Deep Dive since Feb 2021. Marsh has been visiting the site for conducting operational survey in the past. The report provides an overall update of the organisation's Inspection activities and should be read in conjunction with the latest full underwriting report.

Objectives and Acknowledgements

The purpose of this report is to provide information for the client, insurers and reinsurers who may be interested in underwriting the following insurance covers for:

- Material Damage.
- Business Interruption.

Information contained in this report was to an agenda sent to the plant prior to the visit, structured meetings with the Management, Operations and Maintenance personnel together with records checks followed by a site tour. Observations made during a tour of the plant provided more information of site operations.

There was no physical testing of systems carried out at the time of this visit.

Salman Ibrahim of Marsh Company (Saudi Arabia) conducted the survey. The following team accompanied the survey.

Eric Teh	-	Sr. Risk Engineer – HDI, Singapore
Edward Lim	-	Sr. Risk Engineer – CV Star, Singapore

We gratefully acknowledge the contribution of everyone involved in the survey and in particular the following personnel.

Omar Al-Ahmadi	-	CEO
Sami Alzahrani	-	Plant General Manager
Muhammad Abbas	-	CTO
Abduljabbar Sethar	-	TSD Manager
Khalid Alharbi	-	Sr. Manager
Oqab Almutairi	-	Operation Manager
Meshal Sonbul	-	Maintenance Manager
Mohammad Ruzii	-	Mechanical Section Head– ROMCO
Bandar Al-Harbi	-	HSE Manager

Section Two

Executive Summary

Deep Dive Overview

Avoidable expensive losses in the power generation industry are quite often caused by “failure on demand” of safety relevant equipment. Such failures may be caused by design issues, component failures, human factors, etc.

The emphasis of this Deep Dive will be to go in details on the topic of “ASSET INTEGRITY MANAGEMENT – ROTATING EQUIPMENT” and look for any possible gaps within Operation and Maintenance departments. Safety relevant equipment shall be defined in this context as “equipment that will cause a loss when failing while being requested”.

The reason this specific topic was selected was due to the loss happened in the plant (STG20 generator), selecting a topic that is related to a recent loss or an incident gives a good opportunity to discuss in detail various aspects of this loss and the possible measures that help the plant to avoid reoccurrence of the same loss in the future not only for the generator but also for other major rotating equipment at the site, STs, GTs…

The current portfolio within Power industry of losses are centred around Machinery Breakdown issues and globally these are seen, in many instances, to have causal factors related towards failure of safety related systems when they are needed during emergency situations, taking this in consideration a detailed discussion was held with the plant team about the emergency systems related to rotating machinery with emphasis on emergency power supply and the latest emergency DC battery discharge test was revived in detail.

In view of the above, the topic of “ASSET INTEGRITY MANAGEMENT – ROTATING EQUIPMENT” is a vital part of the healthy operation of the plant and is crucial from the Insurance point of view.

This Deep Dive review of Al Mourjan for Electricity Production Company is conducted by the risk engineers from Marsh and accompanied by markets engineers.

Background

The owner of Rabigh 2 Independent Power Plant (R2IPP) is Al Mourjan for Electricity Production Company (AMJ), a company registered in the Kingdom of Saudi Arabia, with the following shareholders:

- Saudi Electricity Company (SEC) – 50%.
- ACWA Power – 50%.

Some of the key dates for the project are as follows:

- Notice to Proceed – 30 April 2013.
- Project Financial Close – 25 July 2014.
- COD 1 – 24 August 2017.
- COD 2 – 24 September 2017.
- PCOD – 23 February 2018.

AMJ has a twenty-year Power Purchase Agreement with SEC, with payments being received for capacity and fuel cost is passed through at the guaranteed annual Heat Rate.

Fuels used are Natural Gas and Arabian Super Light (ASL) crude oil which are supplied to SEC from ARAMCO.

The Operations and Maintenance Contractor is First National Operation & Maintenance Company (NOMAC). NOMAC has LTSA with Siemens for twenty years.

Project Description

Location

The plant is located some 150km to the north Jeddah, on the shore of the Red sea, cloase to Rabigh City in the Kingdom of Saudi Arabia. It is south-east of the existing Rabigh IPP plant (RABEC).

The coordinates for the site are:

Plant	Latitude	Longitude
Rabigh2 IPP	22.6295 North	39.0464 East

Road and sea access is good with road connections to the main highways.

The site is in a Munich Re Zone 0 earthquake area and a Zone 2 Flash Flood area.

There are no immediate neighbours, the nearest being around 0.5km away, and third party risks are considered negligible.

The site has a good security fence with good security controls in place.

The site covers an area of 1.2km x 0.6km on the shore line. The ground surface at the project site was level and even. The ground elevation for the Plant area is +4.40m MSL.

Plant

The plant configuration is in three Blocks delivering 2,060MW of electrical output. Each Block consists of two GT's and their respective HRSG's supplying a single ST unit. The main equipment was being supplied by Siemens for the GTG, STG and DCS, BHI for the HRSG's and a consortium of Hyundai Heavy Industries (HHI) and Asea Brown Boveri (ABB) for the Electrical Special Facility (ESF).

The GT's are Siemens SGT6-5000F5ee units with an ISO rating of 232MW. The F5ee features a number of enhancements over the F5 including:

- Turbine Exhaust System.
- Air Inlet Manifold.
- Improved Thermal Barrier Coating.

The steam turbines are the Siemens SST6-5000 with rated output of 250MW.

Generators for the GT's and ST's are Siemens SGen6-1000A, TLRI 118/55 generators of the Totally Enclosed Water to Air Cooled (TEWAC) design, rated at 305MW.

The plant is designed to run on back up fuel, which will be ASL. There are no bypass stacks on the GT's and the ST's have bypasses to dump steam to the condensers.

The gas and liquid fuel is supplied by SEC under a pass through arrangement as outlined in the Power Purchase Agreement.

The 380kV connection from the GSU Transformer to the ESF is by underground cables.

All the water demand from site is supplied by a Reverse Osmosis (RO) plant supplying potable water, general service water and other auxiliary water demands.

Asset Integrity Management

This Deep Dive topic of “Asset Integrity Management” covered Steam Turbines, Gas turbine systems, ST and GT Generators, Main Step-up Transformers and Auxiliary Transformers.

In addition a detailed discussion and review of the records of DC emergency power systems performance and testing and ST 20 generator failure has been conducted.

Discussions were held with Operations and Maintenance (O&M) personnel to understand the O&M philosophy associated with these systems. Various plant documents, drawings, P&IDs, standard operating procedures and operations / maintenance records were verified and studied to understand the practices followed.

A special discussion was held about the battery discharge testing of the plant emergency battery banks, the latest report was discussed in detail to understand the result of the test and how it is reported and showed to the plant team by the third party contractor, and whether the contractor who conducted the test is certified, the reference and certification of the contractor was introduced and reviewed.

A detailed discussion was held about the failure happened to STG20 generator, the nature of the failure, the repair plan that executed and the discussion that ongoing currently with the OEM about the root cause of the failure.

