OpEx Shared Practice & Applied Practice

ชื่อโครงการ : Zawtika Sustainable Development through Greenhouse Gas Reduction Initiatives

บริษัท : PTTEP

คณะทำงาน

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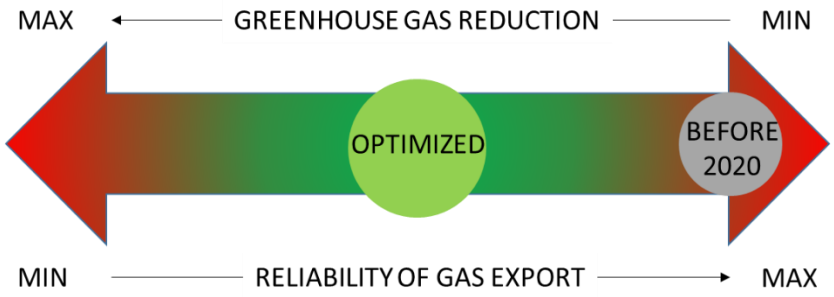
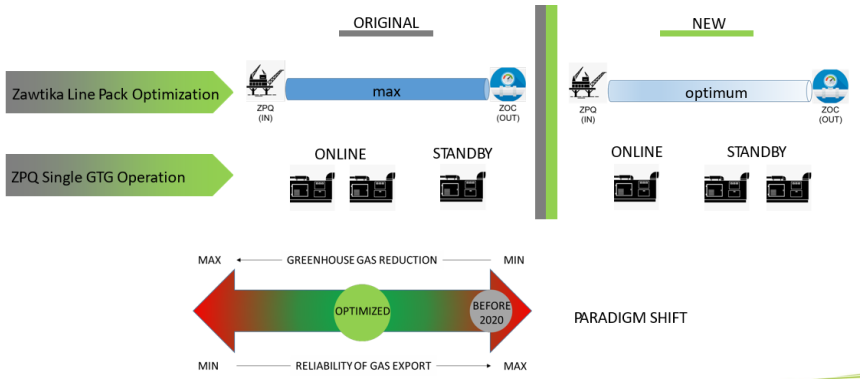
1. Project Details

No.	Title	Details
1	Project Name*	(English*) Zawtika Sustainable Development through Greenhouse Gas Reduction Initiatives (Thai)
2	Objective*	✓ Sustainable Development: To reduce greenhouse gas emission through less fuel gas consumption ✓ Cost saving: To reduce gas-turbine power generator maintenance costs through less equipment running hours
	Project Type *(please select)*	◉ Operation [โครงการที่เกี่ยวข้องกับ core operation ของบริษัท ซึ่งส่งผลโดยตรงต่อประสิทธิภาพหรือประสิทธิผลของการผลิต] ○ Operation-support [โครงงานที่สนับสนุนและส่งผลโดยตรงต่อการดำเนินงานของสายปฏิบัติการ/ธุรกิจหลัก อาทิ โครงการที่เป็นกิจกรรมในสายโซ่อุปทาน (supply chain) ซึ่งได้แก่ Procurement, Inventory, Logistic, Sale & Marketing]
3	Executive Summary*	โครงการเมียนมาได้เล็งเห็นถึงความสำคัญของการลดการปล่อยก๊าซเรือนกระจกและการใช้พลังงานอย่างมีประสิทธิภาพตามนโยบายด้านสิ่งแวดล้อมของบริษัท ตั้งแต่เริ่มผลิตก๊าซธรรมชาติจากโครงการซอติก้าเมื่อปีพ.ศ. 2557 ได้มีการใช้ก๊าซธรรมชาติในปริมาณสูงเพื่อเป็นเชื้อเพลิงสำหรับการอัดเพิ่มแรงดันของก๊าซให้อยู่ในระดับสูงสุดในท่อส่งก๊าซความยาว 230 กิโลเมตรจากแท่นผลิตกลางทะเลมายังสถานีควบคุมซึ่งตั้งอยู่บนฝั่ง และสำหรับการเดินเครื่องผลิตกระแสไฟฟ้าจำนวน 2 เครื่องบนแท่นผลิตกลางทะเล ซึ่งก่อให้เกิดการปล่อยก๊าซเรือนกระจกมากเกินความจำเป็น ในปีพ.ศ.2563 ทางโครงการได้ทำการปรับลดแรงดันของก๊าซในท่อส่งให้อยู่ในระดับที่เหมาะสม และลดการเดินเครื่องผลิตกระแสไฟฟ้าเหลือเพียงเครื่องเดียว ซึ่งทำให้ปริมาณการปล่อยก๊าซเรือนกระจกลดลงบนพื้นฐานความเสี่ยงที่ยอมรับได้ ทั้งยังสามารถลดการใช้เชื้อเพลิง และลดค่าซ่อมบำรุงเครื่องผลิตกระแสไฟฟ้าอีกด้วย
3.1	Detail	According to Zawtika asset's GHG emission data, the major source of GHG emission is stationary combustion of fuel gas used for three gas turbine compressors (GTC) and three gas turbine generators (GTG), together accounting for nearly 82% of total GHG emission from Zawtika. These two equipments convert fuel gas which, after-burnt, releases GHG through their exhausts, to deliver gas export and generate plant electrical power, respectively, so both of them are essential in gas production and delivery. In most cases, ensuring that GTC and GTG are operating at their best-efficiency points are sufficient to bring down GHG emission intensity. However, a unique feature of Zawtika, where custody meterings lie downstream of 28-inch and 230-km pipeline, allows Zawtika to optimize the operations of both gas delivery and plant electricity systems with manageable risk of business impacts in case of temporary gas production disruption. Neither investment nor technology is required for this optimization. What actually is

