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Failure Mode and Effects Analysis of Hotwell System Motor Operated Butterfly Valve

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Keywords

Motor operated Butterfly Valve, Failure Mode and Effects Analysis, Reliability Priority Number, Maintenance, Geothermal Power Plant

ABSTRACT

Olkaria 280 MW Geothermal Power Plants (GPPs) have been experiencing breakdowns of the Motor Operated Butterfly Valves (MOBFVs) over the years with negative impacts on safety, reliability, power plant revenue and cost. The MOBFV function is to control and regulate condensate flow from the condenser to the cooling tower. The failure of these valves have led to turbine trip or delay turbine start up.

This paper applies the Failure Mode and Effects Analysis (FMEA) tool to evaluate the reliability of the MOBFVs in Olkaria 280 MW GPPs in order to improve safety and reliability of the hotwell pump system. FMEA is a method used to study the reliability characteristics of systems, processes and components. Reliability assessment of the MOBFVs will plays a very important role in the definition of a suitable maintenance strategy and hence improve the overall plant availability. The strategy aims to reduce unplanned shutdowns, component repair times and elimination of risk significant components. This evaluation identified the most risk significant components in the MOBFVs as valve seat, disc pins, driven gear, seals and bearings. Upon implementation of new maintenance procedures, there was significant decrease in reliability priority number (RPN) value for individual components leading to a reduced risk of failure. In addition, a financial evaluation estimated that the application of the revised maintenance strategies reduced the financial cost and losses by 51.10%.

1. Introduction

A butterfly valve (BFV) is a flow control valve used for isolating and regulating flow of fluids. The BFV operation time is short because the disc element is rotated a quarter turn (90°) to open or close the passageway. BFVs are quite versatile and can be used for industrial applications under varying conditions such as type of fluid, sizes, pressures and temperatures. (Patil & Basavaraj, 2015). These valves are ideal because they are lower in cost, lighter in weight compared to other valve designs. They can also be used to perform throttling operation. Figure. 1 shows the operation of the motor operated butterfly valve;

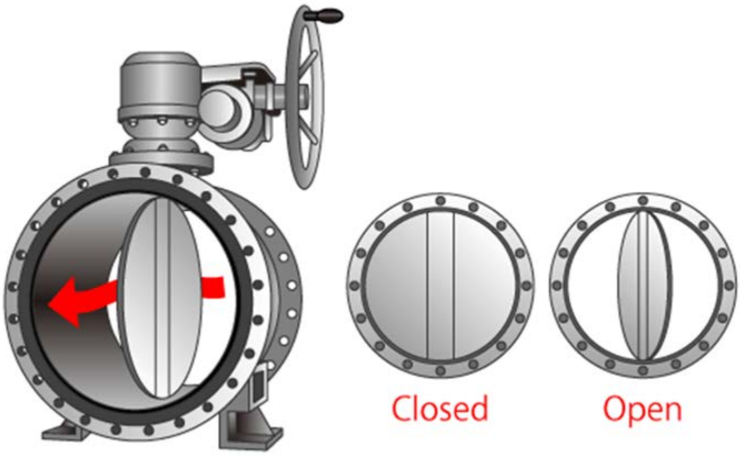

Figure 1: The figure above illustrates the operation of a motor operated butterfly valve (TLV, 2017)

2. Olkaria 280 MW Geothermal Power Plant (GPP)

The 280MW GPP comprises of two geothermal power stations namely Olkaria I AU and Olkaria IV, each with a net capacity of 140 MW. Each plants has two units rated at 70 MW. These power plants were each commissioned in 2014 and 2015. The power plants are made up of various systems which include the steam gathering and supply, circulating water, hotwell pump, non-condensable gas extraction, chemical dosing, water and waste water treatment, and HVAC systems.

3. Problem Statement

This paper seeks to identify major causes of failure in 280MW GPPs MOBFVs, the effects of such failure whenever they occur and calculate the risk significance of the failures by calculating the reliability priority number (RPN). The RPN number gives the importance of the failure and can easily identify which failure bears the highest risk to the operation of the plant. A review of the design and maintenance strategies is done and maintenance tasks are selected that can adequately mitigate the failure. Furthermore, a financial review is undertaken to estimate the benefits of the prescribed changes.

4. Failure Mode and Effect Analysis (FMEA)

FMEA is an analytical technique (a paper test) that combines the technology and experience of people in identifying fore-seeable failure modes of a product or process and planning for its elimination (Reena & Venkatraj., 2013). It is the systematic identification of possible root causes failure, failure modes, the effects of the failure and risks associated the respective failure. The main goal is to identify and then limit or avoid risk within a design. Hence, FMEA drives towards higher reliability, higher quality, and enhanced safety. It can also be used to assess and optimize the design and maintenance plans. FMEA provides the following benefits. They are:

- Improve product/process reliability and quality
- Increase customer satisfaction
- Early identification and elimination of potential product/process failure modes
- Prioritize product/process deficiencies and their elimination
- Emphasizing problem prevention
- Documenting the risk and the actions taken to reduce risk
- Minimizing changes at later stages and associated cost (Besterfield, 2005)

4.1 Reliability Priority Number (RPN)

The RPN calculates the inherent risk from a given failure mode, by assigning numerical values to severity, occurrence and detection. As the risk increases, the RPN values of the failure mode rises. This is what is defined as the risk priority number (RPN). High value RPNs are considered the most risky elements of the design and should be addressed in order increase the reliability of the product. RPN is a product of the severity, occurrence and detection as shown in the formula below.

$$RPN = (S) \times (O) \times (D)$$

Where S, O and D represent Severity, Occurrence and Detection respectively.

