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The Contribution Of the Health Asset on Extend of the Life Cycle and Optimize the Cost of the Substation Equipment

Khalid M. Al-Zarfi
National Grid SA
Asset Maintenance Department Dammam
Elkhabar city
Email: 47522@ngrid.sa

Abdulaziz Marzouq Al-Furaidi
National Grid SA
Asset Maintenance Department- Hail & North East
Hail city
Email: AMFuraidi@ngrid.sa

***Abstract:*—The number of the assets that Saudi Electricity Company/National Grid hold have increased tremendously and that increase came from the government spending on the infrastructure. Saudi Electricity Company Shall introduces a tool that show the health of its own assets and that tool is the asset health indices. This tool is going to be an experimental and it is going to highlight the number of the outages for each asset that occurred in 2014 based on the failure mode of each substation equipment's and compare those equipment's on the three departments in Saudi Arabia and they are: (Dammam, Hail & North East, and Qassim) and this is the aim of this paper. Assets health indices are going to introduce different types of assets that Saudi Electricity company/National Grid hold from Power Transformer, GIS, bus bar, etc. The asset health indices could be used as a strategic planning tool to help the maintenance planning during the preventative maintenance of an asset to increase it or decrease the frequency and it could be used as a strategic decision making tool it help the top management on the replacement of an asset. This paper is going under the asset management for power systems on substation life cycle cost optimization.**

***Keywords*—health asset, life cycle, power substation, maintenance planning, cost optimization.**

I. INTRODUCTION

Substation plays an important role in the power system, it is a connection point between generation and distribution in one hand and there are some bulk customers are connected directly to the substation. So based on that, the reliability of the substation become so crucial for the maintenance and to lower the amount of the outages as much as possible to increase the reliability of the power system. “The purpose of the assessment should be clearly evident as this may affect the choice of which method is used to determine reliability. A method may look at how substation reliability affects the overall system reliability, how the system reliability affects substation reliability” [1]. “Reliability Improvement Strategy has to be developed for each utilities depending upon their requirements” [2].

Moreover, substation contains a lot of equipments such as: power transformer, gas insulated substation (GIS), outdoor substation, oil circuit breaker, bus bar, Reactive equipment such as: capacitor bank & shunt reactor. The total number of the substations at Dammam Department 38, the total number of the substations at Hail & North East Department are 37 and the total number of the substations at Qassim Department are 50. Dammam Department have varieties of voltage levels and they start from: 69KV,115KV, 230KV and 380KV and Hail & North East Department and Qassim Department have three voltage levels and they are: 66KV,132KV and 380KV. In addition, the weighted percentage of outages and their total number for the three Departments, the weighted percentage of outages causes and sub-causes and their total occurrence for the three Departments , the repetitive outages for the three Departments and calculate the MTBF for them, and one of the Company KPI such as (FOFI – SS) to show the reliability for the three Departments.

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Abbreviations:

- DAMD: Dammam Assists Maintenance Department.
- QAMD: Qassim Assists Maintenance Department.
- HAMD: Hail Assists Maintenance Division.
- NEAMD: Northeast Assists Maintenance Division.
- IEEE Institute of Electrical and Electronics Engineers.
- SVC: Static VAR Compensator.
- FOFI-SS: Forced Outage Frequency Index for Substations Equipment. [3].
- MTBF: Mean time between failure. [7 & 8].

