Investigating the effect of distribution transformers on reliability of distribution network of Tehran central region

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***Abstract*— Due to a great impact of distribution systems reliability on power cost and its dependence on customers will, it is one of the most important topics in power industry. Almost 80 to 90 percent of problems of system reliability is related to distribution systems. A correct evaluation and enhancement of distribution systems reliability are important keys to increase customers trust. Transformers are crucial part of distribution systems, so their fix up and maintenance are vital to enhance system reliability. This paper investigates the causes of transformers trips in recent decade in one of the central regions of Tehran and also surveys the emergency and scheduled trips of transformers from 2000 till 2009, accompanied by calculation of reliability indices for mentioned network and some suggestions for effective maintenance and service.**

Keywords- Reliability; distribution transformer; emergency trip ; scheduled trip; service and maintenance

I. INTRODUCTION

Increasing growth of power consumption and significance of electric energy in social welfare makes it difficult to stand against peoples' expectation for secure power. As the last connection ring of generation and transmission of power to users, power distribution companies play an important role in constant power delivery to the customers.

Great distribution system dimensions, number and variety of equipment quality, variety of outage costs, direct communication with customers and their different expectations from outage quantity, fault concentration, lack of information, exact time required for coordination with urban organizations in scheduling and operation, requirement for different methods of contingency management are the special characteristics of distribution networks that increases the requirement for intelligent reliability management and investment management.

Step-down transformers are important parts of distribution networks. With respect to significance of transformers and high investment costs on distribution substations, analysis of outputs and outage of transformers can play an important role in increasing reliability and decreasing the disadvantages of their outages [1,2]. Suggesting technical and economic solutions based on statistical data can help removing or decreasing such events.

Usually two methods are used for evaluation of reliability of distribution networks: 1) Evaluation based on history 2) Predictive evaluation.

In this paper, Reliability coefficients of transformers have been calculated by investigating emergency and scheduled trips in a ten year history in one of Tehran central areas, some methods for improving these coefficients and some suggestions for effective service and maintenance have been presented.

II. SPECIFICATIONS OF STUDIED REGION

A region which has been chosen for investigation of reliability indices is one of the central regions of Tehran. This region is shown in Fig. 1.

The region area is $16km^2$ and consists of 225000 customers. This number of customers is divided into four groups which are: 115000 customers with commercial applications, 98000 customers with home applications, 10000 customers with office applications and 2000 customers with industrial applications. Specification of studied region and distribution network is expressed in Table 1 [3].

III. Statistical Investigation of Trips of Distribution Network Transformers

By investigating trips of distribution network transformers of the central regions of Tehran in last ten years, following conclusions can be drawn as causes of them:[4]

-Increase of temperature degree
-Fault of transformer interconnection cables
-Operation of protection system due to sudden load increase
-Fault of innovative insulators
-Malfunction of protection systems
-Tap-changer problems
-Outer cause such as material hitting, water leakage
-Faults of surge arrestor

Table 2 shows that in recent decade the number of emergency trips of transformers in one region is 2303 which in addition to economic disadvantages, it has also caused some social problems. These statistics reveal the importance of planning for reliability enhancement.

Table 3 shows the scheduled trips of transformers in the same region for purpose of fixing up and maintenance. Almost the taken measures in the scheduled trips of transformers are protection systems check and so on.

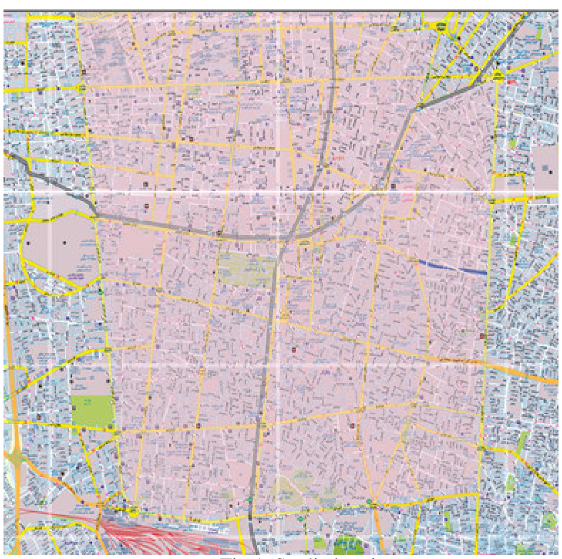

Fig 1. Studied region

Table 1. Specification of studied region

Number of 63Kv substations	16
Number of 20Kv feeders	96
20Kv overhead network length	0
20Kv underground network length (Km)	289
Low-voltage overhead network length(Km)	168
Underground low voltage network length (Km)	760
Number of 20Kv transformers	780
Capacity of 20Kv transformers (KVA)	653800