Severity refers to the magnitude of the end effect of a system failure. The more severe the consequence, the higher the value of severity will be assigned to the effect. Occurrence refers to the frequency that a root cause is likely to occur, described in a qualitative way. That is not in the form of a period of time but rather in terms such as remote or occasional. Detection refers to the likelihood of detecting a root cause before a failure can occur (Patil & Basavaraj, 2015).

FMEA has been used in industries, including Automotive; Aeronautical; Military; Nuclear and Electro-technical, specific standards have been developed for its application. The Severity, occurrence and detection factors are individually rated using a numerical scale, typically ranging from 1 to 10. In order to carry out analysis, the severity, occurrence and detection criterion have been decided and presented in table I, II and III by which the RPN can be calculated.

Table I. Severity Criteria

Rate	Severity Criteria	Rating
Dangerously high	Failure could lead to safety breach causing injury of staff	10
Extremely High	Failure could lead endanger the machine	9
Very High	Loss of primary function	8
High	Lead to significant customer dissatisfaction	7
Moderate	Part of the component to be scrapped	6
Low	Affect performance and generate complaints	5
Very Low	Results in minor performance losses	4
Minor	Failure is nuisance but does not result in performance losses	3
Very Minor	Failure results in minor consequence, but unlikely to be apparent	2
None	No effect	1

Table II. Occurrence Criteria

Rate	Failure Rate Criteria	Rating
Persistent Failure	Failure once a week	10
Very High Failures	Failure once a month	9
High	Failure once a three month	8
Relatively high	Failure once in six months	7
Moderate	Failure once a year	6
Low	Failure once in three years	5
Relatively Low	Failure once in five years	4
Very Low Failures	Once in 7 years	3
Relatively Remote	Once in 10 years	2
Remote	Once in 20 years	1

Table III. Detection Criteria

Rate	Detection Criteria	Rating
Absolute Uncertainty	Design control will not and/or cannot detect failure Mode	10
Very Remote	Very remote chance the Design Control will detect the failure mode.	9
Remote	Remote likelihood current controls will detect the failure	8
Very Low	Very low likelihood current controls will detect the failure	7
Low	Low likelihood current controls will detect the failure	6
Moderate	Moderate likelihood current controls will detect the failure	5
Moderate High	Moderate high likelihood controls will detect the failure mode	4
High	High likelihood controls will detecting the failure mode	3
Very High	Very high likelihood controls will detecting the failure mode	2
Almost Certain	Current controls will almost certainly detect the existence of a failure mode.	1

Table IV. Risk Matrix

RPN Scale	Risk Rate	Criticality Class
1000 - 500	Very high risk	A
499 - 250	High risk	B
249 - 100	Moderate risk	C
99 - 0	Low risk	D

5. Results

To increase understanding level and detailed component knowledge of the MOBFV system, the system is broken down to individual components. The Olkaria 280 GPPs MOBFVs are composed of three major components:

1. Butterfly valve
2. Actuator
3. Electric motor
4. Mechanical Gearbox

5.1 FMEA for Butterfly Valve

Table IV: Butterfly Valve FMEA

Component	Function	Failure Mode	Failure Effect	Root cause
Hand wheel	Open and Close Disc	Break	BFV manual operation fail	Poor handling, Poor material
Stem	Transfer torque	Fracture, wear	BFV motor/ manual operation fail	Too much force, Water hammer material deficiencies, too much cycling
Body	Contain valve internals	Crack	Fluid leakage	Improper handling, material deficiencies
Seat	Ensure disc complete shut	Leakage	Incomplete closure	Foreign material, silica deposit, Wear, poor material, poor seat design, Too much friction
		Tear, Permanent deformation, Swelling	Loss of flow control	Wear, Excessive force/ pressure Disc not fitting, Poor material selection
Disc	Allow and prevent flow	Wear, bending	Poor flow control	Excessive force, debris, poor design
		Fail to Open/ Fail to Close	Failure of valve operation	Poor Installation, Silica scaling and dirt
		Slow Response	Poor flow control	Gear failure, disc is stuck
		Pitting	Poor flow control	Corrosion
Bearing	Hold the stem in position	Wear	Operation fail	Improper lubrication, Improper mounting Shaft misalignment
Bolts	Fasten the valve	Fracture	Leakage	Poor material
		Seizure	Difficulty in opening, threads damage	Lack of lubrication, Over torque
Coupling	Transmit rotation motion	Misalignment, shear	Failure of valve operation	Physical damage, Improper installation, Wear, Improper material, Aging
Pins	Lock disc to the stem	break	Loss of opening or closing of valve	Excessive force, material deficiencies
		bend	Poor valve control	Excessive force
Seal	Prevent leaking into the	leakage	Wetting the lubrication system and gearing system	Installation errors, Abrasion, over compression, twisting, wrong design, thermal and chemical degradation

The figure below shows the parts of a BFV valve.