II. DEFINITIONS

There are some terms have been mentioned in this paper need to be defined as the following:

- FOFI-SS: Forced Outage Frequency Index For Substations Equipment Frequency of equipment forced outages of transformers, reactive equipment & buses in substations for a specified period of time and calculated by the following formula $= \frac{\sum \{ \text{Substation Equipment Unplanned Outage Events} \} \times 100}{\text{Total No.of Substation Equipment)}}$ [3].
- On 2008, the North American Electric Reliability Corporation (NERC) has defined reliability as "Adequacy is the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components". [4].
- November 2012, APA Evaluation of Data Submitted in APPA's 2011 Distribution System Reliability & Operations Survey has defined reliability "from a systems engineering perspective, is the ability of an electric system to perform its functions under normal and extreme circumstances". [5].
- Reliability is the probability of a device or system performing its function adequately, for the period of time intended, under the operating conditions intended". [6].
- MTBF: Mean time between failure is the arithmetic mean (or average) time between failures of a given device or system and is normally measured in hours. This statistical value is meant to represent the average amount of time that will pass between random failures for a large sample over a long period of time for a given component. λ = total number of failures per year for each equipment/ the running time. MTBF = $1/\lambda$. [7 & 8].

III. LIMITATIONS

There are some limitations of this paper are going to follow and they are:

1. The substation equipments this paper are going to focus on are: power transformer, gas insulated substation (GIS), outdoor substation, oil circuit breaker, bus bar, Reactive equipment such as: capacitor bank & shunt reactor.
2. This paper is going to ignore the bus bar configurations.
3. This paper is going to cover the following voltage range as the following: 66KV, 69KV, 115KV, 132KV,230KV and 380KV.
4. There are a lot of KPIs and each utility have its own KPIs.
5. There is no common definition for reliability.

IV. THE IMPORTANCE OF THE RELIABILITY INDICES

1. It's a monitoring tool: it is easy for the top management to monitor the preventive and corrective maintenance through a reliability indices. If the reliability of the indices improved that mean the maintenance are doing good. In other hand, if the reliability indices are falling down or (decreased, or decline) then the maintenance is not doing a good job.
2. Measurement tool: it measures the performance of each department alone, the sector or between different sectors.
3. A Communication tool: between the top management and different maintenance areas and sectors.
4. A planning tool: it is a useful tool to plan if any asset that need to be replaced.
5. A performance indicator: the company could assign a KPI for each or for each business line that is going to tell the top management which sector need to be improved or business line.

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V. RELIABILITY INDICES FOR SUBSTATION

There are some of the reliability substation indices are going to be shown as the following: 1) The weighted percentage for the outages and their total number for the three departments. 2) The weighted percentage of the main Causes and Sub-Causes that lead to outages and their total number. 3) The repetitive outages and The MTBF Calculations for the three department. 4) Reliability of the three departments substation & FOFI-SS.

1) THE WEIGHTED PERCENTAGE FOR THE OUTAGES AND THEIR TOTAL OUTAGES:

In 2014, Dammam Department had 100.00% weighted percentage for 27 outages and they were divided as the following: the weighted percentage of buses bar was 26.63% and their total outages was 8, the weighted percentage of capacitor bank was 14.81% and the their total outages was 4 and the weighted percentage outage for Transformer was 55.56% and their total outages was 27. For more illustration refer to table 1 and figure 1.

TABLE 1: ILLUSTRATION OF THE WEIGHTED PERCENTAGE OUTAGES & THEIR TOTAL FOR DAMMAM DEPARTMENT IN 2014

EQUIPMENT	WEIGHTED PERCENTAGE OUTAGES	TOTAL Outages
Buses Bar	**29.63%**	**8**
Capacitor Bank	**14.81%**	**4**
Transformers	**55.56%**	**15**
Total	**100.00%**	**27**

