Reliability Enhancement of the Power System by the SVC Replacement

Babak Sadeghi[1], M. Rostami[2], H. Torabipour[3], A. R. Gholami[3], Y. Shahsavari[3]
1-MSc Student, Shahed University, Tehran, Iran
Email: babak.sadeghi@shahed.ac.ir
2- Department of Electrical Engineering, Shahed University, Tehran, Iran
Email: rostami@shahed.ac.ir
3- MSc Student, Shahed University, Tehran, Iran

Received: Feb. 2013 Revised: May 2013 Accepted: Sep. 2013

ABSTRACT:
There are relatively few literatures about Flexible AC Transmission Systems (FACTS) in reliability aspects, particularly in composite system reliability evaluation. Reliability of the power system could be studied by some indices that help to compare power system under different conditions from reliability point of view. The actual benefits of the FACTS can be quantitatively estimated using suitable models and techniques. Corrective control as an alternative for the system reinforcement is proposed in this paper as a suitable way to ease the challenges related to building new transmission lines or reconstruction of power grid. Static Var Compensator (SVC) as a member of FACTS family has been used as corrective control. A test case with three scenarios is considered for comparing the effect of SVC on the reliability of the power system. It will be seen that the correct SVC replacement has a great influence on the reliability indices of power grid and losses could be diminished.

KEYWORDS: Active and Reactive Power, FACTS, Losses, Reliability, SVC.

1. INTRODUCTION

Growing societies and industries lead to very high demands which highly affect the power system security and reliability. Though, building new transmission lines can relieve this severe situation, it is hard to be implemented due to various limitations such as right-of-way and cost. However, the costs of building new transmission lines are very high. Furthermore the land on which to construct new lines is rather limited and the situation has mixed up with growing concerns about environmental impacts of any new lines. Thus, the application of traditional network reinforcement schemes is becoming more and more challenging not only economically but politically as well.

Corrective control as an alternative to the system reinforcement is proposed in this paper as one way to by-pass the challenges mentioned above. The system operation based on the corrective control requires a fundamental change of the current system operation philosophy based on the preventive control [1].

Thyristor Controlled Series Capacitors (TCSC) and Unified Power Flow Controllers (UPFC) are the members of FACTS family which is used as power flow controller for a wide range of applications. The reliability impacts of incorporating these two devices in power transmission systems are presented in [2], [3].

The trust in the applications of FACTS members to power systems has based on their ability to improve the system security such as transient stability, voltage stability and oscillations damping. Less attention has been paid to the impacts of these components on the system reliability. The SVC and Thyristor Controlled Phase Angle Regulator (TCPAR) are two members of FACTS. The SVC can provide the system with reactive power and regulate the voltage. The TCPAR can alter the phase shift angle to control the power flow pattern. These two components can benefit the system operation in voltage control and oscillations damping and reliability [4], [5].

By implementation of the corrective control, the power systems are able to accommodate growing loads by utilizing the system margin which should be reserved under the traditional preventive control. The prevailing "N-1" rule is challenged under corrective control. For example, the transmission line may be pushed to its limit under corrective control, the power transmitted is right at the threshold where the line can operate in a stable mode, whereas under preventive control "N-1" rule should be maintained which requires a large capacity of the line to be reserved. Instead of building new transmission lines, the control systems will be built to exploit the reserved capacity inherent in the planned systems under the "N-1" rule. In this way, the

prohibitive cost of building transmission lines is replaced by the relatively low cost of implemented corrective control systems. However, the effect of corrective control on the system risk is still unknown. Many questions have yet to be addressed such as:
1) How will different penetration levels of corrective control affect the system risk?
2) How will different reliability profiles of corrective control devices affect the system risks?
3) What is the optimal level of corrective control in terms of costs and benefits?
4) Is it preferable to implement corrective control to reinforce the network in the traditional way, in terms of cost and benefit?
These questions should be thoroughly investigated before the final strategy of system development is decided. This paper studies SVC replacement based on the corrective control and reliability indices of the power system accordingly.

2. CONCEPT AND MODEL

2.1. The Concept of Corrective Control

Corrective control, as the term suggests, aims to correct the system violations after they have occurred, whereas preventive control aims to prevent violations from occurring by providing enough security margins in advance. The term corrective control has different scopes in the literature. In the widest scope, the traditional means of system management such a: fast spinning reserve, ready reserve, generation re-dispatch and load shedding are all classified as means of corrective control since they all “correct” the problem after it occurs, although some require significant time to perform (the ramp up of generations) or are very costly (such as load shedding).Corrective switching is a fast and economical means of corrective control action, aiming at reducing losses, relieving overload problems and solving voltage problems. The impact it has on system reliability is not in a definite direction, depending on the individual case.
FACTS, as a means of corrective control, provide fast and intelligent control of the power system. FACTS, which are power electronics-based devices, can change parameters like impedance, voltage and phase angle. Therefore they have the ability to control power flow pattern and enhance the usable capacity of the existing lines. The most prominent feature of FACTS is that they can vary the parameters rapidly and continuously, which will allow a rather desirable control of the system operation.
Transmission networks Researchers has paid attention to the effects of FACTS devices on the system security such as transient stability, voltage stability and oscillations damping. Less attention has been paid to the impacts of these components on the system reliability. The SVC as shunt reactive compensation is modeled for reliability studies purpose.