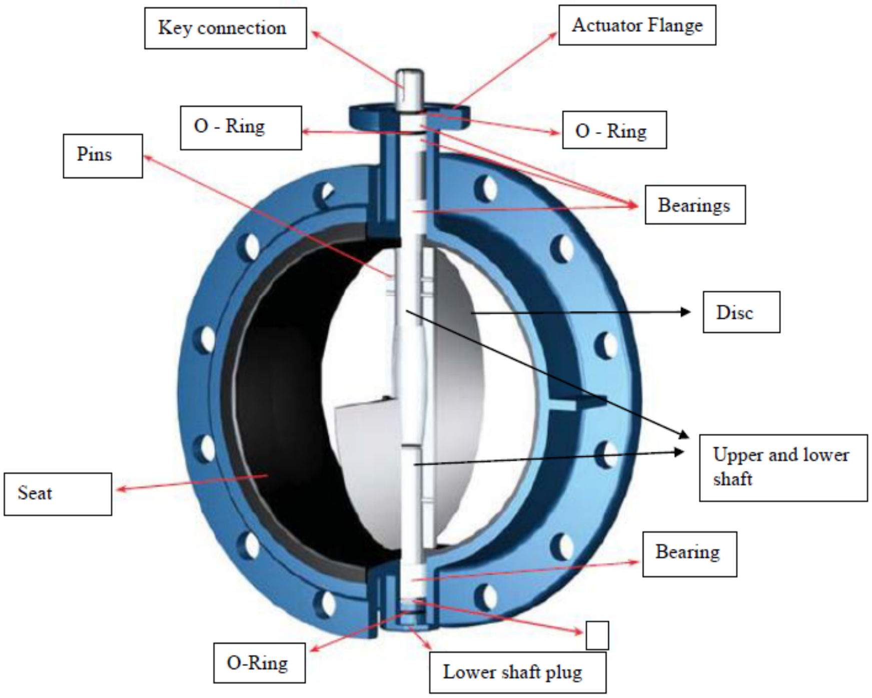

Figure 2: The figure above illustrates parts of butterfly valve

5.2 FMEA for Motor and Actuator

A valve actuator is the mechanism for opening and closing a valve. The actuator positions the valve in compliance with operation commands issued by the DCS. (AUMA, 2017). When reaching end positions or intermediate positions, the actuator stops and signals the status to the control system. The electric actuator uses an electric motor to provide torque to operate a valve.

Figure 3: The figure above is a motor operated actuator with hand wheel

Table V: Part of Motor Operated Actuator

No.	Name
1	Motor
2	Limit, torque and valve travel sensor
3	Gearing
4.	Valve attachment
5.	Manual operation
6.	Actuator Control
7.	Electrical connection
8.	Field bus

Table VI: Actuator FMEA

Component	Function	Failure Mode	Failure Effect	Root cause
Limit & torque and valve travel sensors	Signal when an end position has been reached. Torque alarm and electric motor trip signal in case the valve is stuck. Give real time valve position remotely	Fail Open/ Close Incorrect valve position indicator	Disc does not stop at desired position	Shot, bad connection, switch broken, moved or bent, wiped potentiometer (travel sensor)
Gearing	Reduce the high output speed of the electric motor	Wear, Break, pitting	No torque transmission	Excessive compressive stresses, shock loading, bad lubricant, too much cycling
Valve shaft	Transmit torque to the valve	Wear / Fracture	No torque transmission	Excessive torque Too much cycling
Actuator Controls	Signal open and close	Spurious action	Function fail	Sensor fail due to corrosion, deterioration, blocking, and breakdown. Signal processing unit fail
		Fail to open/close	Function fail	failure in the operative part of the actuators deteriorates its action
Electric Connections	Transmit signals/ connect electrical connection	Break in lines, loose connections	Signal failure No power	Loose connection Shot circuit Oxidation contacts
Field Bus	Real time data transmission in process automation	Communication failure	Signal failure	Shot circuit, bad connections

Table VII: Motor FMEA

Component	Function	Failure Mode	Failure Effect	Root cause
Bearing	Reduce shaft friction	High vibration, Seizure	Overload, overheating, no rotation, hindered rotation	Overloading, Improper, aged/insufficient lubricant, solid/ liquid contaminants, improper mounting, Shaft misalignment
Rotor	Moving part of motor	Eccentric rotor	Bearing damage Motor rebuild High cost of repair	Imbalance, Thermal stress Assembly problems, Poor base
		Broken rotor bars	Bearing damage Motor rebuild High cost of repair	Imbalance, Thermal stress Assembly problems, Poor base
Stator	Generate electricity, Carry current, Retain Armature	Stator defects	Motor inefficiency High cost of repair	Eccentricity, Short lamination Loose iron, These can be caused by high temperature, corrosion and contamination
Coupling	Transmit rotation motion	Misalignment	Shutdown to avoid bearing damage	Physical damage, Improper installation, Wear, Improper material, Aging
Insulation & Winding	Carry current	Winding failure, shortage	Motor failure	Overheat, Moisture, Contamination Insulation breakdown, High vibration, Voltage surges, Bad maintenance