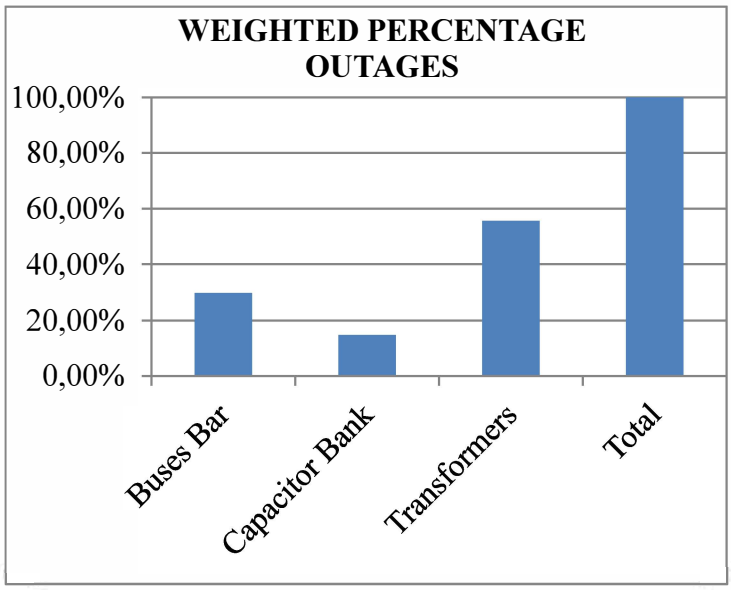

Fig. 1: Illustration of the weighted percentage and the total outages for Dammam Department in 2014

In 2014, Hail & North East Department had 100.00% weighted percentage for 15 outages and they were divided as the following: the weighted percentage of bus bar was 13.33% and their total outages was 2, the weighted percentage of the shunt reactor was 13.33% and the their total outages was 2 and the weighted percentage outage for Transformer was 73.33% and their total outages was 11. For more illustration refer to table 2 and figure 2.

TABLE 2: ILLUSTRATION OF THE WEIGHTED PERCENTAGE OUTAGES & THEIR TOTAL FOR HAIL & NORTH EAST DEPARTMENT IN 2014

EQUIPMENT	WEIGHTED PERCENTAGE OUTAGES	TOTAL Outages
Buses Bar	13.33%	2
Shunt Reactor	13.33%	2
Transformers	73.33%	11
Total	100.00%	15

In 2014, Qassim Department had 100.00% weighted percentage for 43 total outages and they were divided as the following: the weighted percentage of buses bar was 11.63% and their total outages was 5, the weighted percentage of shunt reactor was 6.98% and the their total outages was 3, the weighted percentage of the SVC was 30.23% and their total outages was 13 and the weighted percentage outage for Transformer was 51.16% and their total outages was 22. For more illustration refer to table 3 and figure 3.

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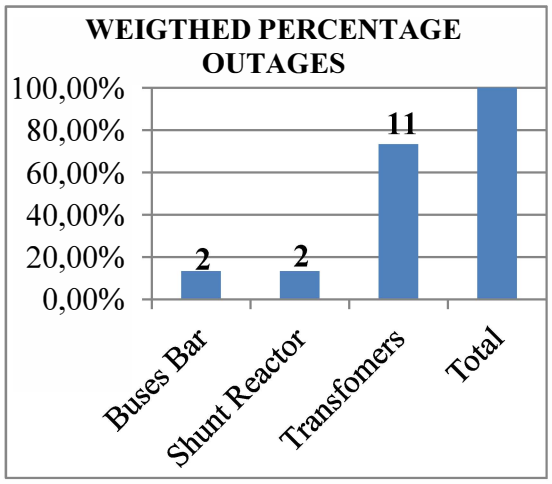
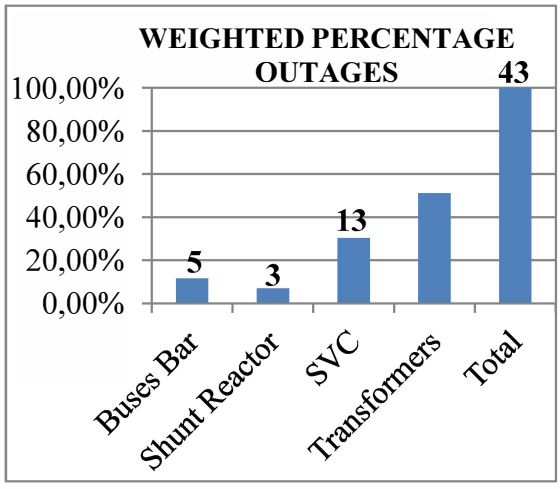


