Influence of automation introduction to power distribution systems on their reliability

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Abstract **– The aim of this paper is to show the impact of automation introduction to power distribution systems on reliability indices of the system and the customer. It provides an analytical technique, generally employed for quantitative evaluations, and shows the influence of SCADA systems installation to control power distribution systems in order to improve their reliability. The results show clearly the improvements on reliability as the automation of lines switches is increased.**

Key Words – Automation, Reliability, Power, Distribution Systems, SCADA, Line Switches.

I. INTRODUCTION

The electric distribution utilities are become affected by the major changes of regulation and technological developments. The deregulation and the competition are affecting with the same width structures and performance requirements while apparatuses and systems technologies are offering an increased flexibility in development and exploitation of distribution systems [2]. These changes were resulted in an increased interesting on systems reliability. The utilities must provide a higher reliability to attract and retain their customers. New technologies allow reliability improvements in ways not possible previously.

Feeder automation has emerged quickly as a practical technology during the last decades. Feeder automation includes the remote control, the supervision and the local control of the apparatuses downstream an HV/MV substation. Feeder automation allows the effective localization of defaults and the fast system reconfiguration for the customer service restoration. This results in the system reliability improvement. Historically, feeder automation for reliability improvement was difficult to quantify and for limited applications.

To improve the reliability of power distribution systems, the attention is given to increase the systems automation level via the installation of SCADA systems. A SCADA system can facilitate the monitoring, the control and the exploitation, and can improve service quality to customers. A significant part of SCADA role is the automatic service restoration. In the event of a system fault, the automated restoration can quickly recover the load which was disconnected by transferring it to another healthy part of the system.

The load restoration in distribution systems is traditionally carried-out by opening/closing two types of switches, i.e., normally open tie switches and sectionalizers. By changing the opening/closing states of switches, loads can be transferred from one feeder to another. Currently, in Algeria, these restoration switching are, generally, carried out manually. With the introduction of automation functions to feeders of distribution systems, it is necessary to evaluate quantitatively the effect of these automatic operations on the customer reliability of electric power supply, and to compare the reliability improvement resulting with the necessary cost for its realization. Clearly, this evaluation requires techniques which allow reliability and cost/benefit ratio calculations [1].

A recent study indicates that the majority of electric power supply utilities use the indices based customer to evaluate the reliability of their exploitations [4]. The most common used indices are: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), and Average Energy Not Supplied (AENS).

This paper relates to the significant subject on the way in which the load restoration using the SCADA systems (remote interruption and restoration) affects the reliability indices from customer and system point of view. It presents a technique which can be employed to evaluate the effect of the automated service restoration.

II. EVALUATION TECHNIQUE AND CONCEPTS

In Algeria, power distribution systems in rural zones are usually composed of many radial feeders. Each feeder is divided into supply areas with manual switches, sectionalizers and has connection points with other feeders by means of normally open switches (tie switches). These normally open line switches play a significant role in the service restoration. In the event of a fault in a part of the system, the normally open points can be closed and the loads which were disconnected could be transferred to the alternative feeders by the intermediary of line switches. This supplying restoration procedure can have an outstanding effect on the reliability indices of a consumption load point, because the loads which would have been differently left disconnected until repair was accomplished can now be transferred to another part of the supplying system.

Currently, many electric utilities put considerable efforts to find means to reduce customer interruption times. By consequence, many utilities showed a progressive interest to increase the power systems automation. With the introduction of automation to power distribution systems, the fault localization, isolation / sectionalizing and re-closing operations can be carried out sequentially and automatically. When these actions go correctly, the time necessary for system reconfiguration and load covering can be reduced clearly.

In order to study the questions related to the automated service restoration and to evaluate its impact, one technique is described in this paper. The technique suggested is based on an approach with three steps. The first step evaluates the system reliability indices with its initial automation level of service restoration. The second step analyzes how the customer reliability indices are affected by replacing the restoration manual actions by automated operations of load restoration. The last step studies how the not-supplied load can be restored by the network reconfiguration using additional automatic line switches and tie switches (alternative supply).

