SUBSTATION MAINTENANCE PRACTICES IN A SAUDI ELECTRIC UTILITY

Ali Ahmad Al-Al-Shaikh[1] and Ibrahim M. El-Amin[2]

1:Engineer, Engineering Design Services, Saudi Electricity Company,
Eastern Branch Region
2: Associate Professor, Electrical Engineering Department, KFUPM

E-mail: imelamin@kfupm.edu.sa

ABSTRACT

The continuity of electric supply is an important requirement in modern societies. Electric utilities are thus required to develop and maintain sound power networks. The maintenance of the electrical equipment in substations plays a major role in this requirement. Failures of equipment may precipitate outages for large service areas and can cost millions of dollars in lost revenues, and damages. The paper presents the results of a survey regarding substation maintenance practices in a Saudi Arabian electric utility. The results of the survey revealed that the utility follows a time-based maintenance concept. It also indicted that many routine tests and inspection tend to provide hundred percent satisfactions. This means that there are opportunities for reducing or canceling some of the non-essential tests. The paper gave approximate monetary savings that may result if the concept of maintenance is changed.

Keywords: *substation maintenance, time-based maintenance, reliability-centered maintenance, and transformer tests.*

الملخص

أن استمرارية التيار الكهربائى تعتبر من ضروريات الحياة العصرية وعليه فان شركات الكهرباء مطالبة بتصميم وتشغيل شبكات موثوقة الاعتمادية. ان صيانة الاجهزة بمحطات الكهرباء تلعب دورا أساسيا لتلبية هذه الاحتياجات. تقدم هذه الورقة نتائج مسح عن النظم المتبعة فى صيانة محطات الكهرباء باحد فروع الشركة السعودية للكهرباء. بينت نتائج البحث ان السركة تتبع برامج صيانة متطلبات زمنية و روتينة. بينت الدراسة كذلك أن هنالك عدة اختبارات بنتائج مطابقة تماما للتوقعات. مما يوحى أن هنالك عدة اختبارات و قياسات يمكن أن تلغى أو أن يقال عددها. أوضحت الورقة كذلك انه يمكن الحصول على وفر نقدى فى حالة تغيير النظم المتبعة فى الصيانة الروتينية.

1. INTRODUCTION

An electric utility is required to provide customers with electric energy as economically as possible and with acceptable degrees of reliability and quality. Supply quality and reliability have become important tasks in power system operation and maintenance. System reliability depends on components' operational condition. The condition of a component directly affects system condition resulting in equipment and system failures. For this reason, the condition of power equipment is an area of great concern for all electric utilities. Failures of equipment may precipitate outages for large service areas and can cost millions of dollars in lost revenues, and damages. The ability to foresee a problem, or at least identify the existence of a questionable condition, which in turn may lead to failure, is highly desirable [Levi, 1992], [Kaminaris, 1991], [Kaminaris, 1993], [Lin, 1992]. Thus the operation and maintenance should be done in an efficient and optimal way so to reduce the number of outages. Substation maintenance, which is the concern of this work, is essential to keep the equipment in good condition leading to more reliable operation of the system with the optimal use of resources. Because of system complexity, the generation, transmission and distribution components must be evaluated on several levels to simplify the planning, operation and maintenance. In particular, substation maintenance is one part of the overall maintenance program of the electric power system. The paper presents the results of a survey regarding substation maintenance practices in a Saudi Arabian electric utility. Section Two of the paper gives a brief review of substation maintenance practices as reported in literature. Section Three of the paper is devoted to the details of the survey and the discussion of the results. Concluding remarks are included in section four.

2. SUBSTATION MAINTENANCE

A substation contains a number of electrical devices and equipment. It is essentially made of power transformers, switchgear, protective and measuring instruments. The Substation equipment must receive a high standard of maintenance in terms of quality and not quantity. The current practices of substation maintenance are basically following the principle of time-based preventive maintenance (TBPM), which is doing routine checks and inspections at fixed intervals. Recently, the maintenance philosophy, shifted towards applying new advanced methods, such as, predicative maintenance and reliability-centered maintenance (RCM).