Fig. 2: Illustration of the weighted percentage outages and their total for hail and North East Department in 2014

TABLE 3: ILLUSTRATION OF THE WEIGHTED PERCENTAGE OUTAGES & THEIR TOTAL FOR QASSIM DEPARTMENT IN 2014

EQUIPMENT	WEIGHTED PERCENTAGE OUTAGES	Total Outages
Buses Bar	11.63%	5
Shunt Reactor	6.98%	3
SVC	30.23%	13
Transformers	51.16%	22
Total	100.00%	43



2) The weighted percentage of the main Causes and Sub-Causes that have lead to the outages and their total number:

In 2014, the main causes and the sub-causes of the outages in Dammam Department have lead to the outage was 100.00% weighted percentage and their Total Times of Occurrence was 53 as main causes and sub-causes and they are break down into the following: the Equipment Problems – Buchholz Operation weighted percentage was 3.77% and their Total Times of Occurrence was 2, the Equipment Problems – Component Failure weighted percentage was 15.09% and the their Total Times of Occurrence was 8, the Equipment Problems – Oil/Gas Leakage weighted percentage was 3.77% and their total number was 2, the Equipment Problems - Totals weighted percentage was 22.64% and their Total Times of Occurrence was 12, the Human Error - Misoperation of a Device/Equip. weighted percentage was 15.09% and the their Total Times of Occurrence was 8, the Human Error – Others weighted percentage was 1.89% and their Total Times of Occurrence 1, the Human Error – Totals weighted percentage was 16.98% and their Total Times of Occurrence was 9, the Protection Problems weighted percentage was 5.66% and their Total Times of Occurrence was 3, the Protection Problems - Defective Relays weighted percentage was 1.89% and their Total Times of Occurrence was 1, the Protection Problems – Unknown weighted percentage was 1.89% and their Total Times of Occurrence was 1, the Protection Problems - Totals weighted percentage was 9.43% and their Total Times of Occurrence was 5, the System Problems weighted number was 1.89% and their Total

Equipment Problems - Buchholz Operation	3.77%	2
Equipment Problems - Component Failure	15.09%	8
Equipment Problems - Oil/Gas Leakage	3.77%	2
Equipment Problems - Totals	22.64%	12
Human Error - Misoperation of a Device/Equip.	15.09%	8
Human Error - Others	1.89%	1
Human Error - Totals	16.98%	9
Protection Problems	5.66%	3
Protection Problems - Defective Relays	1.89%	1
Protection Problems - Unknown	1.89%	1
Protection Problems - Totals	9.43%	5
System Problems	1.89%	1
Totals	100.00%	53

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Times of Occurrence was 1. For more illustration refer to table 4 and figure 4.

TABLE 4: ILLUSTRATION OF THE MAIN CAUSES AND SUB – CAUSES FOR THE EQUIPMENT OUTAGES OCCURRENCE FOR DAMMAM DEPARTMENT IN 2014

Equipment Problems - Component Failure	8.14%	7
Human Error - Misoperation of a Device/Equ	5.81%	5
Human Error - Others	2.33%	2
Human Error - Totals	8.14%	7
Miscellaneous	2.33%	2
N/A	58.14%	50
Protection Problems	1.16%	1
Protection Problems - Incorrect Relay Settings	3.49%	3
Protection Problems - Loss AC/DC Voltage	1.16%	1
Protection Problems - Unknown	1.16%	1
Protection Problems - Totals	6.98%	6
System Problems - Others	1.16%	1
Totals	100.00%	86