III. ANALYTICAL SIMULATION

The analytical simulation models each system event, calculates the impact of each event and weighs this impact based on the expected event frequency. This method can suitably model the complex behavior of the system and dynamically list each possible state of the system [3]. The analytical simulation is very well suitable to model several restoration strategies types.

The events sequence after a fault is:

A. Incident

A default occurs into the system.

B. Reclosing

A reclosing device opens in order to allow the default elimination. If the default disappears, the reclosing device is closed again and the system is restored to the normal state.

C. Automatic Interruption

The automatic switches, which see the current default, try to isolate the default by opening themselves when the system is put out of energy by a reclosing device.

D. Locking

It refers to the tripping of a protection device and remains open until it will be rearmed (for example, a fuse which fuses or a circuit-breaker which remains opened after many attempts to eliminate the default). If the default persists, the temporal overload protection will eliminate the default. Locking must be carried out by the same device which run the reclosing function or by different apparatuses which are closest to the default.

E. Upstream Restoration

An interruption point upstream the default is open (an interruption point is any device such as a sectionalizer or a fuse). This allows the protection apparatus to be reinitialized as well as the restoration of all the customers upstream the interruption point.

F. downstream Restoration

The other sections which remained de-energized are isolated from the default by manual switches. The customers downstream these points are restored by alternative ways by closing the normally open switches.

G. Reparation

The default is repaired and the system is returned to its before default state.

The algorithmic structure of the evaluation used is:

(a) Consider each consumption point of the analyzed system ;

(b) Consider each failure event of the consumption points ;

(c) Identify the restoration procedure the most appropriate :

- if the service can be only taken again when repair and/or replacement were achieved, therefore take again the supply by repair and/or replacement ;
- if the service can be taken again by manual switching actions, take again the service by the manual isolation operations ;
- if automatic operations are possible, then simulate the sequential operation of the suitable switching of closed and open tie switches ;
- if the not-served load can be restored by the network reconfiguration using an alternative power supply, then automate the suitable normally open points and the associated sectionalizers, and evaluate how the system reliability can be improved by providing automated ways of load transfer.

(d) Evaluate the reliability indices at each consumption point by considering all the events leading to the default of the consumption point and their associated restoration process ;

(e) Repeat the procedure for each failure event and each consumption point ;

(f) Evaluate the reliability indices of the global system by suitably combining the reliability indices of the consumption points.

IV. APPLICATION STUDY

The technique suggested was employed to analyze a real Algerian power distribution system as represented on figure 1. This system is a 30 kV rural feeder with an overall length of 325 km in which there is a mixture of automats such as manual and automatic sectionalizers and, actually, all the existing line switches are operated manually.

The studied system has 08 supplies areas (great derivations) and 04 tie points with bordering feeders ensuring the alternative supply through the associated switches: I4, I7, I15 and I16. The incidents number history to the 100 km for this feeder during the 05 last years is given in table 1.

According to table 1, the average of incidents number to the 100 km is about: 2.26. By using the technical characteristics of this feeder, we can obtain the failure rates for each section as shown in table 2. Also, the load characteristics for the supply areas of the studied feeder are given in table 3. .

We suppose for this study that the average time required to carry out the necessary operations to isolate faulty part is about 02 hours and its repair or replacement is about 04 hours. Also, we suppose that the time necessary for an automat to isolate the part which it protects is among 0.015 hours and that for the supervision agent to isolates the faulty part and reconfigures the network to ensure the supplying to the disconnected healthy parts is about 0.05 hours.

A series of case studies was carried out to examine the various procedures of service restoration, including the restoration by using manual operations, the restoration by using the automatic sectionalizing (sectionalizers), and the restoration by using feeder automated switches (switches remote-controlled). The five following scenarios were studied to try to recall the feeder automation evolution with the passing of years:

TABLE I
INCIDENTS HISTORY OF THE STUDIED FEEDER

YEAR	2005	2006	2007	2008	2009
INCIDENTS NUMBER IN 100 KM	2.691	2.691	2.960	1.345	1.614

Case (1): All the switches are manual line switches.