2.2. Structure and Operation of SVC

SVC has been used in transmission systems since the 1970s. This paper aims to show the provided support by SVCs during system contingencies and also the availability and reliability issues necessary to address in order to secure the SVC operability when called upon to. Some SVCs have been in operation for over 20 years while others have only three years in service. The typical transmission SVC is a Vernier controlled device consisting of applicable combinations of Thyristor Switched Capacitor banks (TSC), Thyristor Controlled Reactors (TCR) and fixed filter banks as required. The reactive branches are connected to a MV bus and connected to the transmission voltage level through a step up transformer. There are also discretely controlled SVCs consisting solely of TSC branches or of Thyristor Switched Reactors (TSR) and TSC branches in combination. Both types are depicted in figure 1 but it should be said that the latter type is not as common as the Vernier controlled device even though there are a decisive number of discretely controlled SVCs in operation worldwide [6].

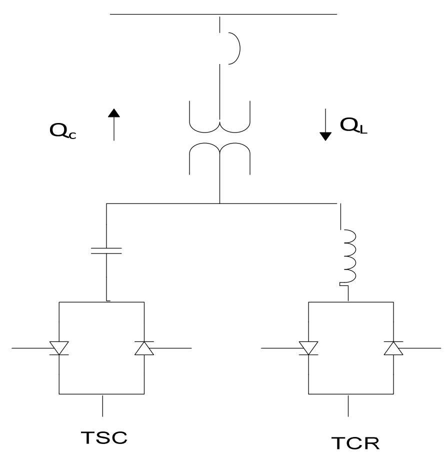

Fig. 1. A basic TSC-TCR type SVC

Fig. 1 is the schematic diagram of a typical SVC which has TSC and TCR. In practice, the numbers of TSC and TCR are decided by many factors such as maximum reactive power output and current rating of the thyristor valves. It implies that we can add more TCRs to increase the inductive reactive power range. Under the control of the thyristor valves, the output of the SVC can vary from the maximum inductive to maximum capacitive power rapidly and continuously.

2.3. Reliability Model of SVC

A TSC-TCR type SVC consists of a certain number of TSCs and TCRs. We are mainly concerned with the failures of these components, which are in parallel. To

set up the reliability model of the SVC, we make the following assumptions:
After a TSC or TCR fails, it will be isolated by a bypass breaker. Therefore other normal components can still work. If all the TSCs and TCRs of the SVC fail, the SVC will be simply disconnected by a bypass breaker from the transmission line with which the SVC is in parallel. Here to simplify the matter, we just give an example of an SVC with a TSC and a TCR. The state-space model of the SVC is shown in the figure below:

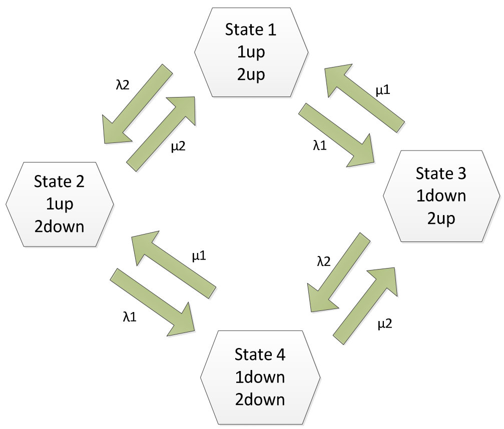

Fig. 2. Reliability model of SVC (a TSC and a TCR)

In Fig. 2, 1 and 2 states stand for the TSC and TCR respectively. Suppose the TSC has a limit of 5 MVAR capacitive power and the TCR can consume as much as 5 MVAR power. Hence in state 1 where both the TSC and TCR are at work the SVC can either absorb or generate reactive power and the range is [-5 , 5] MVAR. In state 2, the TCR is down and isolated by a bypass breaker from the rest of the SVC. However, the SVC still can provide [0 , 5] MVAR, which controls the available TSC. State 3 is similar to state 2. The difference is that the SVC now can only absorb reactive power because only the TCR is available. In state 4 both the TSC and TCR are down and The SVC has no effect.
We can get the Probability (P_i) of each state based on Figure 2 as follows:

$$P_1 = \frac{\mu_1\mu_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad (1)$$

$$P_2 = \frac{\mu_1\lambda_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad (2)$$

$$P_3 = \frac{\mu_2\lambda_1}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad (3)$$

$$P_4 = \frac{\lambda_1\lambda_2}{(\lambda_1+\mu_1)(\lambda_2+\mu_2)} \quad (4)$$