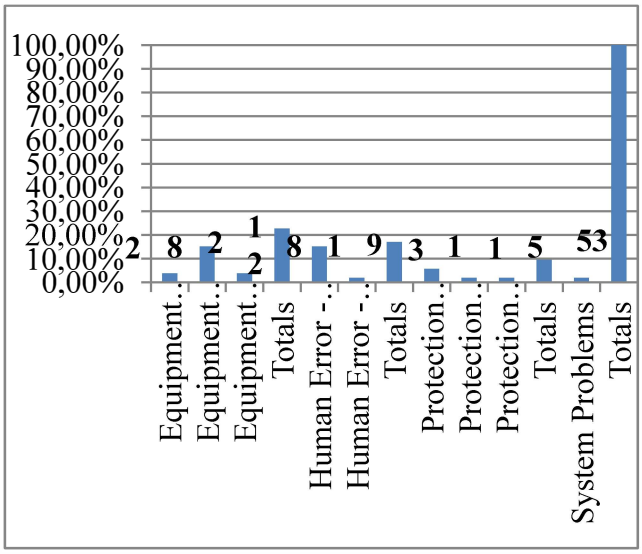

Fig. 4: Illustration of the main causes and sub – causes for the equipment outages occurrence for Dammam Department in 2014

In 2014, the main causes and the sub-causes of the outages in Hail & North East Department have lead to the outage was 100.00% weighted percentage and their Total Times of Occurrence was 86 as main causes and sub-causes and they are break down into the following: the equipment problems – Component Failure weighted percentage was 8.14% and their Total Times of Occurrence was 7, the Human Error - Misoperation of a Device/Equip. weighted percentage was 5.81% and the their Total Times of Occurrence was 5, the Human Error – Others weighted percentage was 2.33% and their Total Times of Occurrence was 2, the human error totals weighted percentage was 8.14% and their Total Times of Occurrence was 7, the miscellaneous weighted percentage was 2.33% and their Total Times of Occurrence was 2, the N/A weighted percentage was 58.14 and their Total Times of Occurrence was 50, the Protection Problems weighted percentage was 1.16% and their Total Times of Occurrence was 1, the Protection Problems – Incorrect Relay Settings weighted percentage was 3.49% and their Total Times of Occurrence was 3, the Protection Problems – Loss AC/DC voltage weighted percentage was 1.16% and their Total Times of Occurrence was 1, the Protection Problems – Unknown weighted percentage was 1.16% and their Total Times of Occurrence was 1, the Protection Problems totals weighted percentage was 6.98% and their Total Times of Occurrence was 6, the System Problems - Others weighted number was 1.16% and their Total Times of Occurrence was 1. For more illustration refer to figure 5 and table 5.

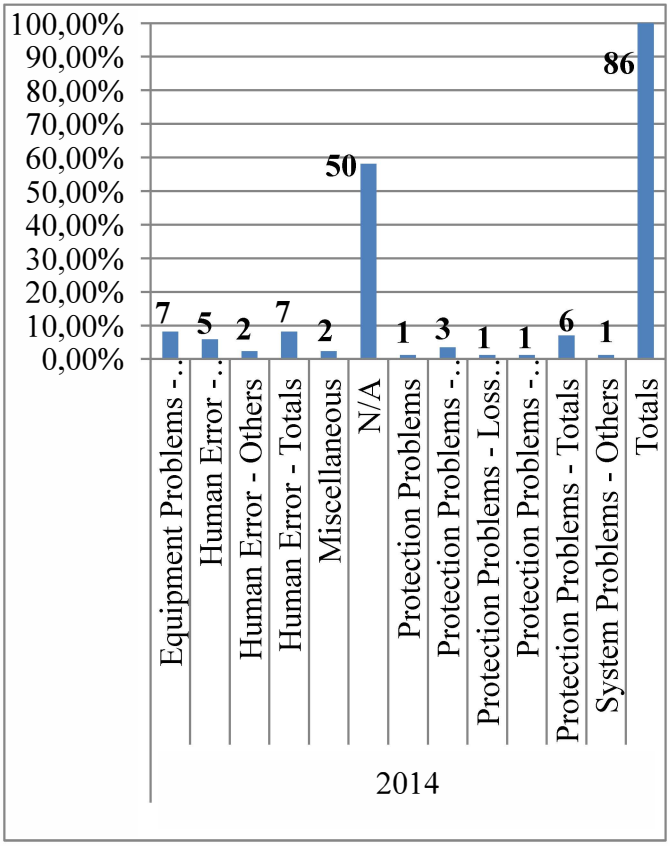

Fig.5: Illustration of the main causes and sub – causes for the equipment outages occurrence for Hail & North East Department in 2014

