GA-Based Reliability Enhancement in Distribution Systems through Sagged Bus Numbers Reduction by Optimal Placement of Unified Series-Shunt Compensator

Mohammad Mohammadi
Department of Electrical Engineering, Borujerd Branch, Islamic Azad University, Borujerd, Iran
Mohamadi.m@iaub.ac.ir

***Abstract* –This paper presents a new method to reliability improvement of distribution system by optimal sizing and placement of unified series -shunt compensator (USSC).The GA based approach is used to solve the USSC optimization problem with considering capital cost of USSC installation and interruption costs due to interruption of loads in sensitive point. In this paper using ETAP software, the worst point that if three phase fault occur, therefore leads to the propagation of voltage sags to most number of system buses is investigated and located. Simulation results show that the proposed method is efficient and feasible for improving the system reliability level by reducing the number of sagged bus and load outages and momentary interruptions. Finally in this paper, after optimal location of USSC, the reliability improvement is investigated through expected energy not supplied (EENS) index, average system interruption frequency index (ASIFI) and the momentary average interruption frequency index (MAIFI).**

I. *Index terms* — Genetic Algorithm, Reliability, Voltage Sag, Unified Series Shunt Compensator

I. INTRODUCTION

Some researchers have developed suitable algorithms to analyze security of distribution system by predicting the response of the network seen by customers to the expected range of faults [1-2]. Many algorithms were also introduced on reliability assessment and improvement. An algorithm for reliability improvement using a static series voltage regulator (SSVR) can be found in [3]. The algorithm considers the effects of distributed generation (DG) units, alternative sources, system reconfiguration and load shedding. In a different approach, distribution static compensator (DSTATCOM) was utilized mainly to mitigate voltage sag propagation and avoid process interruption [4]. Voltage sag which is generally caused by short circuits may cause sensitive equipment to malfunction and process interruption. Once the process is interrupted it takes several hours to restart the process, hence affecting the reliability level in distribution systems. Voltage sag is defined as a decrease in rms voltage magnitude between 0.1 and 0.9 pu at duration of 0.5 cycle to 1 min [5]. In a related work, a method was introduced for voltage sag assessment based on whether the equipment will trip or not. As such voltage acceptability curves are introduced as a reliability indicator from the customer's perspective [6-7]. Based on the above discussion, it can be concluded voltage sag causes power supply interruption for many types of loads and reliability level in distribution system is extremely affected by voltage sag performance. In other words, voltage sag mitigation methods can be employed for improving the reliability of distribution systems. Science the STATCOM and dynamic voltage restorer (DVR) are only useful for compensating a particular type of power-quality problem and therefore, in order to reduce total investment and installation cost of FACTS device, for avoiding from separates investment costs for DVR and D-STATCOM installing , it is necessary to develop a new kind of unified series-shunt compensator (USSC) which can mitigate various power-quality problems that results to not any need to DVR and D-STATCOM installation [8], [9]. By using a unified approach of series-shunt compensators, it is possible to compensate for a variety of power-quality problems in a distribution system including voltage sag compensation, swell compensation, unbalance voltage mitigation and flicker reduction. This paper deals with the optimal location of this device facts compensator and it's effectiveness in mitigating various power quality problems [10-11].

In this paper, a new method for improving reliability of distribution system is presented based on the optimal placement of the USSC. In the proposed method, an algorithm for reducing the exposed area of voltage sag propagation due to weak area is first developed using ETAP software analysis. Then, USSC placement is employed for reducing the number of propagated sags throughout the distribution systems. A genetic algorithm (GA) based method is used as heuristic computational optimization tool to determine the optimal USSC placement. Finally, for reliability assessment, a method for calculating the number of sags which may be experienced at each load point in distribution system is used along with reliability indices such as ASIFI and MAIFI. The proposed method may assist utility engineers in taking the right decision for system reliability improvement.

II. USSC MODELING

The Unified Series Shunt Compensator is a combination of series and shunt voltage source inverters as shown in Figure 1. The basic components of the USSC are two 12-pulse voltage source inverters composed of forced commutated power semiconductor switches, typically Gate

Turn Off (GTO) thyristor valves. One voltage source inverter is connected in series with the line through a set of series injection transformers, while the other is connected in shunt with the line through a set of shunt transformers. The dc terminals of the two inverters are connected together and their common dc voltage is supported by a capacitor bank [12]. The USSC is almost similar to the UPFC, but the only differences are that the UPFC inverters are in shunt series connection and used in transmission systems whereas the USSC inverters are in series-shunt connection and used in distribution systems [13].