The methodology followed to identify the gaps was based on the factors that can cause failures to these systems such as:

- Component failures by
  - mechanical/electrical/physically or chemically induced failures
  - external influences like fire, flooding, explosion
  - operator/maintenance deficiencies
  - corrosion and other deterioration effects
- Loss of redundancies by
  - Common failure modes by external factors (fire, flood, earthquake, wind, rain,..), operational issues (see also: failure of control below).
  - Unintentional or intentional loss of redundancy, e.g. during maintenance
- Failure of control for safety relevant systems
  - Commands are not given (either by control systems or manually) caused by …..
  - Unsafe commands are given (either by control systems or manually) caused by ….
  - Potentially safe commands are given, but too early or too late caused by ….
  - Controls stop too soon or are applied too long caused by …..

Section Three

Risk Improvement Recommendation

Prioritisation

The criteria used to prioritise the recommendations are summarised in the following table.

Code	Description
Critical	Extreme Risk; should be brought to the attention of plant management and immediately progressed.
A	High Priority; requires attention of senior management and an action plan developed as a priority
B	Moderate Risk; requires action at the earliest opportunity
C	Low Risk; Opportunity for industry best practice initiatives providing long term benefits

Recommendations Overview

Four new recommendations were raised that highlighted potential areas of improvement and risk reduction. New recommendations have been well received by the management team. These recommendations are different to those raised as part of regular survey and are covered under the latest underwriting report.

From previous Deep Dive session, five are in progress and four completed that shows good progress.

New Recommendations Summary

Description	Category	Reference DDR #	Status
Expedite and follow up on ST20 Generator failure RCA	B	2023/03/01	New, Completed*
GT DC lube oil pump testing on falling pressure	C	2023/03/02	New
IRIS system utilization	B	2023/03/03	New
Formalization of ST valves leakage test records	C	2023/03/04	New

*recommendation considered completed with a post survey submission, RCA received.

Previous Recommendations Summary

Description	Category	Reference DDR #	Status
EDG Testing	B	2021/09/02	In Progress
Competency assessment	B	2021/09/03	In Progress
Emergency Scenarios Desktop Exercises	B	2021/02/01	In Progress
Checklists to Include Condition Measures	C	2021/02/02	In Progress
Tracking of Third Party Reports	C	2021/02/05	In Progress

Completed Recommendations Summary

Description	Category	Reference DDR	Status
Motors PM & Risk Assessment	B	2021/09/01	Completed
EDG Control Panel Battery Replacement Strategy	B	2021/09/04	Completed
Start-up & Shutdown Assessments	B	2021/02/03	Completed
Procedures Review Process	C	2021/02/04	Completed
DC Lube Oil Pump Annual Performance Test	A	2021/02/06	Withdrawn
CBM Reporting quality	C	21/09/01	Completed
Field Records quality of documentation	C	21/09/02	Completed
Availability of Emergency Scenario Procedures in CCR	B	21/09/03	Completed
EDG Testing	B	21/09/05	Completed
Seal Oil Pump Performance Testing	A	21/09/06	Completed
ST AC/DC lube Oil Pump motor cables fire resistant coating	A	21/09/07	Completed
Checklists to Include Condition Measures	C	21/04/01	Completed
Document Management	C	21/04/02	Completed
Management of Change	B	21/04/03	Completed
Technical Risk Assessment	A	21/04/04	Completed
Emergency Scenarios	B	21/04/05	Completed
Tracking of Third Party Reports	C	21/04/06	Completed
DC Lube Oil Pump Annual Performance Test	A	21/04/07	Completed

New Recommendations Details

Expedite and follow up on ST20 Generator failure RCA	**Category B**	**DDR # 2023/03/01**
Date Raised / Revised	March 2023	
Risk Exposure	Machinery Breakdown	
Description	Following the failure happened to the ST2 generator which led to insurance claim, the site team started and in continues communication with the OEM to issue the RCA report that will indicate the root cause of the failure. The RCA report has not been issued till the time of the visit.	
Recommendation	The feedback from the site team about the continues communications and meetings with the OEM is appreciated however Considering the time passed since the incident and the number of similar generators available at the site and in another site of ACWA, it is recommended to expedite and follow up closely with the OEM till the issuance of the final RCA and we appreciate sharing immediately the report with Marsh team once finally issued.	
Client Response	**March 2023:** RCA report is received from the OEM post the survey and shared. The recommendation considered completed.	
Status	**March 2023:** **New, Completed**	

GT DC lube oil pump testing on falling pressure	Category C	DDR # 2023/03/02
Date Raised / Revised	March 2023	
Risk Exposure	Machinery Breakdown	
Description	The plant operation team is testing the DC lube oil pump of GTs using the available functional motor start stop in the DCS. No testing procedure or records found for testing the DC pump based on a falling pressure, this test is supposed to simulate the real case of a trouble in the lube oil system that lead to a pressure drop and trigger the starting of the DC lube oil pump.	
Recommendation	It is recommended to explore the possibility of testing the starting of the GT DC lube oil pump based on falling pressure. To simulate that the lube oil pressure is falling below a specific value (the set point of DC lube oil pump start) then to check the DC pump started properly.	
Client Response	**March 2023:** OEM Siemens was consulted and their recommendation is attached, wherein Siemens mentioned process limitation to carry out DC lube oil pump test by dropping the lube oil header pressure, while machine is on load.	
Marsh Comment	**Match 2023:** Below is the OEM response: • Typically, the tank oil temperature is > 70°C. The DC pump discharge bypasses the cooler so it will pump hot oil. However, the DC pump test will be done with the AC pump in service allowing the hot oil from DC pump mixing with colder oil from the AC pump but still there is a chance of the bearing feed oil temperature exceeding the unload/trip limit. • A DC pump test is performed during GT startup in step 2 and an operator-initiated test is also possible, but this does not check the functionality of the pressure switch-initiated DC pump start. • Currently the logic is set up to initiate a trip if the DC pump is running for 60 seconds. The logic assumes that the AC pumps have failed. • The test requires a procedure to conduct the test and return to operation since it requires draining the pressure switch for test activation. • Bearing temperatures will need to be monitored for any abnormal increases or shifts during and after the test. Could SE develop a solution for this test? I don't know but can check if you would like to pursue that option.)) Considering the above mentioned feedback, Marsh would recommend to pursue the option further with the OEM to conclude a final decision, the functionality of the DC pump on a falling pressure condition is very important to avoid any possible loss in the assumed case (turbine coasting down with no lube oil system functioning).	
Status	**March 2023:** **New**	