No.	Title	Details
		required is **operation paradigm shift** which brings Zawtika from maximum to optimized gas export reliability by applying LEAN concept under commercial and technical risk assessment processes. This shift will reasonably lower down GHG emission with energy efficiency improvement towards company's goal of sustainability.  In order to shift from maximum gas export reliability to an optimized one, high-impact LEAN wastes were identified and analyzed to find ways to eliminate these wastes without impact to business revenues. The two LEAN wastes are; 1) Overproduction excessively packing the gas export pipeline which is addressed by Zawtika Line Pack Optimization 2) Extra-processing of gas turbine generators delivering non-optimal electrical power reliability which is addressed by ZPQ Single GTG Operation **1) Zawtika line pack optimization** "Line pack" is the term that Zawtika asset calls its sales gas inventory packed into 28-inch and 230-km offshore gas export pipeline. Since Zawtika first gas in 2014, operation philosophy had always been to maximize gas export reliability by maintaining line pack pressure at a maximum of 137 barg at all time. Line pack inventory at this maximum pressure was around 120 MMscf which can continue to deliver gas to customers at their normal demands for almost half a day even in the event of total disruption of gas production from Zawtika Processing Quarters (ZPQ) which is statistically unlikely. However, in doing so, it requires relatively high fuel gas consumption for engines of all 3 gas turbine compressors (GTC) to deliver the required compression power against highest possible pressure at 137 barg. LEAN waste generated here was the overproduction of sales gas to pack into the gas export pipeline just to maximize,

No.	Title	Details
		but not to optimize the gas export reliability based on fuel gas consumption and this waste resulted in higher GHG emission from Zawtika. The original operation concept to maximize this line pack at all time therefore had to be improved in the sense of environmental responsibility towards reduction of GHG emission. Customer demand obligations and gas sales maximization are undeniably crucial for company's business whereas GHG reduction commitment is relatively as important in terms of company's sustainable growth. The new operation concept has to handle all these important aspects. Less GHG emission intensity requires lowering line pack pressure, resulting in an unavoidable shift from maximized gas export reliability to a lower one. In order to keep the business risk of revenue loss within a manageable level with optimized reliability, Zawtika asset had to ensure that this new concept covered credible ZPQ production disruption scenarios and properly addressed how much line pack was sufficient. Zawtika Gas Export Pipeline Packing Management Guideline has been established for the first time in 2020 to fulfill this objective. In order save fuel gas, the line pack pressure has been optimized by maintaining ZPQ gas export pressure as specified in Zawtika Gas Export Pipeline Packing Management Guideline which accounts for sufficient line pack both to continue gas delivery following ZPQ unexpected shutdown and to rebuild pressure from optimized one to 137 barg easily whenever maximum reliability is required based on total gas demand. This operating concept eliminates unnecessary inventory while preventing disruption of gas delivery to customers at the same time. The benefit of this optimization is that whenever total gas demand from customers drops, fuel gas will be rationally saved as ZPQ export pressure will no longer be kept at a maximum of 137 barg as practically done in the past. By significantly saving fuel gas in this way, less GHG is emitted to the atmosphere and there is less impact to the environment. Expected reduction in GHG emission from this part is 3,000 tonne CO_2e per year with a daily average fuel gas saving of 0.16 MMscfd.