Table VIII: Motor FMEA

Cmponent	Function	Failure Mode	Failure Effects	Root Cause
Gears	Transfer torque from actuator	Wear, Pitting	Open/ closing fail	Excessive compressive stresses, shock loading, bad lubricant, too much cycling
Shaft Seal	Prevent water from accessing the gearbox	Tear, wear	Leakage to into gearbox, contamination of grease leading to wear and corrosion	Damaged seal, poor installation, non fitting seals, over compression, twisting
Driven Gear	Rotates the valve disc	Shear, Wear	Open/ closing fail	Grease contamination, corrosion
Bearings	Carry gear loads and hold gear shaft in position and reduce rotational friction	High vibration, Seizure, wear, pitting, fatigue, corrosion	Overload, overheating, no rotation, hindered rotation	Overloading, Improper, aged/insufficient lubricant, solid/ liquid contaminants, improper mounting, Shaft misalignment

5.3 Reliability Priority Number Analysis

Table IX: Reliability Priority Number Analysis

Component	Sub - Component	Severity	Occurrence	Detection	RPN	Group
Butterfly Valve	Hand wheel	8	4	3	96	D
	Stem	10	6	7	420	B
	Body	8	4	3	96	D
	Seat	8	8	8	512	A
	Disc	10	7	6	420	B
	Bearing	10	4	8	320	B
	Bolts	5	8	8	320	B
	Coupling	8	7	7	392	B
	Pins	8	7	8	448	B
	Seals	5	8	8	320	B
Actuator	Limit, torque and valve travel sensors	8	4	6	192	C
	Gearing	8	6	5	240	C
	Shaft	8	4	7	224	C
	Controls	10	6	5	300	B
	Electrical Connections	8	6	6	288	B
	Field bus	8	5	6	240	B
Motor	Bearing	8	7	8	448	B
	Rotor	8	4	6	192	C
	Stator	8	6	6	288	B
	Insulation	8	6	6	288	B
Gearbox	Gears	8	5	7	280	B
	Shaft Seal	5	8	8	320	B
	Driven Gear	8	7	7	392	B
	Bearings	8	5	7	280	B

5.3.1 Ranking of High Risk Sub - components

Table X: Ranking in Order of Priority

COMPONENT	SUB COMPONENT	RPN	RANKING
Butterfly Valve	Seat	512	1
	Pins	448	2
	Disc	420	3
	Stem	420	4
	Bearing	320	5
	Seals	320	6
	Bolts	320	7
	Hand wheel	96	8
	Body/ casting	96	9
Actuator	Actuator Controls	300	1
	Electrical connection	288	2
	Gearing	240	3
	Field Bus	240	4
	Shaft	224	5
	Limit & torque sensors	192	6
Motor	Bearing	448	1
	Insulation and Wiring	288	2
	Stator	288	3
	Rotor	192	4
Gearbox	Driven Gear	392	1
	Shaft Seal	320	2
	Gears	280	3
	Bearings	280	4

Figure 4 and 5 below show the RPN values of the risk significant components in the MOBFV and their respective severity, occurrence and detection ratings respectively.