Substation performance and reliability are critical for the operation of the power system. Substations, operated and maintained in a cost effective manner, can provide the competitive advantages to the utilities that seek a reduction in the overall costs of system operation. This is especially true under the new deregulated competitive environment. To achieve these advantages, substations must operate effectively while minimizing and reducing costly maintenance [Maintenance, 2001]. The only way to permanently reduce maintenance costs is to reduce the need for maintenance. Reducing the need for maintenance comes from diligent

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efforts to improve materials, designs, and operation [Maintenance, 2001]. The improvement of substation reliability has its price as it implies higher investment costs. To improve the reliability of electric supply it is important to reduce the time needed for the restoration of the ability of supplying power after failure of components or due to general maintenance work [Nahman, 991].

The deterioration of substation's electrical equipment is natural and it begins as soon as the equipment is installed. If the deterioration is not checked it can cause electrical failures and malfunctions. With a well-organized preventive Maintenance (PM) program, potential hazards that can cause failures of equipment or interruptions of electrical services can be discovered and corrected. However, it is inevitable that some failures will occur [Gill, 1998].

The goal of the substation PM program is to ensure that all the substation's equipment will function properly when called upon to operate. All of the diagnostic testing and maintenance work, necessary to achieve this goal, must be performed in as efficient manner as possible [Saudi, 1998].

Traditionally, maintenance philosophy for substations has been to perform work on a time-based requirement, i.e. planned (scheduled) maintenance (doing routine tests and inspections at fixed intervals), without any regard to the actual in-service duty or the condition and performance of the equipment [Pang, 1997]. However, maintenance is changing from a concept focused on how well a process or an individual machine works to a more complex concern with safety, quality, commercial availability, and cost efficiency. Also, computerized maintenance management systems are changing from programs constructed to control the worker to integrated maintenance information systems that support self-managing maintenance [Maintenance, 2001]. There has been a growing tendency towards predictive maintenance philosophies. That is, maintenance should only be performed when required and according to maintenance priorities.

Nowadays, additional competition and growing complexity in power systems as well as a need for high service reliability and low production costs, are provoking additional interests in automatic scheduling techniques for maintenance of generators, transmission and related equipment capable of providing optimal maintenance schedules [Marwali, 1998], [Smith, 1993], [Patton, 1983].

This paper concerns the practices adopted by Saudi electric utilities for substation maintenance.

3. SURVEY OF SUBSTATION MAINTENANCE PRACTICES

3.1 Objective of Survey

The authors conducted a survey of substation maintenance practices in a Saudi electric utility. The main objective is to understand the existing maintenance practices, programs and the scheduling procedures within electricity utilities. This is achieved through data collection from an electric utility. The data is collected through surveys and questionnaires. The survey lasted for around three months for twelve 69/13.8kV substations.

3.2 Survey Sample

A substation contains many components. Chief among them is the power transformer. Other components are the On Load Tap Changers (OLTC), high and low voltage circuit breakers. Station service transformers, storage batteries, switchgear busbars, automatic transfer switches. The survey consists of ten parts for each substation. Each part concentrates on one or two equipment's tests and inspections. The substation name, location and date of the data collection were first recorded. The following were recorded, the duration of each test (in hours), the frequency of each test (in months), number of data samples taken, how many time the samples taken are acceptable?

The tests and inspections in the survey were chosen based on the PM program of the utility. The following tests and inspections were considered for the power transformer.