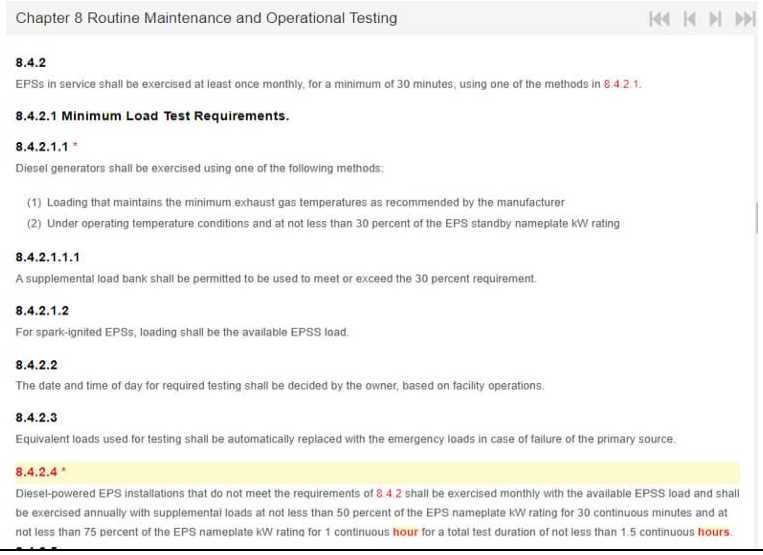
IRIS system utilization	Category B	DDR # 2023/03/03
Date Raised / Revised	March 2023	
Risk Exposure	Machinery Breakdown	

Description	The ST and GT generators at the plant are equipped with IRIS system for partial discharge detection, however it is noticed that there the regular program of readings acquisition and analysis need to be improved.
Recommendation	It is recommended and discussed with plant team: • To expedite the agreement that currently in discussion to utilize the system in appropriate way (communication with Siemens are ongoing) • A suggestion of discussion with the OEM or the system provider on why the system didn't give any indication about the failure happened in ST20 generator (the failure discovered while conducting the offline partial discharge pressure before start up)
Client Response	**March 2023:** • Call of contract is signed with system OEM (IRIS) • IRIS and Siemens recommended to carry out PD detail analysis on 6 Monthly basis. • Data is being sent on 6 monthly basis to IRIS for detail analysis and report.
Status	**March 2023:** **New**

Formalization of ST valves leakage test records	**Category C**	**DDR # 2023/03/04**
Date Raised / Revised	March 2023	
Risk Exposure	Machinery Breakdown	
Description	The plant team reported that the ST valve tightness test is being conducted on a yearly basis however the records shown is not reflecting the proper procedure of doing the test. One record is complete and reflect the test requirements as in the OEM manual however the other two are not reported properly.	
Recommendation	It is recommended that all the records of this test or any other test to be issued and recorded formally in the same format. In this specific case, the test records should be similar to the one issued for ST10.	
Client Response	**March 2023:** Observation is noted and updated reports will be shared.	
Status	**March 2023:** **New**	

Previous Recommendations Details

EDG Testing	**Category B**	**DDR # 2021/09/02**
Date Raised / Revised	September 2021	
Risk Exposure	Machinery Breakdown	
Description	It was noted that EDG testing cannot be performed on load unless complete plant is out of service. There is no provision to test the EDG functionality in real life scenario.	
Recommendation	It is recommended to conduct the feasibility study to find the issues of testing EDG in real black out condition. If it is not possible, at least groupwise testing to be conducted to cut in the EDG in auto mode.	

Client Response	**Sept 2021:** During weekly EDG test, EGD is load test by synchronizing with grid. Blackout test of EDG will be performed in Group-2 outage in April 2022.
Marsh Comment	**Mar 2023:** EDG testing was discussed in detail with plant operation team and agreed to follow NFPA 110 guidelines and OEM manuals as below: • Monthly test load - minimum 30% rated kW and 30 minutes • Annual test load – minimum 75% rated kW [1 hour] + 50% rated kW [30 minutes] = 1.5 hours for overall test time. • Consult the OEM manual for the requirements of the no load test if any, if not specified the monthly test can serve the purpose. • The purpose of the testing is to ensure the full health and readiness of this important emergency power source. • All systems and accessories of the engine (start-up batteries….) to be carefully checked regularly and to be maintained in a proper and healthy condition  Chapter 8 Routine Maintenance and Operational Testing **8.4.2** EPSs in service shall be exercised at least once monthly, for a minimum of 30 minutes, using one of the methods in 8.4.2.1. **8.4.2.1 Minimum Load Test Requirements.** **8.4.2.1.1** * Diesel generators shall be exercised using one of the following methods: (1) Loading that maintains the minimum exhaust gas temperatures as recommended by the manufacturer (2) Under operating temperature conditions and at not less than 30 percent of the EPS standby nameplate kW rating **8.4.2.1.1.1** A supplemental load bank shall be permitted to be used to meet or exceed the 30 percent requirement. **8.4.2.1.2** For spark-ignited EPSs, loading shall be the available EPSS load. **8.4.2.2** The date and time of day for required testing shall be decided by the owner, based on facility operations. **8.4.2.3** Equivalent loads used for testing shall be automatically replaced with the emergency loads in case of failure of the primary source. **8.4.2.4** * Diesel-powered EPS installations that do not meet the requirements of 8.4.2 shall be exercised monthly with the available EPSS load and shall be exercised annually with supplemental loads at not less than 50 percent of the EPS nameplate kW rating for 30 continuous minutes and at not less than 75 percent of the EPS nameplate kW rating for 1 continuous hour for a total test duration of not less than 1.5 continuous hours.
Status	**Sept 2021:** New **Mar 2023:** **In Progress**

Competency assessment	**Category B**	**DDR # 2021/09/03**
Date Raised / Revised	September 2021	
Risk Exposure	Process Safety	
Description	During site discussions emphasis has been placed on the importance of procedures. Equally so is the importance that people are trained and competent to fulfil their duties correctly in emergencies, as outlined in those procedures. Once such emergency scenarios are developed, it is important that staffs have familiarized themselves with the expected actions.	
Recommendation	It is recommended that site include emergency response competency as part of the position competency assessment, where emergency response is part of the position requirements to understand Operation staffs awareness of the actions expected during such emergency situations	

Client Response	**Sept 2021:** Corporate ERP has trained our whole ERT team in Oct 2021. The 10 days theoretical and practical assessment training was conducted by Corp ERP officer Mr. Mohammad Azam from 10th to 21st Oct 2021. Upon completion of 10 days trainings the drill was also exercised to evaluate the overall ERT response and also to gauge abilities of each ERT member. We have updated ERT list as per corporate requirements and we also have developed site internal ERP procedure covering all the emergency scenarios where role and responsibilities are clear for each ERT member. In addition, we have annual drills schedules, and we are exercising announced/unannounced drills on prescribed frequencies led by the ERT leader, which also enhance ERT response and making each ERT member familiar with their roles and responsibilities during the sudden emergency scenario.
Marsh Comments	**Mar 2022:** The recommendation is about technical scenarios be included as part of position competency assessment, where emergency response during those technical emergencies is part of the position requirements to understand Operation staffs awareness of the actions expected during such emergency situations, not general safety which is included in the above explanation as part of ERP training. **Mar 2023:** The requirements is further discussed with plant operation team and will be implemented accordingly.
Status	**Sept 2021:** New **Mar 2023:** **In Progress**

Emergency Scenarios Desktop Exercises	**Category B**	**DDR # 2021/02/01**
Date Raised / Revised	February 2021	
Risk Exposure	Machinery Breakdown	
Description	Plant technical emergency scenarios are not captured as part of Emergency Response Plan. Once captured they need to be tested by carrying out routine exercises.	
Recommendation	Capture all possible technical scenarios as part of the Emergency Response Plan and carry out desktop exercises such as, Lube oil spillage and fire, emergency lubrication system failure, GCB not opening, EDG not starting, freeze-up of control system, stuck steam admission valves, contamination of water steam cycle with chemicals from the water treatment plant, etc.	