λ_1, λ_2 stand for Failure rates of the TSC and TCR respectively, And μ_1, μ_2 are their repair rates. With regard to the other types of SVC, we can follow the same method to build their reliability models [6-8]. In Table 1 Reliability Data of a SVC is presented:

Table1. Reliability Data of a SVC

Device	Failure rate (1/ yr)	Repair rate (1/yr)
TSC	0.0005	0.0210
TCR	0.0005	0.0210

3. POWER SYSTEM RELIABILITY

The power system reliability is one of the features of power system quality in addition to the required voltage and constant frequency. The electric utility industry has developed several performance measures of reliability or reliability indices. These reliability indices include measures of outage duration, frequency of outage, number or customers involved or their lost power or energy and the response time. The Institute of Electrical and Electronic Engineers (IEEE) defines the generally accepted reliability indices in its standard number. This standard lists several important definitions for reliability, including what are momentary interruptions, momentary interruption events and sustained interruptions.
The standard distribution and transmission reliability indices and factors that affect their calculation are collected and presented. The indices are intended to be applied to the power distribution and transmission systems, substations, circuits, and defined regions. Some of the standard distribution and transmission reliability indices are presented.

3.1. System Average Interruption Frequency Index (SAIFI):

The SAIFI means that how often the average customer experiences a sustained interruption over a predefined period of time, usually a year.

$$\text{SAIFI}= \left(\frac{\text{total number of customer interruptions}}{\text{total number of customers served}}\right)$$

$$\text{SAIFI}= \left(\sum_{i=1}^{n} N_i\right)/N_T \quad (5)$$

Where the sum is taken over all events (i), Eitherat all voltage levels or only at selected ones. N_i is the number of customers interrupted by each incident i. N_T is the total number of customers in the system for which the index is calculated. SAIFI can also be measured by the mean time between failure (MTBF), which is the reciprocal value of the failure rate λ.
SAIFI typical value is mostly between one and two sustained interruptions per year. The value depends on the system configuration and is higher for the radial

configuration, smaller for the underground residential, and the smallest for the grid network.

3.2. System Average Interruption Duration Index (SAIDI):

SAIDI indicates the total duration of interruption for the average customer during a predefined period of time. It is usually measured in customer-minutes or customer hours of interruption.

$$\text{SAIDI}= \frac{sum\ of\ customer\ interruption\ durations}{total\ number\ of\ customers}$$

$$\text{SAIDI}= (\textstyle\sum_{i=1}^{n} N_i \,.\, r_i)/N_T \quad (6)$$

Where r_i is the restoration time for each interruption (i). Typical values of SAIDI are between 1.5 and 3 h per year.

3.3. Customer Average Interruption Frequency Index (CAIFI):

CAIFI gives the average frequency of the sustained interruptions for those customers who experience sustained interruptions. The customer is counted once regardless of the number of times interrupted for this calculation. Like SAIFI, it is usually expressed in interruptions per customer per year.

$$\text{CAIFI} = \left(\frac{\text{total number of customer interruptions}}{total\ number\ of\ customers\ affected}\right)$$

$$\text{CAIFI} = (\textstyle\sum_{i=1}^{n} \text{Ni})/\text{Nc} \quad (7)$$

Where Nc is the total number of customers that have experienced at least one interruption during the reporting period.

This index differs from SAIFI only in the value of the denominator. It is particularly useful when a given calendar year is compared with other calendar years since, in any given calendar year, not all customers will be affected and many will experience complete continuity of supply.

The value of CAIFI therefore is very useful in recognizing chronological trends in the reliability of a particular distribution system. In the application of this index, the affected customers should be counted only once, regardless of the number of interruptions they may have experienced in the year.

3.4. Energy Not Supplied (ENS):

ENS gives the total amount of energy that would have been supplied to the interrupted customers if there would not have been any interruption. It is usually expressed in MWh.

$$\text{ENS} = \textstyle\sum_{i=1}^{n} \text{Pi} \,.\, \text{Ri} = \sum_{i=1}^{n} \text{Ei} \quad (8)$$

Where Pi is the average load interrupted by each interruption (i) and Ei is the energy not supplied because of each interruption (i).