No.	Title	Details
		2) ZPQ single gas-turbine generator (GTG) operation Zawtika Processing Quarters (ZPQ) has 3 main power generators, which are called gas turbine generators (GTG), to supply electricity for facility operation. Since ZPQ start-up in 2014, operation philosophy was always to keep two generators running as per design even though the electrical capacity of one generator is sufficient to sustain all plant operations. The main reason to run with 2 generators was that any unexpected shutdown of one generator would immediately stop ZPQ gas export and require subsequent plant restart, the delay of which could result in potential gas-delivery disruption. LEAN waste generated here was the extra-processing of one additional power generator to maximize reliability without taking GHG reduction into consideration. In other words, two power generators are better than one in terms of reliability but it is not the case when it comes to GHG reduction. In order to improve environmental performance, Zawtika team challenges ourselves to the question of how much risk can be tolerated and would it be possible to run with only one power generator. Similar to Zawtika line pack optimization, this new concept to run with only one generator poses a concern that gas export reliability will no longer be maximized. However, with proper study and mitigation plan, it would become more optimized. This reflects Zawtika commitment to environmental responsibility with willingness to lean out operaton margin to support PTTEP's GHG reduction goal. This initiative simply increases energy efficiency and reduces greenhouse gas (GHG) emission through less consumption of fuel gas and less stationary fuel gas combustion, respectively. Estimated reduction in fuel gas consumption when running with only 1 GTG is around 0.137 MMscfd compared to the original practice of running with 2 GTGs. GHG emission from GTG operations can be reduced by 15% on average. However, taking into account higher consequences of gas production disruption in certain cases, the plan is to apply this philosophy only about 9 months in each year excluding high-demand periods and other technical-related constraints in order to balance between risks borne and benefits gained. Expected reduction in GHG emission from this part is 1,901 tonne CO_2e/year with fuel gas saving of 0.10 MMscfd on yearly average.

No.	Title	Details
		Not only that no investment has been made to achieve this sustainability target like it is usually required for a typical energy efficiency improvement project, ZPQ Single GTG Operation initiative also brings direct financial benefit to PTTEP with LEAN maintenance. High-cost maintenance tasks are scheduled based on GTG running hours. Switching from two units running (3x50%) to one unit running (3x100%) simply reduces overall GTG running hours by nearly a half (not exactly one half as it is not implemented 365 days a year as explained earlier). Zawtika project will be able to save 4.04 MMUSD with the reduction in maintenance costs, considering until end of Production Sharing Contract in 2044. 
4	Best Practice Process / Procedures *	The key driver of "Zawtika Line Pack Optimization" and "ZPQ Single GTG Operation" is GHG reduction which is the issue that becomes increasingly important as the world is facing climate change impacts. There are a lot of efforts going on in many countries to tackle this problem with the Paris Agreement in mind. PTTEP plays an important role for Thailand to overcome this challenge of reducing GHG emission for sustainable future. These two initiatives from Zawtika contribute together around 4,900 tonne CO_2e per year of GHG reduction for PTTEP and also demonstrate how our operations can adapt to global trends smartly with paradigm shift. <u>Zawtika line pack optimization</u> - Optimally reduce fuel gas consumption of gas turbine compressors (GTC) without risk of gas under-delivery as a result of ZPQ unexpected production shutdown despite less sales gas inventory in the export pipeline