Client Response	**2021:** Missing Emergency Response Plan will be prepared. **Sept 2021:** Still under preparation **March 2022:** Still under preparation **Marsh 2023:** The requirements is further discussed with plant operation team and will be implemented accordingly.
Status	**Feb 2021:** New **Mar 2023:** **In Progress**

Checklists to Include Condition Measures	**Category C**	**DDR # 2021/02/02**
Date Raised / Revised	February 2021	
Risk Exposure	Process Safety	
Description	Plant checklists (not just those at R2PP) often require a simple “tick” that the check was made. This foregoes the opportunity to gather critical information as to the state of the aspect (heat, pressure, level, flow etc.) being measured. Operational parameters measured will have safe operating ranges and it is critical to observe and record where within that safe operating range the current condition is sitting. Recording and trending of such conditions allows prediction of faults, likewise indicators to those observing the condition whether action is required.	
Recommendation	It is recommended that R2IPP review and amend where necessary, plant check lists to include: • Parameter Range • Record of parameter state (measurement of heat, pressure, level, flow etc.) • Recording of parameter OK / NOT OK Plant check records should be filled, trended, analysed and recorded.	
Client Response	**2021:** Check list will be updated accordingly. **Sept 2021:** Some are updated however still in progress **March 2022:** Check lists are updated and implemented	
Marsh Comment	**Mar 2022:** As recommended above, It is expected to include the range of the reading to be included in the checklist sheet. **Mar 2023:** The plant team explained that there is ongoing project to digitalize all the checklists and the elements of this recommendation will be implemented.	
Status	**Feb 2021:** New **Mar 2023:** **In Progress**	

Tracking of Third Party Reports		Category C	DDR # 2021/02/05
Date Raised / Revised	February 2021		
Risk Exposure	Machinery Breakdown		
Description	Tracking of third party technical reports is always a better way to track observations from these reports, if there are any. This ensures that the actions are tracked based on the timeframe of their completion.		
Recommendation	Establish a system by which the third party technical reports can be tracked for any observations/actions mentioned in them. This system will ensure that the report is analysed by a competent person and actions mentioned are tracked/completed as when they are due. If there are no actions mentioned in the report, it can be accepted as read with no comments.		
Client Response	**2021:** A tracking sheet / system will be established for actions/observations given in the third-party technical reports. **Sept 2021:** Still in progress **March 2022:** In progress		
Marsh Comment	**2023:** Discussed with the site technical team and samples of tracking sheets of third party reports will be shared.		
Status	**Feb 2021:** New **Mar 2023** **In Progress**		

Completed Recommendations Details

Motors PM & Risk Assessment		Category B	DDR # 2021/09/01
Date Raised / Revised	September 2021		
Risk Exposure	Machinery Breakdown		
Description	It was noted that bigger motors such as BFP, CEP, CWP PM is followed in line with OEM guidelines however if there is a deviation from the OEM recommendation PM practices, risk assessment be carried out.		
Recommendation	It is recommended to carry out risk assessment for such scenarios supporting documents like, condition monitoring program measurements, vibration, bearing temperature, etc. A procedure is developed that can substantiate the practice to be followed for such PM plans.		
Client Response	**Sept 2021:** PM of big motors is being performed mostly in line with the OEM recommendation and CBM of these motors is also being performed.		
Status	**Sept 2021:** **Completed**		

EDG Control Panel Battery Replacement Strategy		Category B	DDR # 2021/09/04
Date Raised / Revised	September 2021		

Risk Exposure	Machinery Breakdown
Description	Emergency diesel generators (EDGs) are used as a back-up source of emergency power in power plants, powering critical equipment necessary for maintaining the safe shutdown of the plant. The control panel plays important role in giving commend to start the EDG when in loss of power. Within the power industry there have been losses due to inability of the battery bank to provide supply to the control panel to give command in real blackout scenario. Hence, reliability of the control panel battery set is extremely important.
Recommendation	It is recommended to establish strategy to test the small battery set and also replace them on regular basis considering the small cost against the risk exposure.
Client Response	**Sept 2021:** The power supply of the EDG control panel is supplied from the Plant UPS and the EDG battery is for starting the engine only. Health of EDG battery is ensured during weekly testing of EDG. In case of EDG fails to start, EDG battery is replaced immediately.
Status	**Sept 2021:** **Completed**

Start-up & Shutdown Assessments	**Category B**	**DDR # 2021/02/03**
Date Raised / Revised	February 2021	
Risk Exposure	Machinery Breakdown	
Description	It has been seen that some of the equipment defects can be identified from the earlier signs observed during various plant operational stages. Identifying such indication and initiating early measures to address such issues could avoid plants undergoing unplanned downtime. Comparing Start-up and shutdown curves along with the process parameters could be such helpful initiative.	
Recommendation	Compare Start-up and Shutdown curves with design curves along with the process parameters such as vibrations, various key stages temperatures, ignition temperatures, Steam temperatures limits during typical Hot and Cold start-ups. Such comparisons could indicate operational parameter changes and upon detailed analysis could highlight potential issues.	
Client Response	**2021:** Comparing Start-up and Shutdown curves will be performed accordingly. **Sept 2021:** Comparing Start-up and Shutdown curves will be performed accordingly.	
Status	**Feb 2021:** New **Sept 2021:** **Completed**	

Procedures Review Process	**Category C**	**DDR # 2021/02/04**
Date Raised / Revised	February 2021	
Risk Exposure	Machinery Breakdown	

Description	Al Mourjan O&M team have developed a comprehensive list of various procedures. As per the corporate procedure it was noted that that all operations and maintenance procedures are reviewed every three years. The procedures list submitted indicated that all procedures were dated 2017.
Recommendation	It is recommended, in line with corporate procedure to review and re-date all operations and maintenance procedures and communicate the changes to all concerned staffs of the change. Extend the review process to Risk Register and formally document the completion of review process.
Client Response	**2021:** Procedures will be reviewed as per IMS procedure review policy, i.e. every three years. **Sept 2021:** Still ongoing as part of IMS 2018, review will take place during 2022 Q1. **March 2022:** All plant procedures are updated. Risk register is also updated.
Status	**Feb 2021:** New **Mar 2022:** **Completed**

