Evaluation of Libyan Transmission network reliability using Annual Average Customer Interruption Rate (AACIR).

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Abstract-

In this paper we conclude the theoretical approach to practical application for Libyan 220 KV network . Starting with introduction to Annual Average Customer Interruption Rate (AACIR) method, and brief description to Libyan power system, then analysis for whole Libyan transmission network reliability data with calculation of some reliability indices , after that we explain some different case studies that concludes the various states of operation conditions of transmission grid, then the full calculation of AACIR for whole 220 KV transmission network was achieved for all 220 KV substation loads for three years 2017, 2018, and 2019 as two load points for each substation. The transmission line reliability takes important place in overall power system reliability evaluation, because the transmission lines are the most exposure part to the fault in power system, mainly due to bad weather conditions. The evaluation of transmission lines reliability is accumulated with power system operations , that leads to the new reliability term called " Operational reliability ".

1. Introduction

The aim of modern power systems is to satisfy load as economically as possible with reasonable level of continuity and quality. The power system reliability is the ability of the system to perform adequately its intended for the period of time required under the operating conditions encountered. Reliability evaluation is an integral part of engineering economic analysis, its provide an additional degree of consistency in evaluation of alternate proposals. In the area of power system design and development, the application of reliability evaluation can provide valuable input for high decision making process. The basic steps of reliability assessment are shown in Figure 1. The first step is to define the system being analyzed and its operating policies. The models of the components and system need to be defined and specified. Component states together with system operating strategies describe system states. A possible approach would be to select each possible state in turn and evaluate it for its status as success or failure defined for a subsystem or the system. Then based on the probability of the failed states and the magnitude and location of problem, the relevant reliability indices can be computed. It can be seen from this process that the following are needed for the reliability evaluation:
Component and system models, data and operating strategies;
A state evaluation procedure;
Definition of failure and specification of reliability indices are computed.

System reliability analysis could be done basically, by three stages inherent in any reliability method: state selection, state evaluation and index calculation. [1,2]

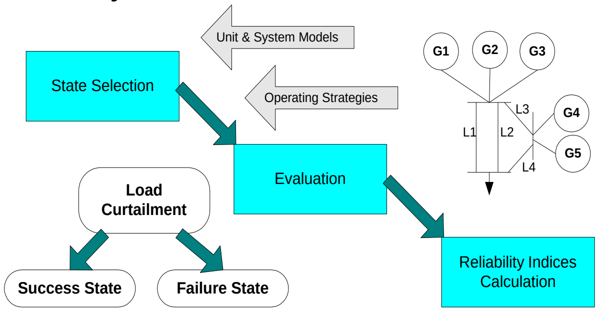


Figure 1: Reliability evaluation steps

Transmission system reliability takes an attention in last few decades, although the outages are localized effect, but it's important to evaluate whole power system reliability in generation, transmission, and distribution systems, also the transmission reliability achieves the acceptable customer reliability and services it.[5]

The transmission reliability evaluation could helps in reinforcement schemes, allocation of equipments, redesign, and improvement of operation and maintenance policies.

In this paper, Libyan transmission network is selected to be the case study; this network includes various types of substations, lines, cables, and transformers, from different manufacturers . Also this network includes a different load characteristic such agriculture, industrial, and residential, with different load value, the main construction of Libyan transmission network is meshes with few redials, those constructions contain different types of lines and cables with different lengths and ages, as well as transformers. Beside all that this area will be improved and upgraded in next few years by redesign and changing of old and aging substation, cables, lines, and transformers.

One of most reliability indices is Annual Average Customer Interruption Rate (AACIR) , AACIR will computed for Libyan transmission network, beside failure probability indices for all substations and feeders in the network.

2. Average interruption rate

This method is quite straight forward and can be applied to a relatively complicated network. It provides a measure of continuity rather than service quality by examining the simultaneous condition that must exist for power flow in series and parallel combination of system components. The application is based upon four relatively simple principles.[1]

A component operates in only two states, available and unavailable. Maintenance is not considered and the probability of a component being unavailable is given by its forced outage rate "p ". If "q" is the availability rate then p + q=1.0

Component failures are assumed to be independent and therefore the probability of simultaneous failures is given by the product of the respective probabilities.

In a series system all components must be available for power flow into a receiving point. The probability of success is the product of the availability probabilities. For a two unit system with outage rates p_1 and p_2 and availability rates q_1 and q_2:

$$q_s = q_1 q_2 \qquad (1)$$

$P_s = 1 - q_1 q_2 = P_1 + P_2 - P_1 P_2$ (2)

If p_1 and p_2 are much less then unity the p_1 p_2 product can be neglected. The failure probability of a series system in

This cases us the element failure probabilities.