No.	Title	Details
		ZPQ single gas-turbine generator (GTG) operation - Reduce fuel gas consumption of gas turbine generators (GTG) without risk of gas under-delivery as a result of ZPQ production shutdown caused by GTG failure. - Mitigations are in place to ensure production from ZPQ can be resumed as quickly as possible in the event of electrical power loss. - Reduce GTG maintenance costs due to less equipment running hours.
5.1	Operation Duration*	**start date**: Jan 2020 **end date** : Apr 2020
5.2	Lifetime of Project*	24 Years
6	Application*	In the process, Zawtika operations were able to eliminate two LEAN wastes which are gas overproduction excessively packing the gas export pipeline and extra-processing of gas turbine generators delivering non-optimal electrical power reliability. LEAN concept, which has improved operations across PTTEP, enables Zawtika project to optimize its operations and reduce greenhouse gas emission as part of its sustainable development journey. Novel way of thinking and agile way of working applied for these two sustainable development initiatives were also crucial to their success which can be built on with many more initiatives to come.
7	Investment (Mil.Baht)*	Zero (in-house study)
8	Project Cost & Investment per year (Mil.Baht/ Yr)*	Zero (in-house study)
9	Benefit*	Estimated greenhouse gas reduction 4,900 tonne CO_2e per year Cost saving for maintenance of GTGs Fuel gas saving of GTCs and GTGs 0.26MMscfd fuel gas saved

<table>
<tr><th>No.</th><th>Title</th><th>Details</th></tr>
<tr><td>10</td><td>Benefit Value (Mil.Baht/Yr)*</td><td>
Benefit Value :
<table>
<tr><th></th><th>Total</th><th>Unit</th><th>Year 0</th><th>Year 1</th><th>Year 2</th><th>Year 3</th><th>Year 4</th><th>Year 5</th><th>Year 6</th><th>Year 7</th><th>Year 8</th><th>Year 9</th><th>Year 10</th></tr>
<tr><td colspan="14">1) Potential Benifit</td></tr>
<tr><td>1.1) Revenue Increase</td><td>0</td><td>MM USD</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1.2) Cost Saving</td><td>7.32</td><td>MM USD</td><td>0.52</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td></tr>
<tr><td colspan="14"></td></tr>
<tr><td colspan="14">2) Investment Cost</td></tr>
<tr><td>2.1) CAPEX</td><td>0</td><td>MM USD</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>2.2) OPEX</td><td>0</td><td>MM USD</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>3) Net Benefit</td><td>7.32</td><td>MM USD</td><td>0.52</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td><td>0.68</td></tr>
</table>
Discounted Rate 10%
Project life 10 years
NPV @ 10% 4.698 MM USD
</td></tr>
<tr><td>11</td><td>Benefit Value Calculation</td><td>
1) Cost saving from less fuel gas consumption of GTCs and GTGs (applied from year 0 onwards)

0.26 MMscfd fuel gas saved
This gas volume remains in reservoir to be produced for 650,000 USD per year
PTTEP cost saving benefit = 80% x 0.65 MMUSD = 0.52 MMUSD per year

2) Cost Saving from less maintenance of GTGs (applied from year 1 onwards)
<table>
<tr><th></th><th>Operating 3x50%</th><th>Operating 3x100%</th><th>Reduction</th></tr>
<tr><td>Total running hour</td><td>402,960
(17,520 per year)</td><td>251,850
(10,950 per year)</td><td>151,110</td></tr>
<tr><td>Engine exchange cycle</td><td>10 times</td><td>6 times</td><td>4 times</td></tr>
<tr><td>8000-hr Preventive Maintenance (8K PM) cycle</td><td>50 times</td><td>31 times</td><td>19 times</td></tr>
<tr><td></td><td></td><td>Unit Cost</td><td>Reduction</td></tr>
<tr><td>Engine & Reduction Gearbox (RGB) spare part</td><td>4 times</td><td>812,206 USD/Unit</td><td>3.25 MMUSD</td></tr>
<tr><td>Service cost for replacement activity</td><td>4 times</td><td>70,000 USD/unit</td><td>0.28 MMUSD</td></tr>
<tr><td>Transportation cost (round trip)</td><td>4 times</td><td>70,000 USD/unit</td><td>0.28 MMUSD</td></tr>
<tr><td>8000-hr Preventive Maintenance (8K PM) spare part</td><td>19 times</td><td>12,000 USD/unit</td><td>0.23 MMUSD</td></tr>
<tr><td colspan="3">Estimated Total Cost Saving</td><td>4.04 MMUSD</td></tr>
</table>

Reduction of 2 cycles for engine replacement in 10 years = 1.904 MMUSD
Reduction of 8 cycles for 8K PM in 10 years = 0.096 MMUSD
Total cost saving = (1.904 + 0.096)/10 years = 0.20 MMUSD per year
PTTEP cost saving benefit = 80% x 0.20 MMUSD = 0.16 MMUSD per year