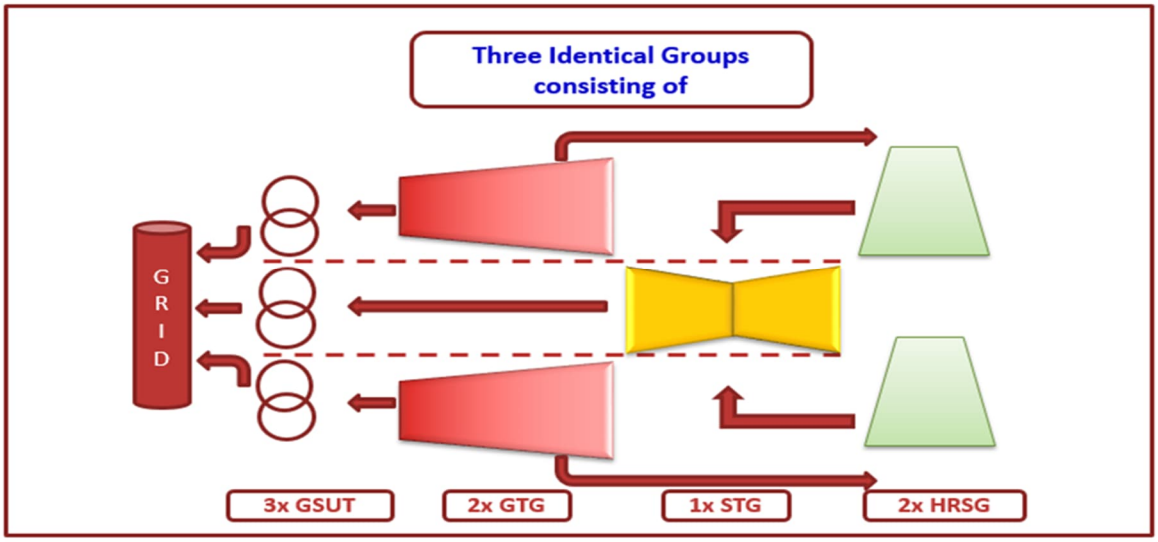
DC Lube Oil Pump Annual Performance Test	**Category A**	**DDR # 2021/02/06**
Date Raised / Revised	February 2021	
Risk Exposure	Machinery Breakdown	
Description	Most commonly, testing of DC L.O. pumps is to ensure starting on demand and rarely is the performance of the pump set measured. A number of issues can arise that detract from the performance of the pump (pump wear, loss of pressure and flow), or place the pump in jeopardy of failure. As such it is important to supplement normal testing (start – run) with a routine to monitor pump set performance against key parameters: pressure, speed, power consumption	
Recommendation	It is recommended that site introduce an annual (as a minimum) maintenance routine to check the DC L.O. pump set performance, looking for deviations from rated discharge pressure, speed and power consumption. The results should be compared to factory or site acceptance test records and plotted for trending.	
Client Response	**2021:** DC lube oil pump performance test will be performed annually. **Sept 2021:** This recommendation is also part of operational survey report and hence it is withdrawn from here however site has included the testing as part of HGPI work scope.	
Status	**Feb 2021:** New **Sept 2021:** **Withdrawn**	

Section Four

Process Description

Overview

This was the first CCGT plant operating on gas along the western coast comprising three groups of two Gas Turbines with two HRSG and one ST. The net power generating capacity is 2,060 MW. The three identical groups are shown as below configuration.



Gas Turbines

Gas turbine details are shown in the following table.

Combustion Turbine	Unit #11 #12 #21 #22 #31 #32
Manufacturer	Siemens
Type	Heavy Duty
Model	SGT6-5000F5ee
Country	USA
Serial number	GT379053, GT379054, MB000007, MB000006, MB000082, MB000083
Year of manufacture	2015
Speed (rpm)	3,600
Rated capacity (MW)	232 (ISO)
Compressor stages	13
Compressor pressure ratio	??
Combustor	16
Combustor type	Canannular
Nozzles	16
Fuel	Natural Gas & ASL
Turbine stages	4
Starting	SSD

Combustion Turbine	Unit #11 #12 #21 #22 #31 #32
Service	Base load / partial load
Control	SPPA-T3000
Spacing	40m

The SGT6-5000Fee is an enhanced version of the SGT6-5000F5 which itself evolved from the original Westinghouse 501F which was first introduced in 1993. The F5ee is the sixth version of the 501F. There are over 300 units in operation with in excess of 12 million operating hours.

The F5ee features a number of enhancements over the F5 including:

- Turbine Exhaust System.
- Air Inlet Manifold.
- Improved Thermal Barrier Coating.

Air Intake

The air intake filters are cylindrical/conical type from Braden and are of type F8 as per CEN/EN 779 class. The air intake system has alarm and protection based on differential pressure switches supplied by the manufacturer.

A separate measurement of differential pressure has been installed and is displayed on the Yokogawa DCS.

HRSG

The HRSGs were designed and are being built to ASME standards and will be tested and stamped accordingly by certified inspectors.

The details of the HRSGs are outlined in the following Table.

HRSG	Unit #11 & #21 #21 & #22 #31 & #32
Designer	
Design Code	ASME Sec I
Manufacturer	BHI CO. LTD
Type	Horizontal, natural circulation
Country	Korea
Serial number	
Year of manufacture	2015
HP Steam flow (kg/s)	69.374
HP Steam pressure (barg) design	152
HP Steam temperature (°C) design	591
RH Steam flow (kg/s)	78.15
RH Steam pressure (barg) design	44
RH Steam temperature (°C) design	591
IP Steam flow (kg/s)	11.76
IP Steam pressure (barg) design	45
IP Steam temperature (°C) design	321
LP Steam flow (kg/s)	10.68
LP Steam pressure (barg) design	15
LP Steam temperature (°C) design	257

HRSG	Unit #11 & #21 #21 & #22 #31 & #32
Fuels	Exhaust gas only
Combustion	None
Gas inlet flow (kg/s)	571.87
Gas inlet Temperature (ºC)	604.7
Protection	Boiler Protection is a Safety Instrumented System that complies with IEC 61508 (2010) (SIL3)
Boiler Feed Pumps	3 x 50% per Block
Water Chemistry Testing / Controls	All Volatile Treatment
Service status	Continuous
Spacing	Outdoors

Drum level control and protection is taken from three differential pressure transmitters.

Steam Turbine

The SST5–5000 series is characterized by the following main features:

- Two-cylinder design in low -level arrangement with double side exhaust.
- Modular design concept with different LP ends and exhausts areas.
- Advanced blading and sealing technology and optimized steam path.
- Designed for short start-up times and operational flexibility.
- Standardized auxiliary skids.
- 10 to 12 years major inspection intervals.
- Proven design in single- and multi-shaft configurations.

The SST5-5000 is a dual-cylinder condensing turbine with a HP/IP turbine section (HI) and a double flow LP turbine (L).