3.5. Average Energy Not Supplied (AENS):

The AENS index indicates how much energy on average was not served to the customers during a predefined period of time. It is usually expressed in MWh.

$$\text{AENS}= (\textstyle\sum_{i=1}^{n} \text{Pi} \,.\, \text{ri})/(\sum_{i=1}^{n} \text{Ni}) \quad (9)$$

3.6. Customer Average Interruption Duration Index (CAIDI):

The CAIDI represents the average time required to restore service. It is expressed in units of time per interruption, usually in minutes per interruption. From customer point of view, it is closely related to the term mean time to restore or mean time to repair (MTTR).

$$\text{CAIDI}= \frac{sum\ of\ customer\ interruption\ durations}{total\ number\ of\ customers\ interruption}$$

$$\text{CAIDI}= (\textstyle\sum_{i=1}^{n} \text{Ni} \,.\, \text{ri})/(\sum_{i=1}^{n} \text{Ni}) \quad (10)$$

The value of CAIDI depends on the system configuration and is lower for the radial configuration, higher for the underground residential, and the highest for the grid network.

3.7. Average Service Availability Index (ASIA):

The ASAI represents the fraction of time that a customer has received power during the defined reporting period.

$$\text{ASAI} = \frac{customer\ hours\ of\ available\ service}{customer\ hours\ demanded}$$

$$\text{ASAI} = 1 - \{(\textstyle\sum_{i=1}^{n} N_i \,.\, r_i)/(N_T \,.\, \text{T})\} \quad (11)$$

Where T is the time interval (8.760 or 8.784 h in a leap year).Another way of looking at ASAI on the annual basis is defined by SAIDI, whereSAIDI is expressed in hours.

$$\text{ASAI} = (\text{T-SAIDI})/\text{T} \quad (12)$$

3.8. Average Customer Curtailment Index (ACCI):

The ACCI indicates how much energy on average was not served to the interruptedcustomers during a predefined period of time. It is usually expressed in MWh.

$$\text{ACCI} = (\textstyle\sum_{i=1}^{n} \text{Pi} \,.\, \text{ri})/(\sum_{i=1}^{n} \text{Ni}) \quad (13)$$

This index differs from the AENS in the same way that the CAIFI differs from the SAIFI. It is therefore a useful index for monitoring the changes of average energy not supplied between one calendar year and another.

3.9. Interrupted energy assessment rate (IEAR):

One suitable form being used in Canada is known as the interrupted energy assessment rate (IEAR) expressed in $/kWh of unsupplied energy. The IEAR is calculated as the ratio of the total cost and total Loss of Energy Expectation (LOEE):

$$\text{IEAR} = \left(\sum_{i=1}^{n} \text{mi}\,.\,\text{fi}.\,\text{ci}.\,(\text{di})\right)/\left(\sum_{i=1}^{n} \text{mi}.\,\text{fi}.\,\text{ci}\right) \quad (14)$$

Where m, is the margin state capacity for the load loss event i (kW), fi is the frequency of load loss event i (occ/day), di is the duration of load loss event / (hr), and N is the total number of load loss events. Ci(di) is the cost of the ENS during load loss event [9], [10], [11].

4. CASE STUDY

The Digsilent reliability test system with 13 buses is used as a test case. In the appendix the simulated test system is shown. The system voltage level is 33/11kV. For comparison purposes, some reliability indices are calculated where a constant peak load level is considered. The SVC is implemented as the means of corrective control. The SVC is placed in all 12 non-generation buses, and some reliability indices are calculated in order to reducethe risk. Several scenarios are therefore selected with the gradual increase of the corrective control penetration:

1) the base case with no corrective control;
2) one SVC installed at each 12 non-generation buses (buses 2 to 13) separately;
3) two SVCs at some buses that are selected based on the last scenario results;

4.1. First and Second Scenarios:

We can see the results of the reliability indices calculated for the scenarios 1 and 2 where number 1 in horizontal axis stands for the case without SVC and number 2 to 13 represent the number of buses on which the SVC is replaced on (Fig. 3 to Fig. 12).

Table 2 shows the reliability assessment results for 1&2 Scenarios. The whole test system active and reactive loads are constant and equal to 52.08 MW, 9.71 Mvar.

When we calculate the load flow for the system under different scenarios, we can obtain some parameters such as Total Losses, No Load Losses, Load Losses, External Infeed, Compensation and Power Interchange. Table 3 shows the power flow results for 1 and 2 scenarios.

The SVC reactive power range is [-5(QL), 10(QC)] Mvar.