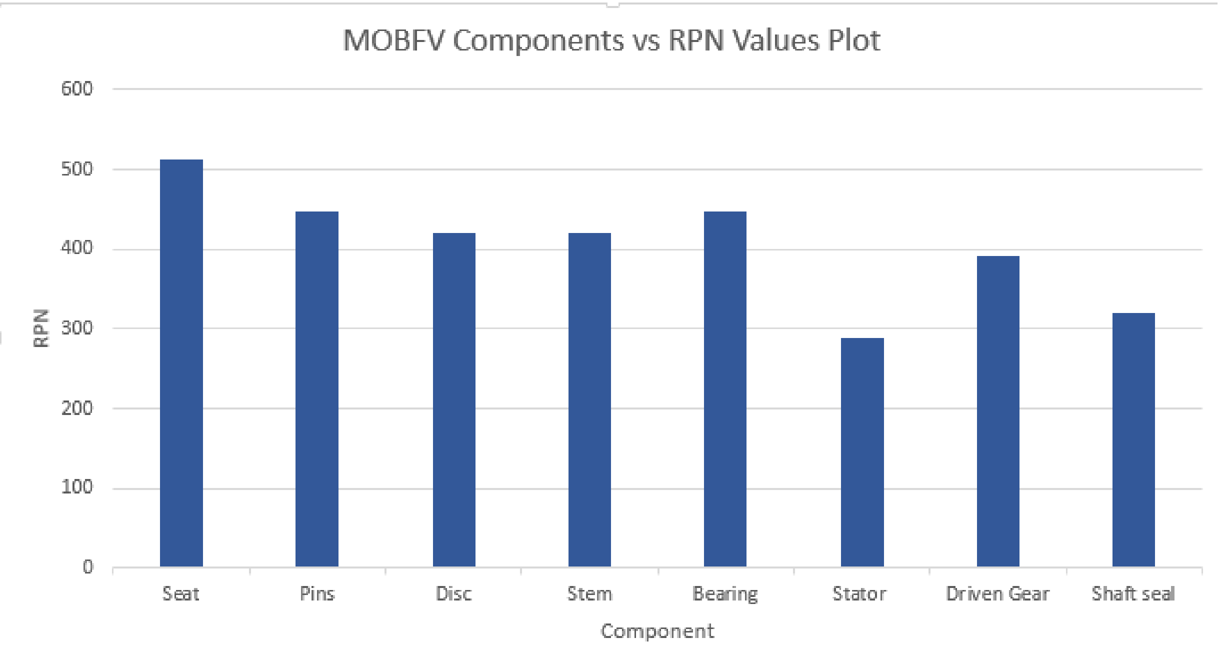

Figure 4. Motor operated valve components with high RPN values

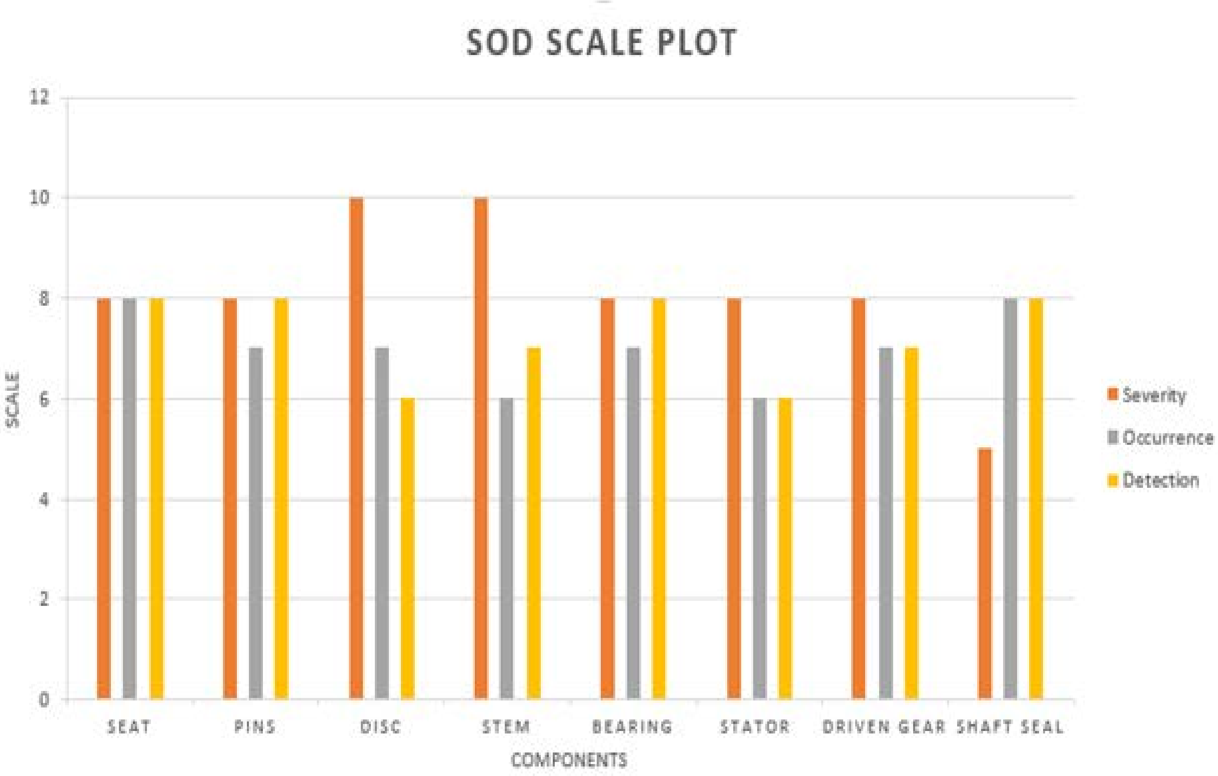

Figure 5. Severity, Occurrence and Detection (SOD) scale of high risk components

5.3.2 Recommended Maintenance Strategies

The maintenance tasks available for consideration are:

i. Failure finding tasks (whose failure modes are hidden and require functional tests to detect);

ii. Condition based tasks (tasks that monitor the degradation levels of failure modes);

iii. Time directed task (maintenance tasks performed periodically as scheduled);

iv. Re-design (where there is neither feasible condition directed nor time directed tasks applicable) and,

v. Run to failure is applied on less safety and economical failure modes. Their failures are tolerable and corrective action is applied after failure. (Ouma, Osama, Mpakani, Baik, & Gomma, 2015)

The process of application of maintenance strategy is illustrated in figure 6 below.