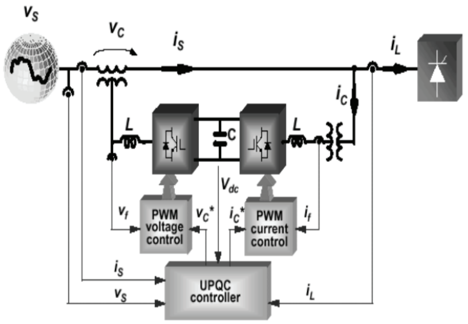

Figure 1: General configuration of Unified Series Shunt Compensator-USSC

III. CAPABILITIES OF USSC VERSUS D-STATCOM AND DVR

Since the introduction of FACTS and custom power concept [14], devices such as unified power-flow controller (UPFC), synchronous static compensator (STATCOM), dynamic voltage restorer (DVR), solid-state transfer switch, and solid-state fault current limiter are developed for improving power quality and reliability of a system [15], [16]. Advanced control and improved semiconductor switching of these devices have achieved a new era for power-quality mitigation. Investigations have been carried out to study the effectiveness of these devices in power-quality mitigation such as sag compensation, harmonics elimination, unbalance compensation, reactive power compensation, power-flow control, power factor correction and flicker reduction [17-18]. These devices have been developed for mitigating specified power-quality problems. By using a unified approach of series-shunt compensators it is possible to compensate for a variety of power-quality problems in a distribution system including sag compensation, flicker reduction, unbalance voltage mitigation, and power-flow control [19]. Usually individual custom power devices such as DSTATCOM and DVR focus on solving specific power quality problems in a distribution system. However, by using USSC, it is possible to compensate a different power quality problem as compared to DSTATCOM and DVR as indicated in Table I [20].

Table I Power quality mitigation using USSC versus others custom power devices

Power Quality Mitigation	DVR	D-STATCOM	USSC
Sag Compensation	YES	Limited	YES
Voltage Flicker	NO	YES	YES
Unbalance	NO	YES	YES
UPS Mode	YES	YES	YES
Power Flow Control	NO	NO	YES
Harmonic Elimination	NO	YES	YES

It is noted that, mitigated load voltage by the DVR is a steady state value but this value is lower than mitigated value obtained by USSC. In other words the USSC can mitigate voltage sag better in compared to DVR and D-STATCOM. Also in case of voltage flicker, unbalance and harmonics elimination it is much effective. Similarly, D-STATCOM is unable to control power flow. It is seen that the proposed USSC can mitigate variety of PQ problems [21].

IV. USSC INSTALLATION IN DISTRIBUTION SYSTEM

Before modeling the USSC, all distribution system components, i.e., lines and cables, loads, transformers, large motors and generators have to be converted into equivalent reactance (***X***) and resistance (***R***) on common bases. The main system component models are used in the formulation of impedance matrix for voltage sag calculation [22]. In steady state analysis, the series and shunt inverters of the USSC are presented by two voltage sources V_{dq} and V_{sh} respectively as shown in Figure 2.

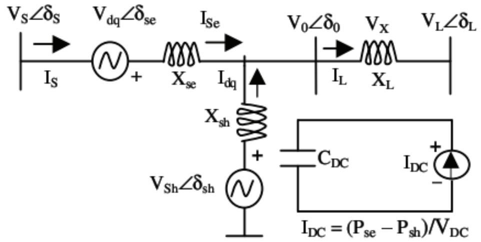

Figure 2: Equivalent circuit of USSC

X_{sc} and X_{sh} represents the reactance of the transformers associated with the series and shunt voltage source inverters, respectively. Therefore, voltage equation of series and shunt inverters can be expressed as follows:

$$V_s = -V_{dq} + I_{se}(jX_{se}) + V_0 \tag{1}$$

$$V_s + V_{dq} - I_{se}(jX_{se}) = V_{sh} + I_{dq}(X_{sh}) \tag{2}$$

$$I_s = I_{se} = I_{dq} + I_L = \frac{V_{sh} - V_0}{X_{sh}} + I_L \tag{3}$$

Where I_{sc} and I_{dq} are the series and shunt inverter currents, respectively.

The voltage across the distribution line reactance, X_L is

$$\begin{aligned} V_X &= V_s + V_{dq} - I_{se}(jX_{se}) - V_L = \\ V_0 - V_L &= X_L.I_L \end{aligned} \tag{4}$$

Where, I_L is distribution line current.

The voltage, V_X, across the distribution line can be changed by changing the inserted voltage, V_{dq}, which is in series with the distribution line. If we consider $V_{dq}=0$, the distribution line sending end voltage, V_S, leads the load voltage by an angle δ i.e $\delta_S - \delta_L$.

The resulting real and reactive power flows at the load side are P and Q, which are given as follows:

$$P_{ussc} = \frac{V_0.V_L}{X_L}\sin\delta \tag{5}$$

$$Q = \frac{V_0.V_L}{X_L}(1-\cos\delta) \tag{6}$$

With an injection of V_{dq}, the distribution line voltage V_0 will lead the load voltage V_L, and $\delta_0 > \delta_L$., thus the resulting line current and amount of flow Will be changed. With a larger amount of V_{dq} injection, V_0 now lags the load voltage V_L, and $\delta_0 < \delta_L$.