The HP/IP turbine is of double flow design and features a horizontally split double shell casing. Steam is admitted near the middle of the casing. Steam flow is towards the front bearing in the HP blading and towards the generator in the IP blading. At the HP exhaust side, the rotor is supported by a combined thrust / journal bearing.

The last stage blade length is 32 inch and stainless steel material X5CrNiCuNb16-4. The LP turbine has an exhaust area of 6.9 m2. They are inspected based on available opportunity. ST20 and ST30 inspection is complete and was found normal. ST10 inspection is not yet done and waiting for the opportunity.

The ST is fitted with a dedicated lubricating oil system consisting of two off 100% duty AC lube oil pumps, one off Emergency DC lube oil pump and two off 100% duty AC jacking oil pumps.

During HRSG start-up and shutdown and in ST bypass operation, high pressure and low pressure steam are fed directly (cooled by injection water) to the condenser via the HP and LP bypass stations.

During combined cycle operation HP main steam pressure is controlled by the ST inlet control according to the natural sliding pressure characteristic between 100% and 60% main steam pressure related to 100% to 60% steam mass flow. Below 60% mass flow the pressure is limited to fixed pressure level, means 60% of rated pressure.

The steam turbine details are shown in the following Table.

STEAM TURBINE - General Specifications	
Designation	ST10, ST20 and ST30
Designer / Manufacturer	Siemens
Model	SST6-5000
Country	
Serial number	A-000567 / 576 / 586
Year of manufacture	2014
Speed (rpm)	3600
Rated capacity (MW)	248.4
Type & cylinders & reheat	Two-casing condensing turbine with reheat and for triple pressure
Turbine HP stages	HP flow with 20 reaction stages (twisted drum stages) - without control stage
Turbine IP stages	IP flow with 13 reaction stages, including 12 twisted drum stages and 1 low reaction stage
Turbine LP stages	Double-flow LP Turbine: with 6 reaction stages per low, including 3 twisted drum stages and 3 standard stages
Stage Inlet steam pressure (bar)	135
Stage Inlet steam temperature (ºC)	565
Steam exhaust pressure (bara)	0.0966
Governor	Electrohydraulic
Lubricating and Control Oil Type	Lube oil: ISO VG32 Hydraulic Oil: HFD-R; Type: acc. TLV 9012 02
Lubricating and Control Oil Volume	28,000 litres
Lubricating and Control Oil Containment	
Protection System	PG-RISK, which is approved by TÜV as being appropriate in the context of IEC 61508 and IEC 61511
Service status	Continuous

Generators

Nine Siemens air cooled generators type SGen6-1000A are installed. Static frequency converters are used to motor the generators and start the GT's, there is one for each Power Group. The generator excitation system is of the static type, consisting of a dry type excitation transformer which is fed from the MV switchgear, AC / DC converter and redundant AVR. GT generators are synchronized using a Generator Circuit Breaker (GCB) and the ST generators are synchronized via the HV breaker, after the transformer.

From the generator terminals, an insulated cable duct (rated 10,300 A) leads to the generator step up transformers.

Normal closed circuit cooling water is used for Generator coolers without any chillers and hence no condensation issue foreseen at this plant.

Two Risk Improvement Recommendations RIR # 19/09/08 and 19/09/09 have been raised for Generator inspection, which have been implamented, and a another recommendation RIR # 19/09/14 for Non Drive End side bearing protection, which has been defended.

The details of the Generators are outlined in the following Table.

Generator	Unit #11 #12 #21 #22 #31 #32	Unit #10 #20 #30
Designer	Siemens	Siemens
Manufacturer	Siemens	Siemens
Type	Air cooled two pole	Air cooled two pole
Model	SGen6-1000A series	SGen6-1000A series
Country		
Serial number	MK700033/34/35/37/64/65	MK700062/63/66
Year of manufacture	2014	2014
Speed (rpm)	3,600	3,600
Rated voltage (kV)	18	18
Rated capacity (MVA)	277	290
Rated current (A)	8,885	9,302
Poles	2	2
Rotor cooling	Air	Air
Stator cooling	Air	Air
Frequency (Hz)	60	60
Power factor	0.85	0.85
Insulation Class	F	F
Service	Base load / part load	Base load / part load
Partial Discharge		
Protection		

Emergency power for each unit is provided by a diesel generator rated at 1250kW at 400/230V AC, three-phase, 60Hz connected to the two 400/230V emergency load centres. It supplies the essential loads to safely shut down the plant in the event of loss of station power. The diesel generator is not intended to provide black start capability for the plant.

Emergency Diesel Generator	
Supplier	BOKUK
Engine	MTU
Rated Output (kW)	1,250
Speed (RPM)	1,800

Transformers

The details of the Generator Step up Transformers (GSUT) and Auxiliary Transformers on the GTs are outlined in the following Table.

Transformers	GSUT #11 #12 #21 #22 #31 #32	GSUT #10 #20 #20	Auxiliary Unit #11 &#21
Manufacturer	Hyundai	Hyundai	Schneider
Type	Power	Power	Power
Phase	3-phase 2-windings	3-phase 2-windings	3-phase 2-windings
Country	Korea	Korea	Turkey
Serial number			
Year of manufacture	2015	2015	2015

Transformers	GSUT #11 #12 #21 #22 #31 #32	GSUT #10 #20 #20	Auxiliary Unit #11 &#21
Rated capacity (MVA)	174 / 232 / 290	174 / 232 / 290	30 / 50
Rated voltage (kV)	400 / 18	400 / 18	18 /13.8
Cooling	ONAN/ONAF/ODAF	ONAN/ONAF/ODAF	ONAN/ONAF
Oil Capacity (L)	97,800	97,800	11,200
Oil Type	Mineral	Mineral	Mineral
Frequency (Hz)	60	60	60
On Load tap changer	Yes	Yes	No
Load changes	±12X1.25%	±12X1.25%	
DGA on line monitoring	No	No	No
Separation	Yes	Yes	Yes
Drainage / Containment	Yes	Yes	Yes
Fire walls	Yes	Yes	Yes
Bushings			
Protection Relays			
Spare part	No	No	

There is a transformer monitoring system (TMS) installed on the GSUTs supplied by Koncar which monitors:

- HV windings with Partial Discharge sensors.
- DGA using Hydran M2.
- On Load Tap Changer.

The TMS server is located in the Control Room. The TMS sends Alarms to the Alarm Management Systems of each of the Groups. It was observed that the settings for these Alarms were not displayed in the Alarm Management System.

Section Five

Deep Dive Findings

Findings

The findings described below are based on various discussions during the Deep Dive session. Some are captured as part of the recommendation and have been mentioned under the Recommendations section. It is not intended raising new recommendations with the below explanation but these to be treated as supporting points for the recommendations raised.

Systems

The plant is following and applying NOMAC O&M system that govern the operation, maintenance of rotating equipment and engaged in the Reliability of Supply (RoS) program, one of this program pillars is defining and setting the guidelines of best industry practice of operating and maintaining rotating equipment.
In addition the plant has developed all procedures in line with OEM guidelines and has maintained them in the centralized server under Document Management System. In line with OEM guidelines and EPRI standards all PM plans are available in SAP4HANA. There is a good Organisational awareness of the importance of systematic approaches to Asset Integrity Management of Rotating Equipment.