In a parallel system all paths must fail if no power is to flow into the receiving point. For a two element system the failure probability is the product of the two component failure values.

Forced outage rate is usually defined as the total component outage time divided by the total component exposure time and is the probability of component outage existence.

To provide an indication of both outage frequency and outage duration the definition can be modified to indicate the probability of outage occurrence rather outage existence.

If component forced outage rates for different minimum specified duration are compiled, it is possible to predict the frequency of occurrence of this condition at any particular point in the system. [4]

It should be realized that outages can occur on the same day but not simultaneously. This approach assumes that all outages occurring during one day are simultaneous outages thus giving a pessimistic result. This can be partially reconciled by considering that if two components within an area are forced out of service during the same day the probability of simultaneous occurrence is somewhat higher than that implied by absolute outage independence. This method is restricted to the evaluation of continuity at a particular point and cannot be extended to systems that are not fully redundant.[4]

This approach has been applied to the small hypothetical system shown in figure 2

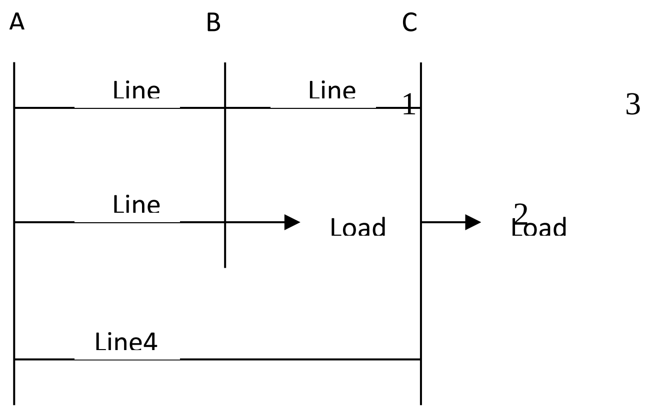


Figure 2: Hypothetical Configuration

The failure rates for each line section are:

Table.1 System parameters for above case

Line Section	Failures/Year
1	0.5
2	0.5
3	0.1
4	0.6

Considering the failures per year as the number of days upon which failures occur within the year, the probability of an outage occurring on lines 1 or 2 is given by :

$$P_1 = P_2 = \frac{0.5}{365} = 1.37 \times 10^{-3}$$

Similarly:

$$P_3 = 0.274 \times 10^{-3}$$
$$P_4 = 1.644 \times 10^{-3}$$

Define Average Annual Customer Interruption Rate (**A .A . C . I . R**) as the expected number of days in a year that the specified outage condition for the load bus will occur .[4]

Assuming that the system is first composed of lines 1, 2 and 3 and then of lines 1, 2, 3 and 4, the results are shown table 2.

Lode B. Lines 1, 2 and 3	6.85×10^{-4}
Lode B. Lines 1, 2, 3 and 4	1.31×10^{-6}
Lode C. Lines 1, 2 and 3	0.1006
Lode C. Lines 1, 2, 3 and 4	0.165×10^{-3}

Table 2

The results shown in table 2 are obtained as follows:

Leaving line #4 out of the analysis

$P_B = (1.37 \times 10^{-3}). (1.37 \times 10^{-3}) = 1.878 \times 10^{-6}$

$AACIR_B = (1.878 \times 10^{-6}) 365 = \underline{6.85 \times 10^{-4}}$

$P_C = (1.878 \times 10^{-6}) + (0.274 \times 10^{-3}) = 0.2759 \times 10^{-3}$

$AACIR_C = (0.2759 \times 10^{-3}) 365 = \underline{0.1006}$

This is almost equal to the 0.1 failures/year figure given in table 5.1 for line #3.

The lode C reliability is dominated by the series element .This characteristic is evident in most studies using a continuity criterion and redundant facilities.

For the complete system show in figure 5.1:

$P_B = (1.878 \times 10^{-6}). (0.274 \times 10^{-3} + 1.644 \times 10^{-3}) = 3.603 \times 10^{-9}$

$AACIR_B = (3.306 \times 10^{-9}) 365 = \underline{1.315 \times 10^{-6}}$

$P_C = (0.2759 \times 10^{-3}). (1.644 \times 10^{-3}) = 0.454 \times 10^{-6}$

$AACIR_C = (0.454 \times 10^{-6}) 365 = \underline{0.165 \times 10^{-3}}$

This approach can be easily applied to a relatively complicated system. It is not valid to introduce transmission load carrying capabilities utilizing a variable load model into this approach as it is assumed that all outages are simultaneous outages.