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TABLE 5: ILLUSTRATION OF THE MAIN CAUSES AND SUB – CAUSES FOR THE EQUIPMENT OUTAGES OCCURRENCE FOR HAIL & NORTH EAST DEPARTMENT IN 2014

Equipment Problems - Buchholz Operation	2.44%	2
Equipment Problems - Component Failure	13.41%	11
Equipment Problems - Totals	15.85%	13
Human Error - Misoperation of a Device/Equ	12.20%	10
Human Error - Others	1.22%	1
Human Error - Totals	13.41%	11
Miscellaneous	4.88%	4
Miscellaneous - Unknown	1.22%	1
Miscellaneous - Totals	6.10%	5
N/A	3.66%	3
Protection Problems	2.44%	2
Protection Problems - Defective Relays	1.22%	1
Protection Problems - Incorrect Relay Settings	2.44%	2
Protection Problems - Unknown	6.10%	5
Protection Problems - Totals	12.20%	10
System Problems - Others	1.22%	1
Totals	100.00%	82

In 2014, the main causes and the sub-causes of the outages in Qassim Department have lead to the outage was 100.00% weighted percentage and their Total Times of Occurrence was 82 as main causes and sub-causes and they are break down into the following: Equipment Problems - Buchholz Operation weighted percentage was 2.44% and their Total Times of Occurrence was 2, the Equipment Problems – Component Failure weighted percentage was 13.41% and their Total Times of Occurrence was 11, the Equipment Problems – Totals weighted percentage was 15.85% and their Total Times of Occurrence was 13, the Human Error - Misoperation of a Device/Equip. weighted percentage was 12.20% and the their Total Times of Occurrence was 10, the Human Error – Others weighted percentage was 1.22% and their Total Times of Occurrence was 1, the human error totals weighted percentage was 13.41% and their Total Times of Occurrence was 11, the Miscellaneous weighted percentage was 4.88% and their Total Times of Occurrence was 4, the Miscellaneous – Unknown weighted percentage was 1.22% and their Total Times of Occurrence was 1, the Miscellaneous – Totals weighted percentage was 6.10% and their Total Times of Occurrence was 5, the N/A weighted percentage was 3.66% and their Total Times of Occurrence was 3, the Protection Problems weighted percentage was 2.44% and their Total Times of Occurrence was 2, the Protection Problems – Defective Relays weighted percentage was 1.22% and their Total Times of Occurrence was 1, the Protection Problems – Incorrect Relay Settings weighted percentage was 2.44% and their Total Times of Occurrence was 2, the Protection Problems - Unknown weighted percentage was 6.10% and their Total Times of Occurrence was 5, the Protection Problems – Totals weighted percentage was 12.20% and their Total Times of Occurrence was 10, the System Problems - Others weighted percentage was 1.22% and their Total Times of Occurrence was 1. For more illustration refer to table 6 and figure 6.

TABLE 6: ILLUSTRATION OF THE MAIN CAUSES AND SUB – CAUSES FOR THE EQUIPMENT OUTAGES OCCURRENCE FOR QASSIM DEPARTMENT IN 2014

Equipment Problems - Buchholz Operation	2.44%	2
Equipment Problems - Component Failure	13.41%	11
Equipment Problems - Totals	15.85%	13
Human Error - Misoperation of a Device/Equ	12.20%	10
Human Error - Others	1.22%	1
Human Error - Totals	13.41%	11
Miscellaneous	4.88%	4
Miscellaneous - Unknown	1.22%	1
Miscellaneous - Totals	6.10%	5
N/A	3.66%	3
Protection Problems	2.44%	2
Protection Problems - Defective Relays	1.22%	1
Protection Problems - Incorrect Relay Settings	2.44%	2
Protection Problems - Unknown	6.10%	5
Protection Problems - Totals	12.20%	10
System Problems - Others	1.22%	1
Totals	100.00%	82