</td></tr>
</table>

No.	Title	Details
12	Apply From	N/A
13	Company	PTTEP
14	Team member*	รายชื่อสมาชิกที่ร่วมในการจัดทำโครงการนี้ 1. Anucha Leelaratsameephanit 2. Sittipong Nubsuwan 3. Tasaporn Visawameteekul 4. Phanuwat Jitputti 5. Chanapol Limsakul 6. Phat Kohmongkoludom 7. Alongkorn Rodthip 8. Sayan Charoensook 9. Sawian Sri-lamai 10. Phatsawat Thanachirat 11. Sathit Chitkla 12. Apichai On-Dam
15	Contact Person*	ชื่อตัวแทนของรายชื่อข้างบน 1 ท่านที่เป็นผู้รับผิดชอบและรู้รายละเอียดของโครงการนี้ **Name :** Anucha Leelaratsameephanit **Phone:** 02-537-4000 ext. 804-3924 **Email:** AnuchaL@pttep.com
16	Year Contest	2021

2. Support Information

- ระบุรายละเอียดเพิ่มเติมของการดำเนินโครงการ (หากมี) เพื่อให้ผู้อ่านท่านอื่นเข้าใจแนวคิด หลักการ วิธีการดำเนินงาน เพื่อไปปรับใช้กับ โครงการอื่นๆได้ เช่น
  - แนวคิดหรือทฤษฎีอธิบายการดำเนินงาน
  - รูปภาพประกอบ ก่อน และ หลังการดำเนินงาน
  - Flowchart หรือ Plant Layout ที่มีการติดตั้งหรือปรับปรุงอุปกรณ์ต่างๆ
  - ผลของการดำเนินงาน เทียบมูลค่าก่อน และ หลัง ปรับปรุง

- ระบุวิธีการคำนวณ Benefit Value เพิ่มเติม (หากมี)

Additional information for ZPQ single gas-turbine generator (GTG) operation

Zawtika Processing Quarters (ZPQ) has 3 main power generators, which are called gas turbine generators (GTG), to supply electricity for facility operation. Since ZPQ start-up in 2014, operation philosophy was always to keep two generators running as per design even though the electrical capacity of one generator is sufficient to sustain all plant operations. The main reason to run with 2 generators was that any unexpected shutdown of one generator would immediately stop ZPQ gas export and require subsequent plant restart, the delay of which could result in potential gas-delivery disruption. LEAN waste generated here was the extra-processing of one additional power generator to maximize reliability without taking GHG reduction into consideration. In other words, two power generators are better than one in terms of reliability but it is not the case when it comes to GHG reduction. In order to improve environmental performance, Zawtika team challenges ourselves to the question of how much risk can be tolerated and would it be possible to run with only one power generator. Similar to Zawtika line pack optimization, this new concept to run with only one generator poses a concern that gas export reliability will no longer be maximized. However, with proper study and mitigation plan, it would become more optimized. This reflects Zawtika commitment to environmental responsibility with willingness to lean out operaton margin to support PTTEP's GHG reduction goal.

The team then assessed all the risks of running with one generator both technically and commercially before launching this new initiative concept through Management of Change (MOC) process. Assessment results are described below.

Safety

After operation philosophy is changed to only one GTG running, failure of one GTG will immediately result in power supply blackout which activates ZPQ ESD-2D and subsequently ZPQ ESD-2. However, the logic will trigger an automatic start of EDG-7200 to supply power to essential bus-bar and also automatically run LQM and topside HVAC systems for all pressurizing systems. Note that manual intervention is required to close ACB-222 and ACB-223 to feed power supply from EDG-7200 to essential bus-bar until automatic function to close these circuit breakers is rectified in next ZPQ full shutdown.

Under ZPQ ESD-2, all plant safety features and functions are still active and plant can be started up in sequence by using power supply from EDG-7200 to restart one of GTGs, after which, all systems can be resumed back to normal. In this case, no general platform alarm will be initiated and therefore no mustering is required. However, in case a single power generator failure occurs and EDG-7200 fails to supply power, especially to UPS-CPP-230 A/B, within 1 hour, EALL-23000A/B from UPS-CPP-230 A/B low voltage will initiate ZPQ ESD-1. In that case, mustering shall be carried out.