4.2. Third Scenario:

If we want to study the third scenario, first we compare the previous scenario results then we can replace two SVCs at some buses that are selected based on the previous scenario results. If we concentrate on the last figures, we find out that SVC replacement at the bus 2 and bus 4 has a good effect on reliability indices and we can replace one SVC at bus 2 and another at bus 4 and then calculate reliability indices (case 1). Also we find out that SVC replacement at bus 5 and bus 7 has a good effect on reliability indices (but less than effect of bus 2 and 4) and we can place one SVC at bus 5 and another at bus 7 and then calculate reliability indices for this case (case 2). For last case we can concentrate on buses that SVC replacement on them has not a good effect on reliability indices and we find out that buses 11 and 13 are buses that SVC placement on them has not a good effect on reliability indices and we can place one SVC at bus 11 and another at bus 13 and then calculate reliability indices (case 3). We can see the results of reliability indices calculated for the third scenarios where number 1, 2 and 3 in the horizontal axis stand for the cases 1, 2 and 3 (Fig. 13 to Fig. 21).When we calculate the Load Flow for the system under third scenario, we can obtain some parameters such as Total Losses, No Load Losses, Load Losses, External Infeed, Compensation, Power Interchange. Tables 4 and 5 show the reliability indices and power flow results for the third scenario.