The reliability indices are based entirely on the continuity of supply to the respective load points therefore assuming a completely redundant system.

In an actual system the failure rates for each line section can be obtained by correctly combining the failure rates of the series and parallel equipment configurations within each section.[5]

3. Transmission reliability indices

To find AACIR reliability index , we have to calculate ad find some related indices, which could be defined as

1- **Outage Time** : is the time where the equipment is out of service by specific forced fault.
2- **Frequency** : Is the number of outages
3- **Forced Outage Rate F.O.R**.: It's a ratio of outage time(down time) to whole time
4- **Failure Probability** : It's a ratio between the time where the equipment is on operation(Up Time) to the whole time.
5- **Failure Rate** : It's indicates to rate of failures that could happen , and also indicates to system behavior during the life time

4. The Libyan network

The Libyan network includes two mainly areas, Eastern and Western, they are connected throw tie lines of 220 KV and 400 KV double circuits each, this connected grid spread over wide area of Libya from Tobruk in East to Abukmash in West with long extends to southern area up to Awanat in west south and Tazrbo in east south. This large network contains more than 14,000 km long of 220 KV circuits and more than 100 substations 220 KV. The grid has peak l load of about 7000 MW with total installed capacity of 1200 MW, and available generated power of about 6000 MW. The nature of load vary between residential and agriculture with small industrial and commercial loads. The network exists over different natural regions that various from mountains, costal, and deserts. Of sure all of above conditions that the system are worked on , have serous effect on its operation specially its transmission reliability.

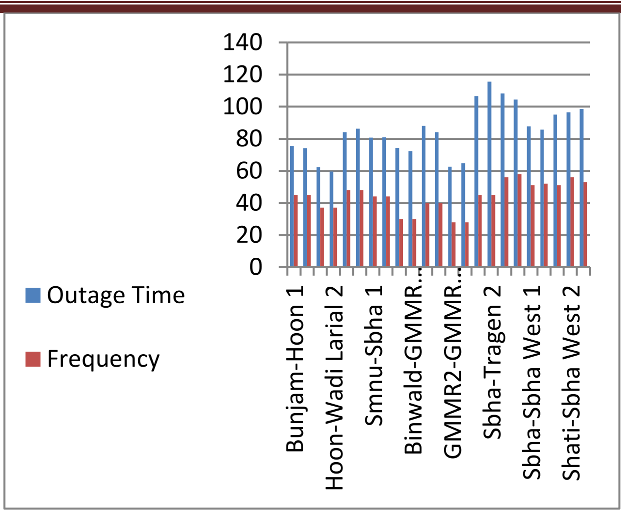
5. Libyan 220 kv substations data analysis

After collecting the data that related to reliability analysis , the following table could be prepared for the **whole** 220 kv substations and outgoing lines , which contains ; Substation name, transmission liness, total outage time , frequency , forced outage rate, and failure rate Libyan Network divided to three major regions : Western, Eastern, and Southern , so we apply reliability techniques to these areas for three years 2017, 2018, and 2019 . Because of huge size of these tables , we put sample of tables followed by curves that indicated to data analysis.

Table 2 Reliability indices

Transmission line	Outage Time (Hr.)	Frequency (No.)	Forced Outage Rate FOR	Failure Probability

Bunjam-Hoon 1	75.6	45	0.00863014	0.991369863
Bumjam-Hoon 2	74.1	45	0.0084589	0.991541096
Hoon-Wadi Larial 1	62.3	37	0.00711187	0.992888128
Hoon-Wadi Larial 2	59.6	37	0.00680365	0.993196347
Smnu-Wadi Larial 1	84.2	48	0.00961187	0.990388128
Smnu-Wadi Larial 2	86.2	48	0.00984018	0.990159817
Smnu-Sbha 1	80.8	44	0.00922374	0.990776256
Smnu-Sbha 2	80.9	44	0.00923516	0.99076484
BinWalid-GMMR _1 1	74.4	30	0.00849315	0.991506849
Binwald-GMMR _1 2	72.3	30	0.00825342	0.991746575
WadiLaral-GMMR _2 1	88.1	40	0.01005708	0.989942922
WadiLaral-GMMR _2 2	84.1	40	0.00960046	0.990399543
GMMR2-GMMR _1 1	62.6	28	0.00714612	0.992853881
GMMR2-GMMR _1 2	64.8	28	0.00739726	0.99260274
Sbha-Tragen 1	106.6	45	0.01216895	0.98783105