Operation team will have to follow additional requirements identified in site instruction "Plant Re-start After Power Loss" to maintain plant air pressure and, if necessary, isolate all deluge valves upon confirmation of worksite

safety and suspension of naked flame hot work and containment break activities. Operator shall be assigned to standby at deluge valve area to operate in case of emergency until all deluge valves are normalized once the instrument air system is back and stable.

Considering in case EDG-7200 is not available, BDG-7205 will have to be started manually and both LQM and topside will remain blackout for a longer period of time although the power generated by BDG-7205 is enough to start one GTG to resume plant back to normal. Hence, whenever EDG-7200 is out of service or under preventive maintenance, two (2) GTGs should be online.

Environmental

Estimated reduction in fuel gas consumption when running with only 1 GTG is 250 lb/hr which is equivalent to 0.137 MMscfd compared to the original practice of running with 2 GTGs. GHG Emission reduction from all stationary combustion (GTCs + GTGs) will be reduced by around 1.4% when this new philosophy is implemented, or around 15% if considering only GHG emission from GTGs.

However, it is planned to apply this philosophy only around 9 months in each year excluding national events and high demand periods. Under these constraints, reduction of fuel gas consumption per year will be proportionally reduced to 37.6 MMscf or 865 MMscf and GHG emission reduction will be 1,901 Tonne CO2e per year from this initiative's contribution which can be derived as below.

CO2 emission factor = 50.5 tonne CO2 / MMscf (based on ZPQ export gas composition)

CH4 emission factor = 0.00102 tonne CH4 / MMscf

N2O emission factor = 0.000102 tonne N2O / MMscf

Total CO2e per year = 37.6 MMscf x (50.5 x 1) x (0.00102 x 25) x (0.000102 x 298) = 1,901 tonne CO2e per year for reduction in GHG emission

These figures are for benefit estimation only as they will change with GTG performances and shall be tracked from actual consumption to claim for any environmental performance improvement.

Operations

After operation philosophy is changed to only one GTG running, failure of one GTG will immediately result in power supply blackout which activates ZPQ ESD-2D and subsequently ZPQ ESD-2. Under blackout condition, all instrument air compressors will be temporary shutdown until EDG-7200 can supply power to essential bus-bar. Operation team is required to closely monitor plant air pressure and perform necessary isolations as identified in

site instruction "Plant Re-start After Power Loss" to avoid loss of instrument air supply to critical users and unnecessary deluge activation.

Electrical and Instrument team has to ensure EDG-7200 is available and ready for automatic start as per logic at all time whenever only one GTG is running. If EDG-7200 fails to start automatically when blackout occurs, the team shall manually start the unit then ensure that ACB-222 and ACB-223 are closed to bring essential bus-bar live as quickly as possible. If EDG-7200 still cannot be started, the team shall start BDG-7205 to provide necessary auxiliary power to start GTG back online. Once either EDG-7200 or BDG-7205 is successfully started, one GTG shall be restarted with liquid mode.

Previously with 2 GTGs running, in any case of ZPQ ESD-2 activation except from loss of power supply from all GTGs, there is a logic for automatic fuel switchover from gas to liquid for one selected GTG while the other one is kept running in fuel gas mode. For new philosophy, there will be only one GTG running so this automatic fuel switchover function shall be assigned to the running GTG (operation team to apply a systematic approach to ensure this is correctly assigned) in order to ensure continuous power supply in the event of ZPQ ESD-2. This is because ZPQ ESD-2 will shut down fuel gas system inlet, resulting in continuous drop of fuel gas system pressure which will be available to supply to GTG only for a limited time period.

After ZPQ ESD-2 is reset and fuel gas system has become stable, operation team is advised to start 2nd GTG in fuel gas mode, synchronize with power system, then either change over 1st GTG in liquid mode to fuel gas mode and normal stop 2nd GTG or stop 1st GTG in liquid mode, depending on engine running-hour management, to resume back to normal operation with only 1 GTG running. However, operation team should consider to continue operating with 2 GTGs running until gas export pipeline pressure is restored.