Table 2. emergency trips in studied region

Year	Number Of 20Kv Trans	Capacity Of 20Kv Trans (KVA)	Number Of Emergency trip	Average Of Trip (trans per year)
2000	635	547175	1824	2.87
2001	653	564605	1737	2.66
2002	670	577765	1814	2.70
2003	701	601695	1907	2.72
2004	710	608225	2188	3.08
2005	718	615355	2013	2.80
2006	742	626205	2057	2.77
2007	760	627515	1993	2.62
2008	771	645760	1984	2.57
2009	780	653800	1870	2.39

Table 3. scheduled trip in studied region

Year	Number Of 20Kv Trans	Capacity Of 20Kv Trans (KVA)	Number Of Scheduled trip	Average Of Trip (trans per year)
2000	635	547175	1824	2.87
2001	653	564605	1737	2.66
2002	670	577765	1814	2.70
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IV. Calculation and Analysis of Reliability Coefficients

Reliability studies are done because of two important causes:

1) Long term evaluation for system design.
2) Short term evaluation for daily protection.

Distribution system consists of many parts such as transformers, switches , overhead lines, underground cables and so on [5].

Each part of the system can be described by a set of reliability parameters. A simple model of reliability is based on failure rate and time period of fixing up. The most important indices which used in calculation of network reliability are as follows: [6]

Overall time duration of transformers trips: **T**

This time duration is defined as sum of instants in which transformers are tripped due to internal faults and not as a consequence of ancillaries.

Interruption rate: **I**

Interruption rate is defined as the ratio of sum of times of transformers trips to their capacity.

$$I = \frac{N}{S}$$

N= Sum of trip times
S= Nominal capacity

Failure rate: **λ**

Failure rate is described as the ratio of sum of times of transformer trip to their overall working instants.

$$\lambda = \frac{N}{(n * 8760) - T}$$

n= Number of transformers

Frequency of failure: **F**

Frequency of failure is defined as the ratio of sum of times of transformers trips to their overall numbers which are being operated.

$$F = \frac{N}{n}$$

Mean time to repair: **MTTR**

Mean time to failure is defined as the ratio of sum of overall studied transformers trip time duration in hour in a year to sum of times of their trip.

$$MTTR = \frac{T}{N}$$

Mean time of failure: **MTTF**

Mean time of operation is defined as the time duration which transformer trips again after being reinstalled.

$$MTTF = \frac{1}{\lambda} \quad (Hour)$$

Availability factor: **AF**

This factor is defined as the ratio of working time to study time duration in percentage.

$$AF = \frac{K}{8760} * 100$$

K=Sum of operation time (Hour)

Forced outage rate: **FOR**

This coefficient is defined as the ratio of trip time duration of transformer to study period.

$$FOR = \frac{D}{8760} * 100$$

D: Sum of forced outage hours

Transformer reliability: **TR**

This index expresses the reliability of transformer to provide secure electrical energy and is calculated as follows:

$$TR = 100 - \left(\frac{I * \frac{E}{S}}{8760}\right) * 100$$

E: Overall energy of tripped transformers

To calculate the transformers reliability, their performance in a decade is considered. Initially, the transformers emergency and scheduled trips in a decade are considered without taking into account their capacity. Finally for detailed analysis, these statistics are analyzed for one year by considering the capacity of transformers.

Table 4 shows the reliability of indices of network transformers due to emergency trip in recent decade.

Table 5 shows these indices for scheduled trip. By investigation of network data and mentioned indices in tables 4 and 5, it can be concluded that since 2006 and by regular fixing up and maintenance schedules, reliability indices have improved. Meantime it is expected that by increase of number of transformers and their derating, the reliability index should have increased.

As seen in table 4, by increasing times of service from 1172 in 2006 to 1406 in 2009, the emergency trip numbers are reduced from 2057 to 1870 in 2009. In these four years a 482Mwh energy which was not to be supplied, is provided which results in financial profit for region. Discussed topics reveal that utilizing a correct schedule for fixing up and maintenance leads to increase of network reliability. So it is essential to have a suitable model for fixing up and maintenance.