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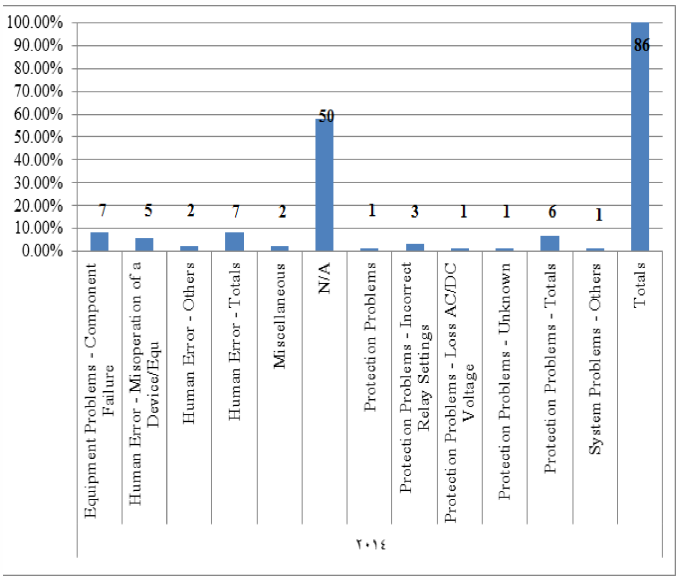

Fig.6: Illustration of the main causes and sub – causes for the equipment outages occurrence for Qassim Department in 2014

1) THE REPETITIVE OUTAGES AND THE MTBF CALCULATIONS FOR THE THREE DEPARTMENT:

To calculate the MTBF for the three department the following formula are going to be used:

λ = total number of failures per year for each equipment/ the running time. Where is N is going to be the total running per which is going to be equal to = 8,760 hours per year.

MTBF = 1/ λ.

For Dammam department had a 380KV & 230KV power transformer had three outages in 2014 and after the following two formula's have been applied the following result are go to be:

λ = 3 failures/8,760 running time (hours) = 3.43X10-4 failure/hour.

MTBF = 1/ 3.43X10-4 failure/hour = 2,924 hours.

Each of those two power transformers are expected to fail every 2,924 hours. (once each four month/Once each quarter).

For Hail & North East department had a 132KV power transformer had three outages in 2014 and after the following two formula's have been applied the following result are going to be:

λ = 3 failures/8,760 running time (hours) = 3.43X10-4 failure/hour.

MTBF = 1/ 3.43X10-4 failure/hour = 2,924 hours.
This power transformer are expected to fail every 2,924 hours. (once each four month/Once each quarter).

For Qassim Department had a 132KV SVC thirteen outages in 2014 and after the following two formula's have been applied the following result are going to be:
λ = 13 failures/8,760 running time (hours) = 14.84X10-4 failure/hour.
MTBF = 1/ 14.84X10-4 failure/hour = 673.85hours.
This SVC are expected to fail every 673.85hours. (once 28 days).

2) RELIABILITY OF THE THREE DEPARTMENTS SUBSTATION & FOFI-SS:

The repetitive outages for the three departments as the following:
In 2014, there are 10 repetitive outages have occurred in 10 substation for Dammam Department as the following statistics is going to show the reliability of the substation as the following:
10 repetitive outages have occurred in substation out of 38 which equal to: 26.32%.
In 2014, there are 14 repetitive outages have occurred 14 substation for Hail & North East Department as the following statistics: 14 repetitive outages out of 37 which equal to: 37.84%.
In 2014, there are 16 repetitive outages have occurred in 16 substation for Qassim Department as the following statistics: 16 repetitive outages out of 50 substation which equal to: 32%.
In 2014, FOFI – SS for Dammam Department was 10.989.
In 2014, FOFI – SS for Hail & North East Department was 16.000.
In 2014, FOFI – SS for Qassim Department was 20.000.
The differences between Dammam Department FOFI – SS & Hail & North East Department was 31.32% increase in FOFI – SS Hail & North East Department.
The differences between Hail & North East Department FOFI – SS & Qassim Department was 20.00% increase in FOFI – SS of Qassim Department.
The differences between Dammam Department FOFI – SS & Qassim Department was 45.055% increase in FOFI – SS Qassim Department.