Air compressors and nitrogen generation package will be offline as soon as no power is fed from generators. After that, remaining air and nitrogen in the systems will be able to supply their critical users for around 10 minutes and 30 minutes, respectively. Once essential bus-bar is normalized, one air compressor can be restarted. Once one GTG is started and synchronized, nitrogen generation package can be restarted. For nitrogen supply to turbo-compressors (GTCs) which require separation gas supply to continue for 4 hours after compressor shutdown until post-lube completion, it is ultimately back-up by bottled nitrogen. Operation team shall ensure that bottled nitrogen is always available, especially every time after nitrogen generation package trips. However, it is unlikely to be consumed as separation gas supply will resume once instrument air system and/or N2 generation package are restarted.

Seal gas supply for first compressor to be started after ZPQ ESD-2 will be taken from fuel gas system. Fuel gas superheating to required temperature of 55 ^{o}C can be completed within 10 minutes and seal gas can be further heated by E-4225A/B seal gas super heaters without additional delay in compressor start-up.

Gas turbo-compressors (GTCs) can be restarted once all related ESD conditions are cleared as there is no vendor requirement to wait until completion of post-lube sequence (4 hours). In almost all cases, it is required to

restart GTC as quickly as possible to resume gas export back to normal. For a restart of the first GTC, it can be done even while only EDG-7200 is running without electrical power supply from GTG. However, if a situation allows, post-lube sequence should not be interrupted to minimize the risk of shaft bearing failure and locked GP rotor.

Zawtika Gas Export Pipeline Packing Management Guideline and its recommended pipeline pressure were developed based on the ability to recover gas production after ZPQ ESD-2 with time margin provided for reasonable troubleshooting duration. Hence, power supply blackout due to one power generator failure is expected to be recovered without having any impact on gas delivery as per customer demands.

From 2017 to 2019, there were only 2 trip cases occurred. Both cases are not directly related to engine/generator failures but rather its protection systems which are F&G detection and low enclosure pressure during strong wind and heavy raining. For F&G system, the risk can be managed by F&G system preventive maintenance. However, for enclosure pressure, operation team should consider to start 2nd GTG whenever alarm low is received and cannot be resolved.

Maintenance, Integrity and Reliability

Time between overhaul (TBO) for each turbo-generator engine is typically allowed for 30,000 running hours and, refer to “Zawtika GTC and GTG RCM Review in 2019” with TA2 Rotating Equipment approval, this can normally be extended to 40,000 running hours if there is no concern on engine conditions. In addition, SOLAR online monitoring system has been installed and TBO can be extended upon agreement with SOLAR if the service conditions observed from online monitoring and other inspections are acceptable.

Maintenance Activity and Cost Consideration

Running with only one power generator will delay every GTG in reaching TBO and will reduce frequencies of preventive maintenance activities. For operation 3x100%, the implementation period is considered as 9 out of 12 months only, excluding period of high gas demand periods from March to May.

Change-over strategy

Change-over of main power generators shall be carried out on a monthly basis as confirmed with TA2 Rotating Equipment in order to minimize the risk of unit trip during power synchronization from change-over. In addition, every 2 weeks, corrosion inhibitor (CI) shall be applied on variable guide vane (VGV) linkage of the standby unit which will then be cranked for VGV fully open as per SOLAR Turbines service bulletin SB 8.6/112D. In order not to

keep each unit standby for too long, each standby GTG shall be started up until full speed (no load) and kept running without synchronization for 15 minutes every 2 weeks to dry out moisture inside engine and remove condensed water in the lube oil system.

Reliability Statistics

Parameters	2017	2018	2019	Average
Failure rate (365/MTBF)	2.99 times/year	4.34 times/year	1.67 times/year	3 times/year
Mean Time to Repair	43.99 hours	152 hours	51.23 hours	82.4 hours

Note: In 2018, failure statistics was high due to exhaust collector crack issue which requires replacements for all GTGs.

Statistically considering, if single generator running philosophy is applied, we may face unplanned shutdown approximately 3 times/year.

However, this statistics reflects for all failures including the ones found during unit under maintenance. If we consider only unit trip while running, historical record showed that there were only 2 times in 3 years (from 2017 to 2019) so ZPQ ESD-2 probability from this philosophy change implementation can be considered as 0.33 times/year.

For SOLAR GTG packages, there is no concern of lockout duration which prohibits unit start-up unlike other vendor packages. System can be reset at local for unit restart immediately after unexpected shutdown. Moreover, lockout shutdowns typically result from a component failure, not because operating conditions have exceeded shutdown levels so, as long as the unit does not have to service beyond TBO, there is no any concern on unit lockout shutdowns.