1. Oil quality test
2. Overall power factor test
3. Megger test
4. Excitation currents test
5. Power factor test to bushings
6. Dissolved gas in oil analysis test (DGA test)
7. Calibration of oil temperature indicators of the transformer
8. Calibration of oil temperature indicators switch settings
9. Calibration of winding temperature indicators of the transformer
10. Calibration of winding temperature indicators switch settings
11. Dielectric breakdown test of the insulating oil (at field)
12. Main tank Buchholz relay test
13. Transformer pressure relief valve test
14. Insulation resistance test
15. General Inspection and Checks which include: cleaning the bushings, checking or replacing silica gel, checking any oil leakage, checking fans and pumps motors, checking the control circuits, and others where applicable

Several tests are also performed on the remaining substation equipment. The details of the tests are not given here [Al-Shaikh, 2001].

3.3 Results and Remarks

The survey is intended to understand the current practices and procedures and to give some recommendations for improving the maintenance work in these systems if any. In the following, the survey results and analysis are pointed out:

Part 1: Survey Results of Transformer Tests

The transformer is the most expensive and important equipment in the substation. Transformer maintenance should be done to keep it in service. However the maintenance tests must be justified and are according to the actual needs. The survey results for transformer tests are given in Table 3.1. The key findings of the results are:

- Out of fifteen different tests, eight were hundred percent satisfactory. These eight tests represent approximately half of the tests. This indicates a sign of over maintenance.
- Dielectric breakdown of insulation oil test (23 samples), insulation resistance test (28 samples) and power factor test (21 samples) are all hundred percent satisfactory. These tests must be reconsidered according to actual needs and not according to manufacturer recommendations.
- The elimination of only one test – for example the insulating resistance test – this will save (84 working hours × 4 persons = 336 working hours).
- Megger tests (12 samples) were hundred percent satisfactory. The frequency of this test must be reconsidered.

Part 2: Survey Results of On Load Tap Changer (OLTC) Tests

The results of OLTC tests, given in Table 3.2, show that out of seven different tests, six were hundred percent satisfactory of all the samples taken. Reconsidering the frequency of these tests may result in a lot of savings. For example, if the frequency of the tests is made as 72×2 = 144 months, this will save 230 working hours × 4 persons = 920 working hours.

Part 3: Survey Results of Circuit Breaker Tests - 13.8kV

Table 3.3 shows the test results on the 13.8 kV circuit breakers The survey results for 13.8kV circuit breakers indicate a need for reconsideration.

- Six out of nine tests were hundred percent satisfactory.
- Megger tests (604 samples, 1208 working hours) do not indicate any problems. The frequency of these tests should be reconsidering.
- Most of the encountered problems were in the general inspections and checks (14.91percent), which mean that they must be emphasized and considered.

Part 4: Survey Results of Circuit Breaker Tests - 69kV

Table 3.4 shows the test results on the 69 kV circuit breakers. The survey results revealed that six out of ten tests were hundred percent satisfactory. Also the Megger tests (135 samples, 405 working hours) do not indicate any problems. Most of the problems encountered were in the general inspections and checks (11.55percent) and pressure checking (7.14percent).

Part 5: Survey Results of Station Service Transformer Tests

The results show that 21.3 percent of the oil quality tests were not satisfactory. Also 11.11 percent of the ratio tests were not satisfactory. These results are considered high (under maintenance). The Megger test results show hundred percent satisfactions. The test must be reconsidered.

Part 6: Survey Results of Storage Batteries and Battery Chargers Tests

The test results show that most problems were low electrolyte level and some damaged cells (11.92 percent of general inspection and checks). For the battery chargers tests, 14.28 percent of equalizing the voltage was not satisfactory. This is a part of the general inspection and checks. The general inspection and checks must be given higher priority. For the rest of other tests, over maintenance is clear. Hence, complete reconsideration of these tests is needed.

Part 7: Survey Results of Disconnect Switch Tests – 69kV

The test results of the 69 kV disconnect survey results reveal almost no problems. The satisfaction is 97.36 percent. This may be a sign of over maintenance. These tests must be reconsidered according to actual needs.