V. MAINTENANCE STRATEGY

In general, there are four models for fixing up and maintenance:

CM: In this model, there is no inspection until failure occurrence. Fixing up and maintenance are done just for failure remove.

TBM: In this model, there are regular intervals for fixing up and maintenance.

RCM: This model is based on priorities and risk management.

CBM: In this model, a situation is always being monitored and in necessary instants, fixing up and maintenance are done.

Due to distribution network expansion and lower rating of transformers, the TBM model is suggested for these networks. This model is based on setting a suitable time schedule. This time interval is calculated upon MTTF. According to table 4, for discussed region, a suitable time interval for fixing up and maintenance of transformers is six months.

VI. CONCLUSION

In investigated services for discussed region network, it can be concluded that scheduling for emergency trips of transformers can lead to a noticeable improvement of system reliability. One solution to reduce the number of transformers emergency trip is effective fixing up and maintenance. This fixing up and maintenance can be described as removing loose joints, inspection of tap-changer and Bouchholz relay. This paper also concludes that since 2006, by regular fixing up and maintenance of transformers, number of emergency trips of transformers has reduced and system reliability has increased. Also by calculation of MTTF for mentioned network, a suitable time interval for fixing up and maintenance of transformers is six months.

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Table 4. reliability coefficients of network transformers due to emergency trip in recent decade

Year	**n**	**S MVA**	**N**	**T**	**E (MWH)**	**I**	**λ**	**F**	**MTTR**	**MTTF**	**AF**	**FOR**	**TR**
2000	635	547	1824	8299	5790.61	3.33	0.0003284	2.872	4.55	3045.12	99.851	0.1492	99.5970
2001	653	564	1737	7347	5139.97	3.08	0.0003040	2.660	4.23	3288.97	99.872	0.1284	99.6796
2002	670	577	1814	8362	5833.06	3.14	0.0003095	2.707	4.61	3230.89	99.858	0.1425	99.6372
2003	701	601	1907	8352	5800.05	3.17	0.0003110	2.720	4.38	3215.74	99.864	0.1360	99.6504
2004	710	608	2188	10349	7178.42	3.60	0.0003524	3.082	4.73	2837.87	99.834	0.1664	99.5150
2005	718	615	2013	8072	5600.37	3.27	0.0003205	2.804	4.01	3120.52	99.872	0.1283	99.6597
2006	742	626	2057	8722	5960.04	3.29	0.0003169	2.772	4.24	3155.66	99.866	0.1342	99.6429
2007	760	637	1993	9745	6616.23	3.13	0.0002998	2.622	4.89	3335.60	99.854	0.1464	99.6290
2008	771	645	1984	9245	6264.70	3.08	0.0002942	2.573	4.66	3399.55	99.863	0.1369	99.6589
2009	780	653	1870	8078	5478.01	2.86	0.0002740	2.397	4.32	3649.58	99.882	0.1182	99.7258

Table 5 reliability coefficients of network transformers due to scheduled trip in recent decade

Year	**n**	**S MVA**	**N**	**T**	**E (MWH)**	**I**	**λ**	**F**	**MTTR**	**MTTF**	**AF**	**FOR**	**TR**
2000	635	547	1112	12621	8806.28	2.03	0.0002004	1.751	11.35	4990.99	99.773	0.2269	99.6264
2001	653	564	1202	15049	10528.31	2.13	0.0002107	1.841	12.52	4746.45	99.737	0.2631	99.5458
2002	670	577	1246	14316	9986.37	2.16	0.0002128	1.860	11.49	4698.94	99.756	0.2439	99.5734
2003	701	601	1178	13653	9481.34	1.96	0.0001923	1.680	11.59	5201.28	99.778	0.2223	99.6470
2004	710	608	1210	15403	10684.04	1.99	0.0001950	1.704	12.73	5127.44	99.752	0.2477	99.6008
2005	718	615	1141	15540	10781.69	1.86	0.0001819	1.589	13.62	5498.81	99.753	0.2471	99.6287
2006	742	626	1172	13548	9258.29	1.87	0.0001807	1.580	11.56	5534.45	99.792	0.2084	99.6839
2007	760	637	1287	16589	11262.48	2.02	0.0001938	1.693	12.89	5160.07	99.751	0.2492	99.5922
2008	771	645	1354	18495	12532.70	2.10	0.0002010	1.756	13.66	4974.49	99.726	0.2738	99.5344
2009	780	653	1406	18371	12457.56	2.15	0.0002063	1.803	13.07	4846.68	99.731	0.2689	99.5311