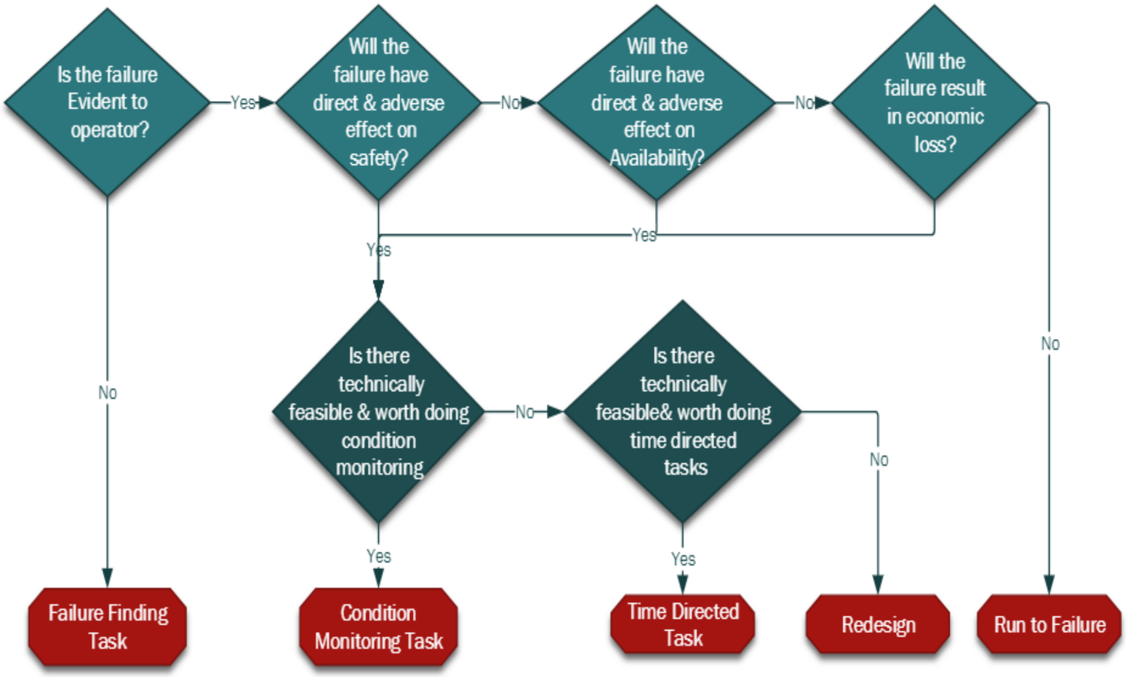

Figure 6: Maintenance task selection process (Ouma, Osama, Mpakani, Baik, & Gomma, 2015)

5.3.3 Application of New Maintenance Strategy

Table XI: Application of New Maintenance Strategy

COMPONENT	SUB COMPONENT	MAINTENANCE STRATEGY
Butterfly Valve	Disc	CBM , visual inspection, phased array ultrasonic, radiography testing
	Stem	CBM, visual, dye penetrant and ultrasonic testing
	Seat	Time based PM, Annual inspection, develop seat replacement capabilities on site & develop program for seat replacement
	Bearing	Time based PM, Annual inspection, rotational tests, thermography, cleaning, vibration tests, and lubrication analysis.
	Bolts	Time based PM, proper lubrication with anti-seize
	Hand wheel	Time based PM, lubrication, visual inspection monthly
	Body	Time based PM, visual inspection monthly
	Coupling	Time based PM, visual inspection annually
	Pins	Redesign, with a tough material
	Seals	Time based PM, Annual Inspection
Actuator	Actuator Controls	CBM, visual, temperature, current signatures
	Gearing	CBM, visual, proper lubrication, wear debris analysis, acoustic signature
	Electric Connection	CBM, visual, temperature, acoustic signature, voltage and current signatures
	Field Bus	CBM, voltage and current signatures
	Valve shaft	Time based PM, Annual inspection
	Limit & torque sensors	Time based PM, Annual inspection
Motor	Bearing	CBM, rotational tests, vibration tests, lubrication analysis, debris analysis
	Rotor	Time based PM, Annual inspection
	Insulation and Wiring	CBM, voltage and current signatures
	Stator	CBM, voltage and current signatures
Gearbox	Driven Gear	Re-design with harder material
	Shaft Seal	Failure Finding
	Gears	Time Based PM, Annual grease replace annually
	Bearings	CBM, rotational tests, vibration tests, lubrication analysis, debris analysis

NB: PM stands for Preventive Maintenance

5.4 Revised Reliability Priority Number

Table XII: Estimated Reliability Priority Number after Review of Maintenance Strategy

Component	Sub - component	RPN				
		Severity	Occurrence	Detection	RPN	Group
Butterfly Valve	Hand wheel	8	4	2	64	D
	Stem	8	5	4	160	C
	Body	8	4	3	96	C
	Seat	8	6	7	336	B
	Disc	10	5	4	200	C
	Bearing	8	4	6	192	C
	Bolts	5	6	4	120	C
	Coupling	8	5	5	200	C
	Pins	8	5	7	280	B
	Seal	5	4	5	100	C
Actuator	Limit & torque sensors	8	4	5	160	C
	Gearing	8	5	5	200	B
	Valve shaft	8	4	5	160	C
	Actuator Controls	10	5	4	200	B
	Electric Connections	8	5	4	160	B
	Field bus	8	5	5	200	C
Motor	Bearing	8	5	5	200	C
	Rotor	8	4	5	160	C
	Stator	8	5	5	200	C
	Insulation & Winding	8	5	5	200	C
Gearbox	Gears	8	5	6	240	C
	Shaft Seal	5	6	7	210	C
	Driven Gear	8	5	6	240	C
	Bearings	8	5	5	200	C

Table XIII: Review of Risk Priority Number

COMPONENT	SUB COMPONENT	INITIAL RPN	REVISED RPN
Butterfly Valve	Disc	420	200
	Stem	420	160
	Seat	512	336
	Bearing	320	192
	Bolts	320	120
	Hand wheel	96	64
	Body/ casting	96	96
	Coupling	392	300
	Pins	448	280
	Seal	320	100
Actuator	Actuator Controls	300	200
	Gearing	240	200
	Electric Connection	288	160
	Field Bus	240	200
	Valve shaft	244	160
	Limit & torque sensors	192	160
Motor	Bearing	448	200
	Rotor	192	160
	Insulation and Wiring	288	200
	Stator	288	200
Gearbox	Driven Gear	392	240
	Shaft Seal	320	210
	Gears	280	240
	Bearings	280	200