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VI. FINDINGS

1. In 2014, Dammam Department the biggest weighted percentage outage for Transformer was 55.56% and their total outages was 27.
2. In 2014, Hail & North East Department the biggest weighted percentage outage for Transformer was 73.33% and their total outages was 11.
3. In 2014, Qassim Department the biggest weighted percentage outage for Transformer was 51.16% and their total outages was 22.
4. In 2014, Dammam Department the biggest cause and sub-cause was the Equipment Problems - Totals weighted percentage was 22.64% and their Total Times of Occurrence was 12.
5. In 2014, Hail & North Department the biggest cause and sub-cause was the N/A weighted percentage was 58.14 and their Total Times of Occurrence was 50.
6. In 2014, Qassim Department the biggest cause and sub-cause was 13.41% and their Total Times of Occurrence was 11.
7. In 2014, Dammam Department the MTBF for two power transformers (230KV &380KV) was expected to fail once each quarter/ each four months.
8. In 2014, Hail & North East the MTBF for one 132KV power transformer was expected to fail once four quarter/ each four months.
9. In 2014, Qassim Department the MTBF for one 132KV SVC was expected to fail each 28 days.
10. In 2014, FOFI – SS for Dammam Department was 10.989.
11. In 2014, FOFI – SS for Hail & North East Department was 16.000.
12. In 2014, FOFI – SS for Qassim Department was 20.000.
13. The differences between Dammam Department FOFI – SS & Hail & North East Department was 31.32% increase in FOFI – SS Hail & North East Department.
14. The differences between Hail & North East Department FOFI – SS & Qassim Department was 20.00% increase in FOFI – SS of Qassim Department.
15. The differences between Dammam Department FOFI – SS & Qassim Department was 45.055% increase in FOFI – SS Qassim Department.

VII. CONCLUSION

The following paper have started by shown the importance of the substation and the different voltage levels for the three departments. Then, this paper have shown some of the Abbreviations of the terms have been mentioned in this paper. After that, this paper to define some of the terms have been mentioned in this paper. Next, there were some Limitations this paper have to follow. Furthermore, this paper have shown the Importance of the Reliability Indices. Moreover, this paper have shown the Reliability Indices for Substation and they includes the followings: 1) The weighted percentage for the outages and their total number for the three Departments, 2) The weighted percentage of the main Causes and Sub-Causes that lead to outages and their total number, 3) The repetitive outages and The MTBF Calculations for the three Department and 4) Reliability of the three Departments substation & FOFI-SS. Finally, a lot of comparison have been made between the three Departments in the term of outages, causes and sub-causes, MTBF and FOFI – SS for the three Departments and the differences between them.

VIII. RECOMMENDATIONS

There are some recommendations this paper are going to show as the following:

1. The equipments outages can't be avoided but it could be reduced.
2. All the three Departments have to increase their preventative maintenance to reduce the outages of the equipments.
3. The causes and the sub-causes for the equipment outages occurrence for the three Departments shall be reduced.
4. There are a heavy training shall be conducted to reduce the human errors.
5. Deep investigation's shall be conducted to reduce the outages for power transformer and the reactive equipments SVC.
6. The bushing of the power transformer and the reactive equipments shall be coated by RTV coating to reduce the effective of the dust and humidity for the three Departments.
7. The repetitive outages and The MTBF Calculations for the three Departments shall be reduced.

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