Part 8: Survey Results of Ground Switch Tests – 69kV

The survey results indicate complete, hundred percent, full satisfactions. This a clear sign of over maintenance. The survey strongly recommends reconsidering or eliminating some of these tests, which shall save a lot time and money.

Part 9: Survey Results of Switchgear Busbars Tests – 69kV and 13.8kV

The survey results show almost no problems. The minimum satisfaction is 99.52 percent. There is a potential for substantial savings. The survey strongly recommends reconsidering or eliminating some of these tests.

Part 10: Survey Results of Automatic Transfer Switch Tests - 13.8kV

Unfortunately, the number of data samples in this part of the survey was not enough to draw any conclusion regarding the tests applied. For this reason this part is canceled.

3.4 Concluding Remarks and Recommendations

In the following, some of the key findings out of the survey are pointed out. Also, some observations, noticed during the period of collecting the data, will be mentioned.

- The maintenance program is following a TBPM concept. This type leads, usually, to over maintenance as seen by the results of the survey. Appropriate tests frequency (time intervals) between regularly performed maintenance tasks is important in achieving more reliable performance at a reasonable cost. TBPM is best suited to failures that have a clear wear-out characteristic. Hence, it is recommended to introduce the new concepts of PdM, RCM or a combination of these concepts into the maintenance program.
- Maintenance sheets are not giving specific information about the results of the tests or inspection. It should not be based on the technician opinion or judgment. There should be a clear range of accepted results and whether it passes the tests or not.
- There is no indication of installation of new equipment. There should be a form to be filled to indicate that some the equipment has been changed.
- The type and name of the applied tests are not clear and sometimes it is not mentioned.
- The technician should clearly indicate what he has done, the parts used and the time taken for the job.
- Most of equipment tests seem to have over maintenance due to the fact that they depend on time rather than a condition.
- It is very important to coordinate work between all crews to get the optimal outage plan. Good coordination was implemented and noticed.
- Adjusting the test items: adjusting or even canceling some of test items is necessary and reasonable. Determination of whether or not certain items are necessary and reasonable depends mainly upon the practice and results from the statistics.
- A much wider survey is needed. It should consider all aspects (direct or indirect), like, spare parts cost, labor cost and loss of power to customers due to outages. Such a survey will give an insight view of the maintenance programs. Based on these results, the maintenance frequency may change (increase or decrease) to reach the optimal maintenance plan.

4. CONCLUSIONS

A survey on the substation maintenance practices in a Saudi electric utility was carried out. The results of the survey revealed that the utility follows a time-based maintenance concept. It also indicted that many routine tests and inspection tend to provide hundred percent satisfactions. This means there are opportunities for reducing or canceling some of the non-

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essential tests. The paper gave approximate monetary savings that may result if the concept of maintenance is changed.

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Table 3.1: Survey Results of Transformer Tests

	Transformer Tests - 25-40MVA - 69/13.8kV	Duration of test (h)	Frequency of test (months)	Number of data samples	How many time it was?					
					OK			Not OK		
					#	Percent	h	#	Percent	h
1.	Oil quality test	Lab	12 to 42	189	180	95.24	540	9	4.76	27
2.	Overall power factor test	4	72	4	4	100	16	0	0	0
3.	Megger test	2	72	12	12	100	24	0	0	0
4.	Excitation currents test	2	72	1	1	100	2	0	0	0
5.	Power factor test to bushings	2	72	21	21	100	42	0	0	0
6.	Dissolved gas in oil analysis test (DGA test)	Lab	12 to 24	70	62	88.57	186	8	11.43	24
7.	Calibration of oil temperature indicators of the transformer	3	24	35	34	97.14	102	1	2.86	3
8.	Calibration of oil temperature indicators switch settings	3	24	29	29	100	87	0	0	0
9.	Calibration of winding temperature indicators of the transformer	3	24	35	32	91.43	96	3	8.57	9
10.	Calibration of winding temperature indicators switch settings	3	24	28	28	100	84	0	0	0
11.	Dielectric breakdown test of the insulating oil (at field)	1	72	23	23	100	23	0	0	0
12.	Main tank Buchholz relay test	2	72	1	0	0	0	1	100	2
13.	Transformer pressure relief valve test	1 to 8	72	-	-	-	-	-	-	-
14.	Insulation resistance - polarization index test	3	72	28	28	100	84	0	0	0
15.	General Inspections/Checks	-	-	120	86	71.67		34	28.33	
	Most problems are:	• Oil leaks • Changing of silica gel • Cleaning of bushings								