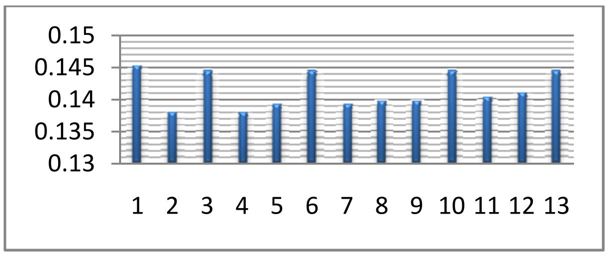

Fig. 3. 1 & 2 scenarios from SAIFI point of view

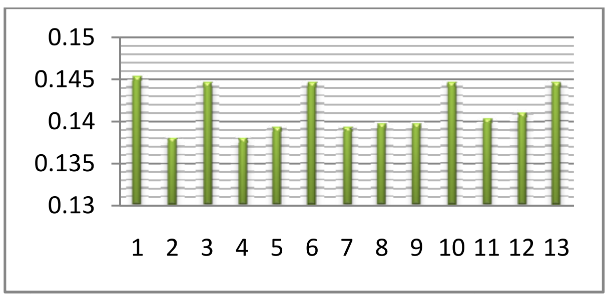

Fig. 4. 1 & 2 scenarios from CAIFI point of view

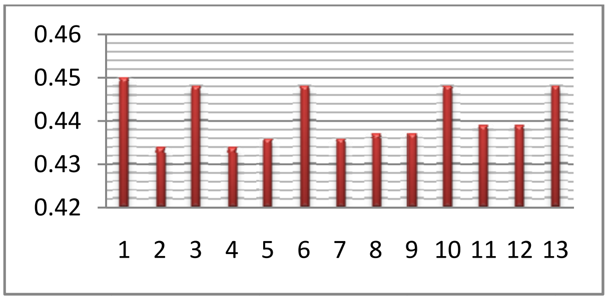

Fig. 5. 1 & 2 scenarios from SAIDI point of view

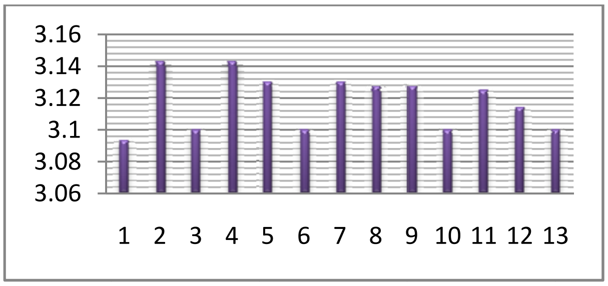

Fig. 6. 1 & 2 scenarios from CAIDI point of view

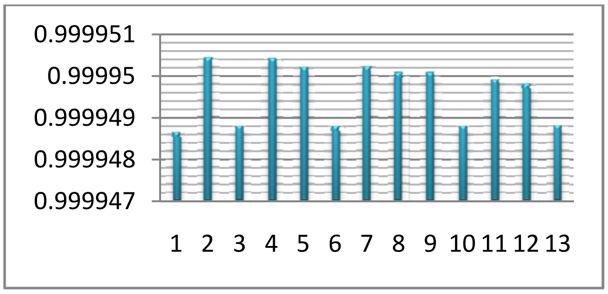

Fig. 7. 1 & 2 scenarios from ASAI point of view

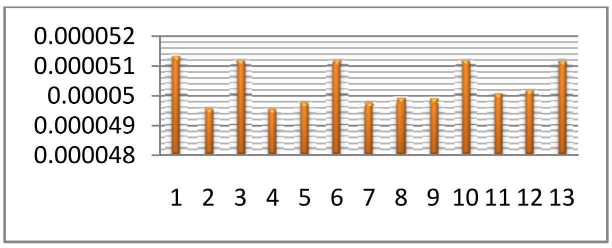

Fig. 8. 1 & 2 scenarios from ASUI point of view

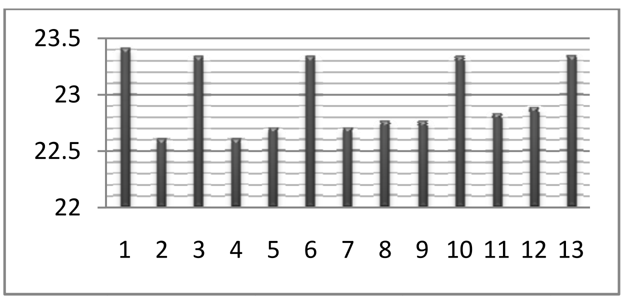

Fig. 9. 1 & 2 scenarios from ENS point of view

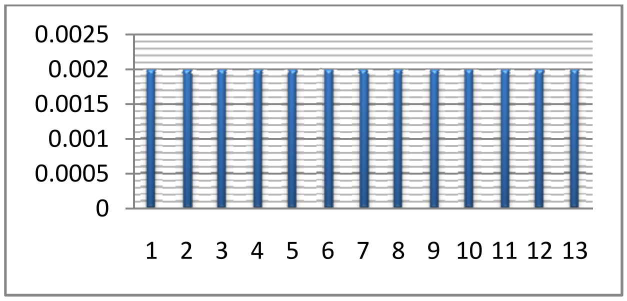

Fig. 10. 1 & 2 scenarios from AENS point of view

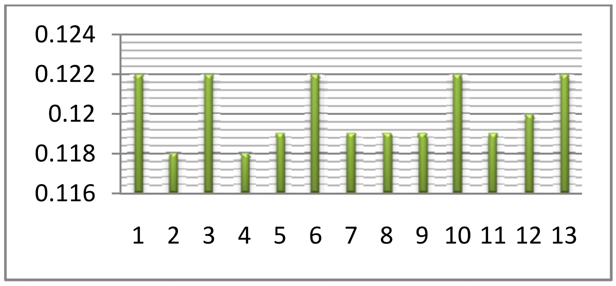

Fig. 11. 1 & 2 scenarios from EIC point of view

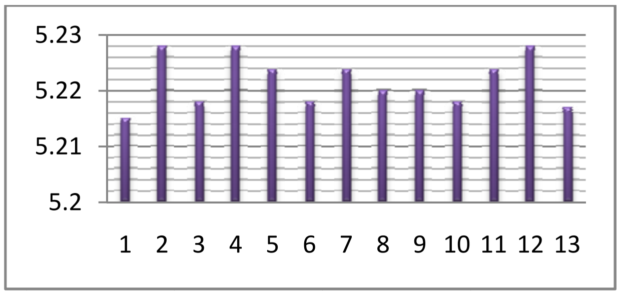

Fig. 12. 1 & 2 scenarios from IEAR point of view

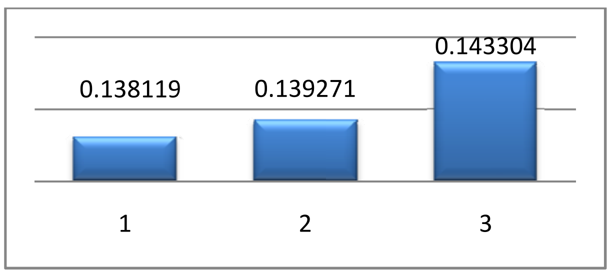

Fig. 13. Third scenario from SAIFI point of view

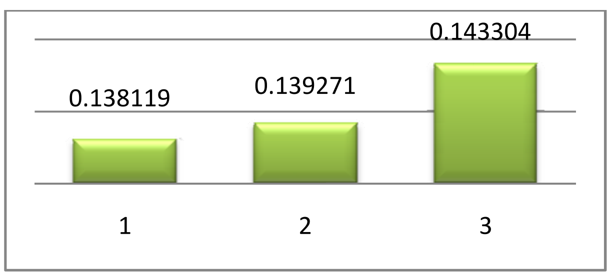

Fig. 14. Third scenario from CAIFI point of view

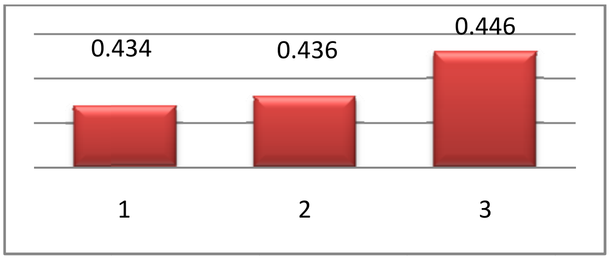

Fig. 15. Third scenario from SAIDI point of view

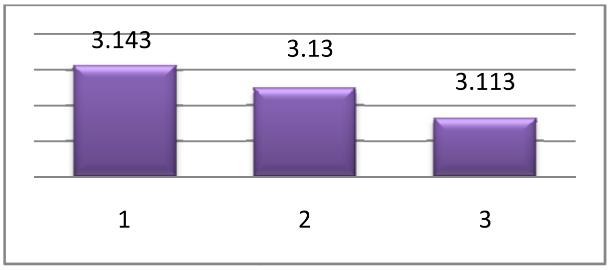

Fig. 16. Third scenario from CAIDI point of view