Safety Critical Devices have been identified along with Single Point of Failure analysis. All these equipment have been captured in SAP4HANA with appropriate priorities. The gap analysis was carried out for the current O&M practices against EPRI standards and additional measures listed out as per EPRI are being uploaded in SAP, this was part of RoS program, Reliability of Supply.

Maintenance department has developed a condition based monitoring program and have implemented value limits for the readings recorded from field with severity for the values that fall outside of the allowable range..
The generators are equipped with IRIS system for partial discharge detection however an improvement is recommended to the utilization of the system, this is a part of the risk improvement recommendation DDR 2023/03/03.

Procedures

Following the IMS system requirements, all the procedure revisions are marked and appropriately documented and communicated to all staffs.

The operators daily check list and CCR log readings book are is currently undergoing an improvement and digitalization project, DDR # 2021/02/02 requirements are taken in consideration in this project as per the feedback from the operation team.

Critical emergency scenario procedures are kept in the control room and updated desktop exercises are conducted as per the feedback from the team however the records of the exercises were not kept properly, improvement for this procedure execution is needed, two DDR are still in progress regarding this activity, DDR # 2021/02/01 and 2021/09/03.

Implementation

The plant is following NOMAC procedure to identifying all the critical Rotating Equipment as part of Asset Integrity Management system and the maintenance of these equipment have been taken up in line with OEM guidelines and more recently after making the gap analysis with EPRI standards.

DC Lube oil pump annual performance tests is conducted for all the units during the GTs HGP and STs Annual inspection in 2022

EDG testing is highlighted in the DDR 2021/09/02, the team reported that test is conducted in regular basis, however it is not in compliance with the recommendation which is highlighting the need to follow the guidelines of NFPA 110.

For Battery testing, plant has a regular maintenance plan in place and the battery discharge test is conducted by a third party and revealed some faulty cells, action plan is in place from the plant side, details and risk improving recommendation in this regard are available in the operational survey report.

The cables for the emergency lube oil pumps of the STs are travelling in the same cable tray. The cables are coated with fire retardant paint coating.

All the planned maintenance of 2022 were executed successfully for all units following the OEM guidelines, it is reported and confirmed that all the pending technical issues of the GTs IGV and VGV are resolved during this outage.

The discussion about the failure happened to STG20 generator revealed that the repair was completed by the OEM, the generator is running normal with no issues since September 2022, and RCA of the failure is not concluded yet two recommendations related to this subject are raised during this deep dive session 2023/03/01 and 2023/03/03.

Review

The review is required for the emergency desktop exercises and the related competency assessment for the operators.

There is a process in place to track the MoC for the changes implemented. The MOCs are tracked during the management meeting on regular basis.

Awareness & Training

Testing of the emergency scenarios as Desktop exercises is one of the best industry practice to keep the staff aware of their expected actions in case of real emergencies to avoid potential losses As highlighted two recommendations are in progress in this regard , one is mainly regarding the desktop exercise documentation, recording and evaluation of the exercise in terms of getting a quick lesson learned of what went right and what went wrong and take this as an improvement note to the future exercises.

The positive thing is that the plant team is following a structured training program under a platform called Mishkaty that have four levels of training..

Competency

There is recommendation in place which is about the performance of the operators during those exercises and how the assessment of the operators during the emergency exercise can be utilized in the overall technical assessment.

Documentation

As noticed during this session NOMAC main procedures are followed, the plant is IMS certified.

Performance Score

It would be beneficial to measure the performance of the implemented O&M practices at plant level discussed during the Deep Dive session. Hence, the topics included during the Deep Dive session are ranked and mapped to provide a visual representation of our findings. These are categorized under Systems, Procedures, Implementation, Review, Awareness & Training, Competency and Documentation on a scale of 0 to 4, 4 being the highest achievement. The Radar Chart mapped for this year's topic, Asset Integrity Management – Rotating Equipment would be compared during next year's session against the status of completed recommendation with a new topic for Deep Dive session.

Based on the discussions with site management, the recommendations have been raised for further improvements in the area of Asset Integrity Management – Rotating Equipment. The below Radar Chart is the reflection of the recommendations raised and the site Operation and Maintenance practices measured against the standard set of seven features named, Systems, Procedures, Implementation, Review, Awareness & Training, Competency and finally Documentation.

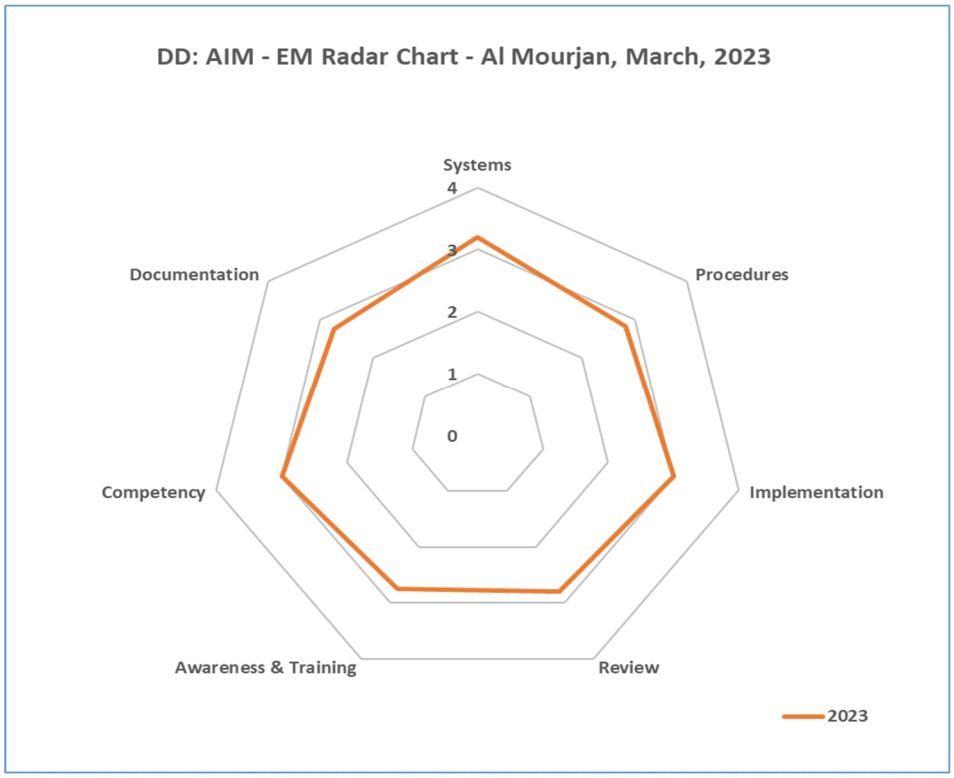


Figure 1: Al Mourjan Deep Dive – Asset Integrity Management: Rotating Equipment (Mar 2023)