Figurer 3 Outage time and frequency

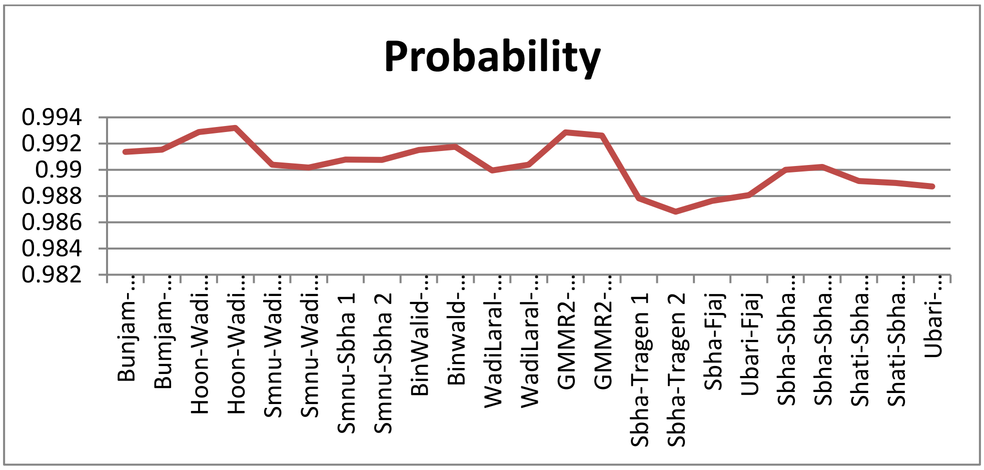


Fig.4 Probability

The given historical data that includes two important indices which are outage time and frequency, that they indicate to reliability behavior of transmission power grid during the past three years 2017,2018, and 2019. The calculated reliability indices driven mainly from both outage time and frequency, which are forced outage rate (F.O.R), failure probability, failure rate, that they indicates to future behavior of power transmission network. First of all , Its clear the diversity between outage time and failure probability , as shown in figures and curves above, where we noticed that , the transmission line having high outage time and frequency meet low failure probability, beside that , generally the transmission lines that locate in free space in suburbs of cities of western area, almost they have relatively low failure probability like Tripoli west – Zhra , that because its agriculture area and over head lines OHL. On other side, the transmission lines with high probability like Tripoli south – Hadba, that because they are bundle supper conductors , and like other transmission line that constructed throw cities which are mainly from cable type with high level of protections. Another important point is about the effect of repairing and enhancement of effective components of power transmission lines after year of 2017 to improve reliability in next year's 2018 and 2019, this is clear when comparing those three years in recent figures. This practical repairing actions could be represented by many steps , upgrading of whole transmission grid voltage from 220 KV to 400 KV in some parts, changing the conductor itself to supper conductor type , and improving performance of tower's insulators by either good cleaning or changing to high quailty insulators that withstand Libyan high pollution , that faced our grid specially at coastal areas.

6. Ain Zara case study

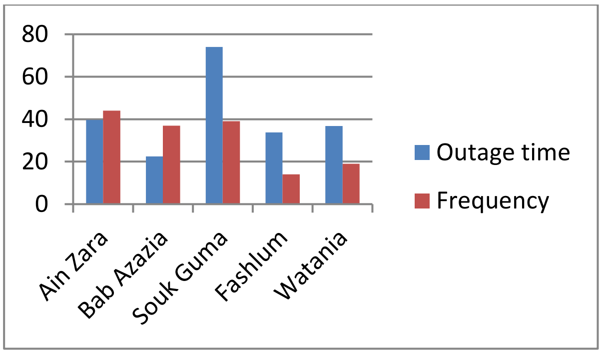


Fig.5 Outage time & Frequency for Ainzara

For the Ain Zara substation ; they are more stable than the others ,that they are GIS [Gas Insulated Substations] so they are widely used in Libyan 220 KV network, even though their troubles which is related to constructional stages and installation periods , like some mistakes during civil stages presented in ground finishing and doors positions . Generally as shown above , they are good enough for heavy duty operation , but the case of relative high tripping in Souk Guma , this is due to aging and lack of maintenance in past time. the network belongs to the 220 KV Ain Zara Ring substation has low interruption rates that because of relative newly networks compared to others , and stable operation of those rings with suitable loading criteria , the two exceptions are clearly appear in Souk Guma and Fashlum outgoing feerds and transformers , in Souk Guma of course because of aging of this substation and nature of industrial loads which has high short circuit level and high starting current, and with respect to Fashlum substation , the main reason of those trips is the reliability , that because this special type of substations has only one transformer with only one incoming and outgoing feeders , so when it's lost the whole substation lost .