Case (2): As in case (1), but the switches I2, I3, I5, I9, I10, I12, I13 and I14 are replaced by sectionalizers that are operated manually.

Case (3): As in case (2), but replace the two switches I1 and I11 by remote-controlled sectionalizers.

Case (4): as in case (3), but envisage three looping points with the bordering feeders ensuring the alternative supplying through the four manual normally open tie switches I4, I7, I15 and I16.

Case (5): as in case (4), but all the manual switches will be replaced by line switches remotely controllable from the dispatching center.

V. RESULTS AND DISCUSSIONS

The results of the application study are shown in tables 4 to 9 (where λ is the failure rate, r is the mean repair time and U is the average unavailability). These results represent the automatic service restoration impact and confirm the improvement expected in reliability by automation. Obviously, the failure rate does not change since the number of failures seen by the principal circuit breaker D remains the same. Nevertheless, the rates of customer-interruption and all the other indices are improved gradually as long as the automation of the line switches is increased and/or extended.

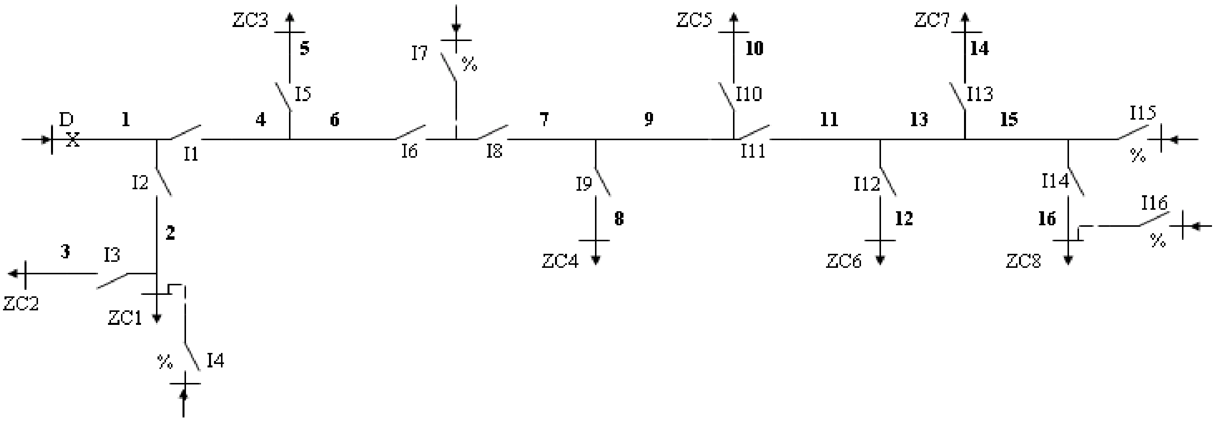

Fig. 1 System Used for the Application Study

TABLE II
SECTIONS FAILURE RATE

SECTION	LENGTH (km)	FAILURE RATE (inc/year)
1	10.139	0.23
2	3.826	0.09
3	12.920	0.29
4	7.591	0.17
5	10.952	0.25
6	3.394	0.08
7	0.813	0.02
8	18.635	0.42
9	4.426	0.1
10	14.072	0.32
11	2.213	0.05
12	80.211	1.81
13	4.435	0.1
14	9.575	0.22
15	6.793	0.15
16	135.201	3.06

It should be noted that the improvement in the reliability indices tends to an asymptote of limiting values when a sufficient automation was added. The flatness of the curves in figure 2 indicates that, at a certain level, add more automation brings less additional benefit. It should be noted that the load zones closest to the supplying source have a better reliability and their reliability indices change little with the increase in the feeder automation. Also, the load areas furthest away from the supplying source undergo longer durations of interruptions.

VI. CONCLUSIONS

This paper addressed with the significant subject on how the automatic restoration of the load using SCADA systems (automatic switches, automatic sectionalizers and remote-controlled tie switches) affect the customer reliability indices. It presents a technique which can be used for the quantitative evaluations.