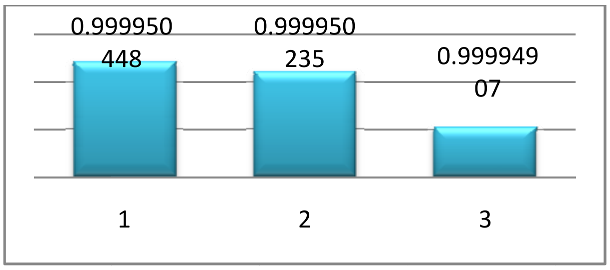

Fig. 17. Third scenario from ASAI point of view

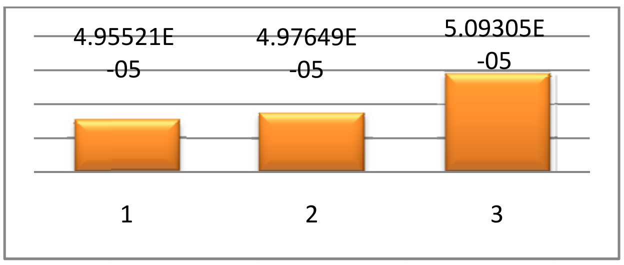

Fig. 18. Third scenario from ASUI point of view

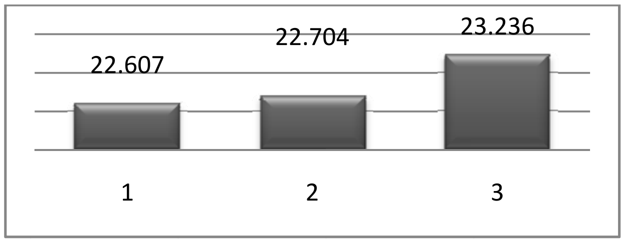

Fig. 19. Third scenario from ENS point of view

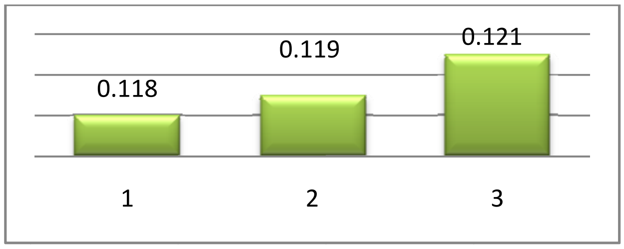

Fig. 20. Third scenario from EIC point of view

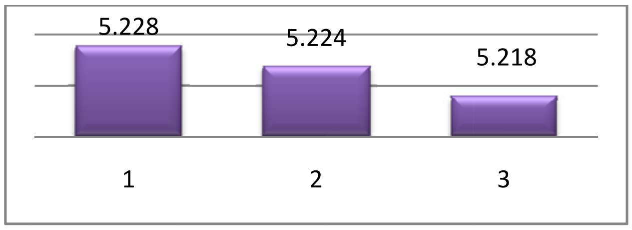

Fig. 21. Third scenario from IEAR point of view

Table 2. Reliability Assessment Results For Scenarios 1 & 2

Indices / Cases	SAIFI	CAIFI	SAIDI	CAIDI	ASAI	ASUI	ENS	AENS	ACCI	EIC	IEAR
1	0.145347	0.145347	0.45	3.093	0.999949	5.13246E-05	23.415	0.002	0.023	0.122	5.215
2	0.138119	0.138119	0.434	3.143	0.99995	4.95526E-05	22.607	0.002	0.023	0.118	5.228
3	0.14459	0.14459	0.448	3.1	0.999949	5.11713E-05	23.345	0.002	0.023	0.122	5.218
4	0.138119	0.138119	0.434	3.143	0.99995	4.95521E-05	22.607	0.002	0.023	0.118	5.228
5	0.139271	0.139271	0.436	3.13	0.99995	4.97654E-05	22.704	0.002	0.023	0.119	5.224
6	0.14459	0.14459	0.448	3.1	0.999949	5.11708E-05	23.345	0.002	0.023	0.122	5.218
7	0.139271	0.139271	0.436	3.13	0.99995	4.97649E-05	22.704	0.002	0.023	0.119	5.224
8	0.139751	0.139751	0.437	3.128	0.99995	4.99066E-05	22.768	0.002	0.023	0.119	5.22
9	0.139751	0.139751	0.437	3.128	0.99995	4.99006E-05	22.768	0.002	0.023	0.119	5.22