5.5 Financial Analysis

The following financial analysis was done to estimate the financial loss due to MOBFV failure

Table XIV: Revenue Loss analysis

Number of Failures annually	No. of days to repair	Outage days Annually	Loss of Revenue per day ($)	Annual revenue loss ($)
6	2	12	60,000	**720,000**

Table XV: Spares cost

Spares	Number	Price ($)	Annual Spare Cost ($)
Butterfly valve	1	50,000	50,000
Actuator	1	2,000	2000
Bolts	10	10	100
Gears	2	700	1,400
Motor	1	1000	1,000
Others			2,000
Total Cost			**56,500**

NB. It is assumed that 1 BFV with motor and actuator will be replaced in one year

Table XVI: Labor costs

Designation	Number	Staff Rate per day ($)	Number of days	Annual Rate ($)
Engineers	3	65	12	2,340
Technicians	10	60	12	7,200
Others staff	5	33	12	1,980
Total Cost				**11,520**

Table XVII: Material costs

Type	Quantity Per day	Units	Rate ($)	Number of days	Annual Rate ($)
Gloves	20	Pcs	5		100
Consumables	10	Pcs	20		200
Gas Masks	30	Pcs	5	2	300
Fuel	100	L	0.9	12	1,080
Others					1,600
Total Cost					**3,280**

Table XVIII: Total financial cost

Cost Item	Cost ($)
Loss of Revenue	720,000
Spares	56,500
labour	11,520
Materials	3,280
Total	**791,300**

Upon implementation of the new maintenance task a financial review was undertaken. The analysis was performed in order to estimate the saving in revenue.

Table XIX: Loss of revenue analysis

Number of Failure annually	No. of days to repair	Outage days Annually	Revenue per day ($)	Annual revenue loss ($)
3	2	6	60,000	**360,000**

Table XX: Spares cost

Spares	Number	Price ($)	Annual revenue loss ($)
Butterfly valve	0.33	50,000	16,500
Actuator	0.33	2,000	660
Bolts	4	10	40
Gears	1	700	700
Motor	0.5	1000	500
Total Cost			**18,400**

Table XXI: Labor costs

Designation	Number	Rate ($)	Number of days	Annual Rate ($)
Engineers	3	65	6	1,170
Technicians	10	60	6	3,600
Others	5	33	6	990
Total Cost				**5,760**

Table XXII: Material costs

Type	Quantity Per day	Rate ($)	Number	Annual Rate ($)
Gloves	20	5		100
Consumables	10	20		200
Masks	30	5	2	300
Fuel	100	0.9	6	540
Others				1,600
Total Cost				**2,740**

Table XXIII: Revised total financial cost

Cost Item	Cost ($)
Loss of Revenue	360,000
Spares	18,400
labour	5,760
Materials	2,740
Total	**386,900**

Estimated saving on the new maintenance strategies is calculated as shown below.

= 791,300 - 386,900
= $ 404,400
Percentage Saving is 51.10%

6. Discussion of FMEA Results

To reduce the risk of component failure or to eliminate a particular failure mode and its inherent failure effect recommended action is taken depending on the failure mode. For example the initial RPN for the valve seat is 512, which is critical A, where the severity was 8, Occurrence was 8 and detection was 8. Upon implementing the recommended maintenance tasks, through preventive maintenance strategies, in this case, seat cleaning, development of local capacity for seat replacement and review of specifications for valve seat. The revised RPN decreased to 336, which is critical B. The severity is considered the same as 8, but due to the recommended action taken the occurrence and detection rating are reduced from 8 to 6 and 8 to 7 respectively. Again the new risk priority number is,

$$\mathrm{PRPN} = (S) \times (O) \times (D) = 336$$

This means risk of failure of seat and its effects are minimized to a greater extent. Figure 7 below is a graph showing the initial RPNs and the revised RPNs of risk significant components.

Furthermore, the change in tasks to be applied to each component is as follows: 11 components to be put under time based preventive maintenance, 10 components to be monitored through condition based maintenance, 2 components will need re-designing to improve the reliability while 1 component will require failure finding in order to identify the reason for failure. Financial analysis was done and estimated the total annual loss of revenue amounted to $ 791,300.00. On application of the new strategies the loss reduced to $386,900.00 which is a reduction of 51.10 %.