TABLE III
CONSUMPTION ZONES CHARACTERISTICS

CONSUMPTION ZONE	POWER (kW)	NUMBER OF CUSTOMERS
ZC1	790	395
ZC2	300	150
ZC3	560	280
ZC4	1330	665
ZC5	2880	1440
ZC6	1660	830
ZC7	330	160
ZC8	3730	1870

TABLE IV
CASE (1) RELIABILITY INDICES

CONSUMPTION ZONE	λ (fail/yr)	r (h)	U (h/yr)
1	7,36	2,087	15,360
2	7,36	2,166	15,940
3	7,36	2,198	16,180
4	7,36	2,277	16,760
5	7,36	2,250	16,560
6	7,36	2,736	20,140
7	7,36	2,304	16,960
8	7,36	3,076	22,640

The results show clearly the improvements in reliability when the automation of line switches increases. This paper also shows that the benefits obtained by the automation tend to an asymptote of the limiting values when a sufficient automation was reached. Thus, for the highly automated systems, try to reach a significant interests in reliability by additional automation is insignificant.

VI. REFERENCES

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TABLE V
CASE (2) RELIABILITY INDICES

CONSUMPTION ZONE	λ (fail/yr)	r (h)	U (h/yr)
1	7,36	0,369	2,716
2	7,36	0,526	3,871
3	7,36	0,524	3,853
4	7,36	0,648	4,771
5	7,36	0,594	4,372
6	7,36	1,482	10,910
7	7,36	0,621	4,574
8	7,36	2,159	15,891

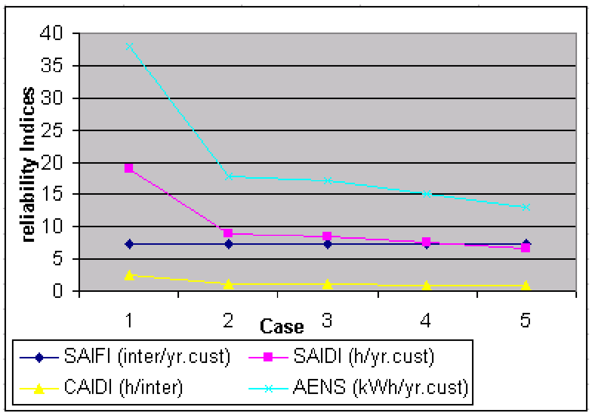

Fig. 2 SAIFI, SAIDI, CAIDI and AENS Variation for cases (1) to (5).

TABLE VI
CASE (3) RELIABILITY INDICES

CONSUMPTION ZONE	λ (fail/yr)	r (h)	U (h/yr)
1	7,36	0,188	1,386
2	7,36	0,345	2,541
3	7,36	0,443	3,258
4	7,36	0,567	4,175
5	7,36	0,513	3,777
6	7,36	1,482	10,910
7	7,36	0,621	4,574
8	7,36	2,159	15,891

TABLE VII
CASE (4) RELIABILITY INDICES

CONSUMPTION ZONE	λ (fail/yr)	r (h)	U (h/yr)
1	7,36	0,126	0,926
2	7,36	0,283	2,081
3	7,36	0,380	2,798
4	7,36	0,437	3,215
5	7,36	0,383	2,817
6	7,36	1,319	9,710
7	7,36	0,458	3,374
8	7,36	1,996	14,691

TABLE VIII
CASE (5) RELIABILITY INDICES

CONSUMPTION ZONE	λ (fail/yr)	r (h)	U (h/yr)
1	7,36	0,065	0,477
2	7,36	0,222	1,633
3	7,36	0,287	2,115
4	7,36	0,310	2,279
5	7,36	0,256	1,881
6	7,36	1,160	8,540
7	7,36	0,299	2,204
8	7,36	1,837	13,521

TABLE IX
RELIABILITY INDICES FOR THE DIFFERENT CASES

CASE N°	SAIFI	SAIDI	CAIDI	AENS (kWh/yr.cust)
1	7,36	18,955	2,575	37,899
2	7,36	8,930	1,213	17,840
3	7,36	8,559	1,163	17,099
4	7,36	7,552	1,026	15,085
5	7,36	6,559	0,891	13,098