10	0.14459	0.14459	0.448	3.1	0.999949	5.11702E-05	23.345	0.002	0.023	0.122	5.218
11	0.140327	0.140327	0.439	3.125	0.99995	5.00665E-05	22.841	0.002	0.023	0.119	5.224
12	0.141134	0.141134	0.439	3.114	0.99995	5.01666E-05	22.887	0.002	0.023	0.12	5.228
13	0.14459	0.14459	0.448	3.1	0.999949	5.11718E-05	23.346	0.002	0.023	0.122	5.217

Table 3. Power Flow Results For 1&2Scenarios

Power Flow / Cases	Load [MW]	Load [Mvar]	Comp [Mvar]	External [MW]	External [Mvar]	Total Loss [MW]	Total Loss [Mvar]	Load Loss [MW]	Load Loss [Mvar]	No load Loss [MW]	No load Loss [Mvar]
1	52.08	9.71	0	52.2	12.53	0.12	2.82	0.12	1.36	0	1.47
2	52.08	9.71	1.22	52.2	11.31	0.12	2.82	0.12	1.36	0	1.47
3	52.08	9.71	8.07	52.21	4.47	0.13	2.83	0.13	1.37	0	1.47
4	52.08	9.71	8.07	52.21	4.47	0.13	2.83	0.13	1.37	0	1.47
5	52.08	9.71	3.63	52.2	8.88	0.12	2.81	0.12	1.34	0	1.47
6	52.08	9.71	2.1	52.2	10.43	0.12	2.83	0.12	1.36	0	1.47
7	52.08	9.71	2.43	52.2	10.1	0.12	2.83	0.12	1.36	0	1.47
8	52.08	9.71	2.35	52.2	10.18	0.12	2.82	0.12	1.35	0	1.47
9	52.08	9.71	3.13	52.2	9.4	0.12	2.83	0.12	1.36	0	1.47
10	52.08	9.71	2.9	52.2	9.63	0.12	2.83	0.12	1.36	0	1.47
11	52.08	9.71	2.94	52.2	9.59	0.12	2.82	0.12	1.35	0	1.47
12	52.08	9.71	2.21	52.2	10.31	0.12	2.82	0.12	1.35	0	1.47
13	52.08	9.71	3.8	52.2	8.71	0.12	2.8	0.12	1.34	0	1.47

Table 4. Reliability indices for 1, 2, 3 cases of Third scenario

Indices / Cases	SAIFI	CAIFI	SAIDI	CAIDI	ASAI	ASUI	ENS	AENS	ACCI	EIC	IEAR
1	0.138119	0.138119	0.434	3.143	0.999950448	4.95521E-05	22.607	0.002	0.023	0.118	5.228
2	0.139271	0.139271	0.436	3.13	0.999950235	4.97649E-05	22.704	0.002	0.023	0.119	5.224
3	0.143304	0.143304	0.446	3.113	0.99994907	5.09305E-05	23.236	0.002	0.023	0.121	5.218

Table 5. Power flow results for 1, 2, 3 cases of Third scenario

Power Flow / Cases	Load [MW]	Load [Mvar]	Comp [Mvar]	External [MW]	External [Mvar]	Total Loss [MW]	Total Loss [Mvar]	Load Loss [MW]	Load Loss [Mvar]	No load Loss [Mvar]
1	52.08	9.71	9.29	52.21	3.25	0.13	2.83	0.13	1.37	1.47
2	52.08	9.71	6.06	52.2	6.45	0.12	2.81	0.12	1.34	1.47
3	52.08	9.71	6.74	52.2	5.77	0.12	2.8	0.12	1.33	1.48

5. CONCLUSION

In order to know how the FACTS devices could change reliability indices, a distribution network has been studied by locating the SVC at different buses using three scenarios. From reliability point of view, it has been figured out that some buses have more advantages for the SVC replacement and are also better for power flow and less losses. The case has been repeated using two SVCs, rather than one and results enhanced. In the third case, it could be seen that although the SAIDI increased which is not suitable from reliability point of view, the CAIDI and interrupted energy assessment rate(IEAR) decreased which means customers endure lower prices for interrupted energy.The IEAR could be assumed as the most important parameter of reliability, because it is related to the cost. Finally, it could be concluded that in the third case, reliability indices and system losses. However reliability increase mostly needs more costs and capitals and based on the importance of the project decision making process will be finalized.

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Appendix: Test System