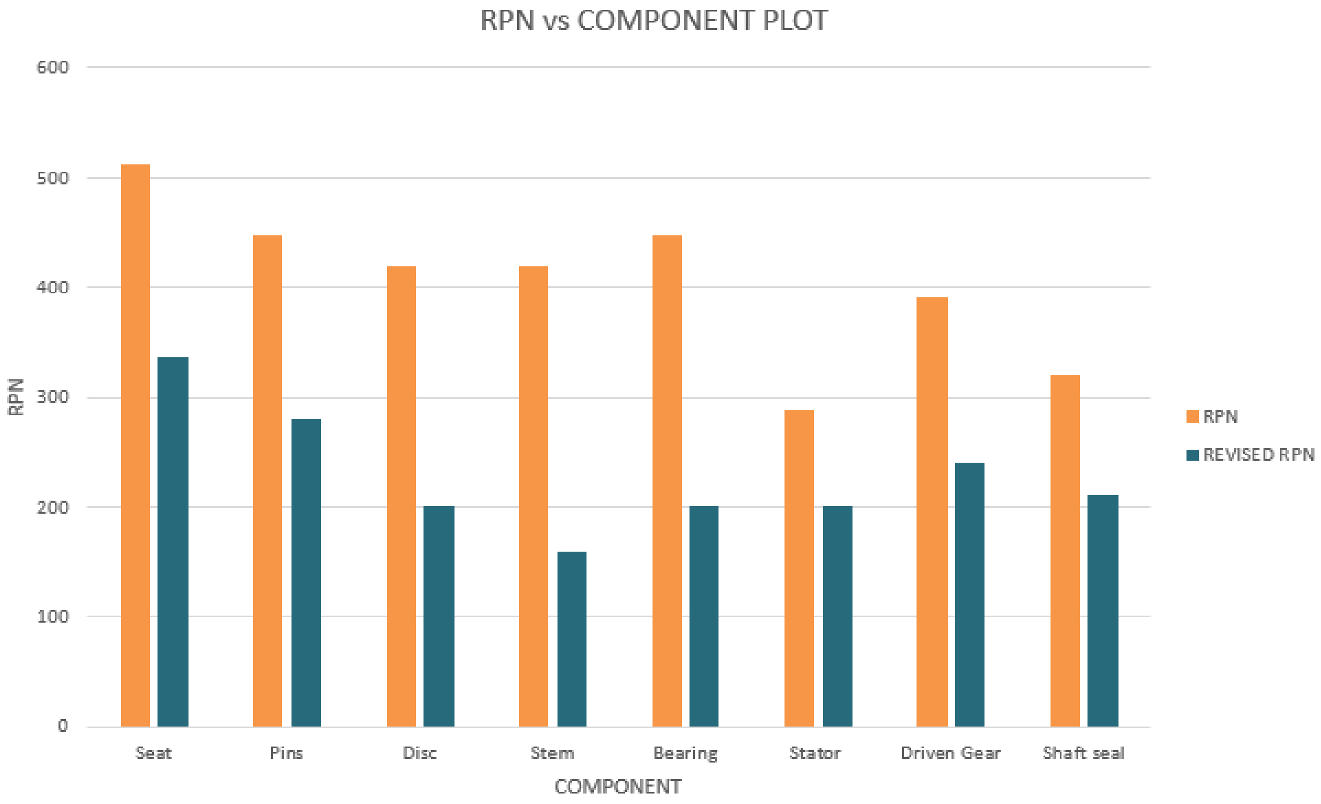

Figure 7. Initial RPN compared to revised RPN values

7. Conclusion

This paper was able to identify the most risk significant sub-components on the MOBFVs. The butterfly valve had the highest number of risk significant components while the actuator had the least. In the BFV the seat, pins, stem and disc were found to have high RPN values, hence risky components. In the actuator the actuator controls and electric connection were found to be risk significant. While the gearbox, the driven gear and shaft seal were identified as risk significant components. Furthermore, motor bearing, insulation and stator were found to be risk significant in the motor. It was observed that there was no maintenance plan for the motor operated butterfly valve prior to this study and the butterfly valves are more or less operated on a run to failure basis. The application of the new maintenance strategies individual component RPN values decreased significantly. This is an indication of improved reliability of the MOBFVs and availability of the 280 MW GPPs. In addition, an estimated loss reduction of 51.10 % annually was predicted.

Recommendations

From this work the following recommendations are made:

1. Application of the tasks in table XI is necessary in order to improve MOBFVs reliability;
2. Development seat replacement capabilities on site would save on downtime and cost;
3. Spares of risk significant components should be readily available in stores. It is recommended to have a minimum of two healthy MOBFVs in the stores. This can reduce the time of replacement significantly. In addition, a design of MOBFV removal structure/ jig is necessary to aid in quick removal and replacement of the butterfly valves;
4. A review in technical specification is necessary for the very risk significant components like the valve seat, driven gear and the pins, and
5. Actual RPN values should be calculated after the full application of the new maintenance strategies.

References

AUMA. (2017). Electric Actuators.

Besterfield, D. (2005). Total Quality Management. Pearson Education.

Ouma, V., Osama, R., Mpakani, H., Baik, J., & Gomma, M. (2015). Reliability Centered Maintenance for CVCS, Charging System. Ulsan: KINGS.

Patil, R., & Basavaraj, K. S. (2015). Failure Mode and Effects Analysis of Manually & Electrically Operated Butterfly Valve. ResearchGate.

Reena, P., & V. V. (2013). Application of Reliability Analysis for Validating the Results obtained by Failure Mode and Effects Analysis for Air Conditioner. International Journal of Advancements in Research & Technology, 2278-7763.

TLV. (2017). Types of Manual Valves. Retrieved from http://www.tlv.com/global/TI/steam-theory/types-of-valves.htm