Electrical Engineering

Actual Power Consumption and Single GTG Rated Power

Single GTG power rating is considered as 3,407 kW taken into account 8% aging of gas turbine in compliance with PEGS Driver Power rating (10008-STD-6-ROT-016-R00). Actual average and maximum total power consumptions from 2-year record are 1974.2 kW and 2378.1 kW, respectively. Previously, maximum load of each generator was only at 37.2% relative to 3407-kW rated power. In case of running with only one power generator, even the maximum load will result in GTG running at 69.8% of its rated power so there is no issue of concern in terms of power capacity that one generator can deliver.

Motor Starting Study

Electrical Motor Starting Study (MM-ZTK-1A-ZPQ-ELE-STU-0003) does not include the case of running single GTG. However, from historical data, single GTG rated power is well higher than the sum of peak load (2378.1 kW) and required starting power (348.98 kW) of ZPQ largest motor which belongs to ZPQ crane. The remaining reserve power is 680 kW in this case.

ZPQ crane comprises of two (2) 132-kW motors, starting one by one using Y-Delta method. To be conservative, assuming that each motor is started using DOL method, the resulting voltage dip at GTG terminal is 4.67% which is within the criteria of 10%.

In addition, ECS has a permissive-to-start-large-motor feature. In case of insufficient spinning reserve, ECS will remove "Start permissive" signal for particular loads. Thus starting each of those particular large loads is inhibited by ECS. This inhibit-to-start signal does not affect the load once it is already running. This feature shall be enabled.

Load Shedding

As recommended by TA2, load shedding shall be configured as listed below in order to reduce the risk of single generator trip and protect the engine in the following scenarios, except for load shedding upon loss of a generator (trip status of generator) which shall be kept disabled as it has no effect when running single GTG.

- Load shed upon Low spinning reserve -> shall be enabled.
- Load shed upon under frequency (Frequency < 49.5 Hz) -> shall be enabled.
- Load shed upon High T5 from GTG -> shall be enabled.

Relay Settings

The current relay setting study has already covered single GTG operation as the minimum case.

Future Electrical Loads

With remaining reserve power, even additional compressor train and condensate heater (ZPQ capacity expansion project) or water injection pump and booster pump can be accommodated with supply from only one main power generator. However, whenever it is required to add an equipment, engineering team shall verify in details whether additional load will impact to running with only one main power generator, assess the impact of motor starting and advise modification of load shedding functions as required.

Commercial Aspects

There is no impact to gas delivery as gas export pipeline management already takes into account reasonable period for plant troubleshooting, start-up and ramp-up after ZPQ ESD-2. National events and other high demand periods are also excluded from the implementation. During those periods, running with two main power generators are advised.

Several mitigations were identified and put in place to minimize future occurrences of full plant shutdown (loss of production), caused by unexpected failures of GTG and also ensured the system start-up was in time to avoid any impact to gas delivery and business revenues. One example of those mitigations was to prepare for the worst consequence which was to clearly identify what operation team had to do when experiencing loss of production due to GTG offline to be able to resume production as quickly as possible, mitigating risk of production impact in a systematic way.

Recommended Mitigations

1. Site operation team shall assign a competent team of responsible persons to support plant start-up on an on-call basis.
2. Trial GTG start-up with liquid mode during change-over shall be performed regularly to ensure GTG liquid-mode function and components are ready whenever ZPQ ESD-2 occurs, resulting in shutdown of gas supply inlet to fuel gas system.
3. For seal gas conditioning skid SK-4205, operation team shall prepare hot spare of 1" 1500# check valve and booster compressor C-4245 A/B overhaul kit ready on board as their failures might delay start-up of first compressor. Note that this particular check valve failure happened in the past.
4. Site instruction "Plant Re-start After Power Loss" shall be available in Control Room at all time and include in Plant Upset Exercise Scenario.
5. ACB-222 and ACB-223 must be checked and confirmed close when EDG-7200 is started after power loss to avoid situation developing from ZPQ ESD-2 to ESD-1.
6. Whenever EDG-7200 is not available, start 2nd GTG.
7. Back-up N2 bottles for separation gas shall be checked regularly and after every N2 generation package shutdown. Operation team shall prepare sufficient spare N2 bottles on board to be ready once replacement is required.

Initiative Benefits – GHG Reduction for Sustainable Development