7. AACIR calculations for ain zara ring

Referring to Fig. 4 for the Ain Zaea Ring , the summary of AACIR and failure probability indices are listed in Table 4

Table 3 Ain zara ring load points .

Load Point	Line Route	Failure probability	AACIR

A	2 or 3	0.002268	19.866
B	2 or 3	0.002268	19.866
C	1	0.000887	7.77
D	4	0.003468	30.383
E	1 and 5	0.002432	21.3
F	4 and 6	0.002025	18.025

8. AACIR FOR LIBYAN NETWORK

In the Table 4 a sample of the important indices that is AACIR and resultant failure probability for whole Libyan transmission network .this index gives the annual average customer interruption rate AACIR, that indicate to hours to considered in future for disconnect specific load , that by using transmission lines supplied this load. AACIR usually helps decision makers, planning people ,and operating engineers , helps them know the real behavior of the load and to expect the outage time , then how they work to decrease or prevent such interruptions.

Table 4: The sample of AACIR for Libyan Transmission Network.

Load Point	Resultant Failure Probability	AACIR (Hours)
Abukmash 1	0.000315421	2.763089712
Abukmash 2	0.000286548	2.510162232
Zuara 1	2.48369E-05	0.217571244
Zuara 2	1.47852E-05	0.129518352
Aglat 1	9.5782E-06	0.083905032
Aglat 2	5.6752E-06	0.049714752
Zawia 1	0.002581594	22.61476607
Zawia 2	0.004785297	41.91920435
Tripoli west 1	0.000297581	2.606812188
Tripoli west 2	0.000241576	2.116209264
Zhra 1	5.82174E-05	0.509984424
Zhra 2	5.87124E-05	0.514320624

Bir ghnm 1	0.009854146	86.32231546
Bir ghnm 2	0.005487368	48.06934193
Shakshok 1	0.000326485	2.860006848
Shakshok 2	0.000329821	2.889231084
Sraj 1	3.33257E-05	0.291933132
Sraj 2	7.41652E-05	0.649687152
Tripoli south 1	1.23478E-06	0.010816673
Tripoli south 2	1.47852E-06	0.012951835
Hadba 1	2.58971E-07	0.002268586
Hadba 2	2.58746E-07	0.002266615
Bab Azazia 1	4.78526E-07	0.004191888
Bab Azazia 2	9.5176E-07	0.008337418
AinZara 1	4.52189E-05	0.396117564
AinZara 2	1.25486E-05	0.109925736

From the above , it's clear that the difference between two routes 1 and 2 for both indices , AACIR and failure probability. That depends on the load nature and route length and related troubles, also the way of feeding this load point either its series or parallel, each load point could feed from different routes but here we apply mainly two important routes just enough to give clear idia about Libyan transmission network reliability indices.

9. Conclusions

We could conclude from this paper the following points :

- The evaluation of transmission reliability takes a vital rule in both power system operation and reliability.
- The evaluation of power transmission reliability could helps in decision making, redesign, system improvement, operation, and maintenance policies.

- Libyan power system network has many facilities to be a good case study for reliability evaluation, like location , economic, area, and long transmission lines.
- AACIR indicates to how the Libyam transmission network behave for normal operation during the year
- AACIR gives clear idea about the more efficient and more stable substation type, this may advice to recommend to use specific type of manufacturer .
- The effect of operating condition for specific OHL due to aging and loading , could be less with real redesign or changing of equipment like CB's , conductor size, or protection system
- The more critical indices always belongs to agriculture far end loads in southern grid like Sabha.
- The AACIR index of all substations schemes is changed with operating condition of Bus coupler , either open or close, of course its more reliable when it be closed, but the operation policy advice to open the bus couplers for security, that to keep half of substation live when bus bar protection operates, which is seldom occur , regardless for reliable operation
- The leak of maintenance in past periods, the careless of correct operation, and some human errors were the reasons of some bad figures during the transmission reliability evaluation for Libyan power transmission network.
- The load points reliability calculations was some how high in some substations , that due to opening bus coupler, so every fault at transformer causes loss of all load , even though little load.
- For the International standers for power transmission reliability , the IEEE and NERC recommended that, every network had its own specifications of equipment types and ages, load characteristics, engineering, and operating policy. So each utility could make its own standers , by comparing reliability indices for the year with past one .
- To get real practical advantages of this study, it recommended to redone again for Libyan grid, and generalized for whole sectors of network like generation and distribution systems of Libya.

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