Table 3.2: Survey Results of On Load Tap Changer Tests

	OLTC Tests - 69kV	Duration of test (h)	Frequency of test (months)	Number of data samples	How many time it was?					
					OK			Not OK		
					#	Percent	h	#	Percent	h
1.	Transformer Turns ratio test (TTR test)	4	72	48	48	100	192	0	0	0
2.	Excitation test	2	72	24	24	100	48	0	0	0
3.	Resistor test	2	72	26	26	100	52	0	0	0
4.	Continuity test	2	72	26	26	100	52	0	0	0
5.	Quality oil test	2	72	30	30	100	60	0	0	0
6.	Dielectric test of insulating oil	2	72	28	28	100	56	0	0	0
7.	General Inspections/Checks	-	-	34	32	94.11	-	2	5.88	-

Table 3.3: Survey Results of Circuit Breaker Tests - 13.8kV

	Circuit Breakers Tests - 13.8kV	**Duration of test (h)**	**Frequency of test (months)**	**Number of data samples**	**How many time it was?**					
					OK			**Not OK**		
					#	**%**	**h**	**#**	**%**	**h**
1.	Timing test	1	48 to 72	523	523	100	523	0	0	0
2.	Contact resistance Ductor test	1	48 to 72	602	602	100	602	0	0	0
3.	Doble power factor test	3	48 to 72	-	-	-	-	-	-	-
4.	Oil quality test	Lab	48 to 72	4	4	100	8	0	0	0
5.	Megger test	2	48 to 72	604	604	100	1208	0	0	0
6.	Dielectric test of insulating oil	2	48 to 72	-	-	-	-	-	-	-
7.	Checking the pressure/moisture/ Oxygen for SF_6	2	48 to 72	50	50	100	100	0	0	0
8.	Hi-pot test	-	-	48	48	100	-	0	0	-
9.	General inspections/Checks	-	-	684	582	85.1	-	102	14.9	-
	Most problems are:	• Minor oil leaks • Compressor oil • Mechanism • Contacts • Lubrications								

Table 3.4: Survey Results of Circuit Breaker Tests - 69kV

	Circuit Breakers Tests - 69kV	Duration of test (h)	Frequency of test (months)	Number of data samples	How many time it was?					
					OK			Not OK		
					#	%	h	#	%	h
1.	Timing test	1	48 to 72	186	186	100	186	0	0	0
2.	Contact resistance Ductor test	1	48 to 72	208	208	100	208	0	0	0
3.	Doble power factor test	2	48 to 72	-	-	-	-	-	-	-
4.	Oil quality test	Lab	48 to 72	14	14	100	28	0	0	0
5.	Purity test	2	48 to 72	73	73	100	146	0	0	0
6.	Moisture content test (Dewpoint test)	2	48 to 72	4	4	100	8	0	0	0
7.	Megger test	3	48 to 72	135	135	100	405	0	0	0
8.	Dielectric test of insulating oil	2	48 to 72	104	103	99.1	206	1	0.96	2
9.	Checking the pressure/moisture/ Oxygen for SF_6	2	48 to 72	56	52	92.8	104	4	7.14	8
10.	General inspections/Checks	-	-	251	222	88.4	-	29	11.55	-
	Most problems are:	• Oil leaks • Mechanism • Contacts • Lubrications								

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