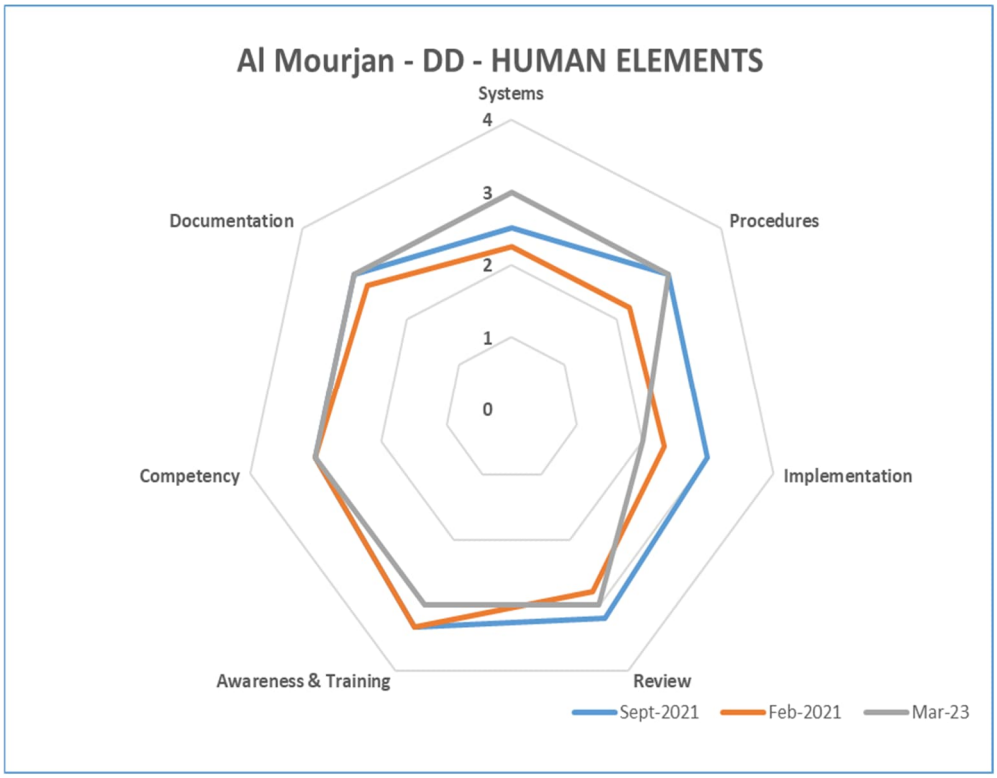
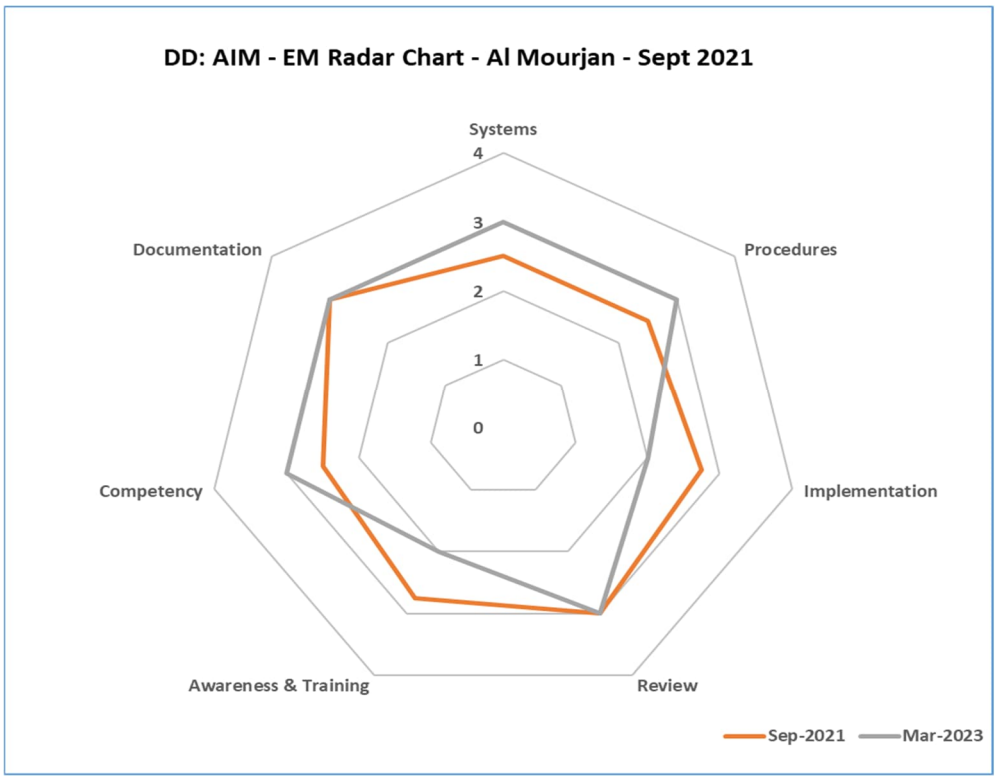


Figure 2: Al Mourjan Deep Dive – Human Elements (Feb 2021 - Mar 2023)



F*igure 2: Al Mourjan Deep Dive – Asset Integrity – Electrical Machines (Sep 2021 - Mar 2023)*

Appendix A

Requested Information

The following information was reviewed by Marsh team during the Deep Dive session.

Document Name	Operations Department	Maintenance Department
Asset Integrity Management – Rotating Equipment	Operations procedures, Operator training scheme, Out of limits reports	Policy and strategy definition documents
	A sample of copies of relevant procedures, evidence of use (e.g. completed associated checklists) Backlog records, deferred or delayed items completed risk assessments.	Compliance register, reference standards lists, approval to operate
	Sample of testing procedures, completion records, defect notifications where raised. Owner / Operator can explain the basis of testing, can cite reference.	Copy of risk register, Corrective Action Request (CAR) tracking and management process
	Sample copies of Rotating Equipment plant history records	Codes and standards reference lists, basis of design documents.
		Copies of Quality Management Systems (QMS) description, QMS elements relevant to AIM – Rotating Equipment, Proof of accreditations. Asset management plan.
		Copies of annual, 5 year plans, OEM recommended periods, whole of life plan, weld inspection plan, life assessment schedules.
		Copy of OEM documentation specifying maintenance intervals and scope of works.
		A sample of copies of relevant procedures, evidence of use (e.g. completed associated checklists) Backlog records, deferred or delayed items completed risk assessments.
		Sample copies of Position Qualification Requirements (PQR), sample copies of training and assessment records. Qualification database if applicable.
		Copies of previous outage reports on these equipment.
		Sample copies of MoC document pack for any MoC's related with Rotating Equipment
		Evidence of QA, inspections, Hold points of Third party inspection work
		Copy of audit plan relevant to AIM – Rotating Equipment, Corrective action tracking mechanism