Consequently, the line current and power flow will be reversed.

V. OPTIMIZATION PROBLEM FORMULATION

In this work, the objective function of USSC placement process is formulated to minimize the total number of sags with optimal investment cost.

i.e this objective function is considered as follows:

Minimize:

$$C_{Total} = \alpha_1 \times C_1 + \alpha_2 \times C_2 \tag{7}$$

Here C_1 represents the interruption cost due to load curtailment in buses affected by voltage and C_2 is related to total investment cost of the USSC devices. α_i are weight coefficients factors in objective function.

The interruption cost is represented as follows [23] :

$$C_1 = \sum_{j=1}^{N_{sag}} \sum_{i=1}^{N_{L,j}} C_{ij}.L_{ij} \tag{8}$$

Where N_{Sag} is the total number of sag events in the specified simulation period.

C_{ij} represents the adjusted per-unit interruption cost and L_{ij} indicates the adjusted average load.

$N_{L,j}$ represents the total number of load connected to ***jth*** bus encountered by voltage sag.

C_2 as investment cost of USSC can be expressed as follows:

$$\text{Cost} = \text{N}_{\text{USSC}} \times \text{C}_{\text{USSC}} \tag{9}$$

According to [24-25], the cost function for USSC is given below:

$$\text{C}_{\text{USSC}} = 0.0003R^2 - 0.2691R + 188.22 \quad (US\ \$/kVar) \tag{10}$$

Here, ***R*** is the operating range of the USSC and is calculated as follows:

$$R = \left|Q_2 - Q_1\right| \tag{11}$$

Where Q_1 is the MVAR flow through the branch before placing USSC device and Q_2 is the MVAR flow through the branch after placing USSC device.

The necessity of optimization in this work is to find optimal solution for voltage sag mitigation problem in distribution systems. The formulation of suitable objective function is the main step in optimization. The solution is by determining optimal placement and sizing of USSC in distribution system. In this work, the objective function of USSC placement process is formulated to minimize total costs including interruption cost and investment cost through minimizing the total number of sags. During the searching process, for every change in the device location, the number of sagged buses N_{sag} must be calculated. This maybe done using calculation of healthy buses (N_{hlth}) and system losses (F_{loss}) must be calculated by short circuit analysis and steady state load flow. The calculation must be subjected to system operation constraints, where these constraints can be mentioned as:

$$\left|V_{\min}\right| \le \left|V_i\right| \le \left|V_{\max}\right| \tag{12}$$

$$\left|\delta_{\min}\right| \le \left|\delta_i\right| \le \left|\delta_{\max}\right| \tag{13}$$

$$\left|I_i\right| \le \left|I_{i,\max}\right| \tag{14}$$

Equation (12) represents the nominal bus voltages must be within standard limits, where ***Vi*** is voltage magnitude of bus ***i***, ***Vmax*** is the maximum limit of nominal voltage magnitude and ***Vmin*** is lower limit of nominal voltage magnitude.

Equation (13) represents the angle bus voltages must be within standard limits, where δ_i is voltage angle of bus i, $\delta_{\max}$ is the maximum limit of nominal voltage angle and $\delta_{\min}$ is lower limit of nominal voltage angle.

Equation (14) represents the current flows must be within the thermal limits of the lines. Where ***Ii*** is the current of line i and ***Iimax*** is the thermal limit of the line i.

The system line loss (Floss) obtained from load flow calculations must also be within acceptable limits.

The number of buses reaching the healthy condition (N_{hlth}) due to the compensation of the USSC must be calculated. In this case a bus is said to be healthy when its voltage magnitude lies between 0.9 pu and 1.06 pu. If ***Ci*** is the healthy condition (0 or 1) for bus i during voltage sag duration, then it can be formulated as:

$$N_{hlth} = \sum_{i=1}^{N_{sys}} C_i \tag{15}$$

$$C_i = \begin{cases} 1......0.9 \le V_i \le 1.06 \\ 0......................esle \end{cases} \tag{16}$$

$$N_{sag} = N_{sys} - N_{hlth} \tag{17}$$

After optimal placement of USSC, in order to evaluate the impact of USSC on reliability of distribution system, the reliability assessment is carried out based on load based index such as the average system interruption frequency index (***ASIFI***) and momentary index such as the momentary average interruption frequency index (***MAIFI***) are most suitable for reliability assessment related to voltage sag problems.

Improvement in voltage sag performance results in reliability level improvement. If the calculated number of sags can be translated into momentary interruptions and load outages, the corresponding reliability indices can be obtained. The calculation of those indices can be carried out directly by using the number of sags. The sustained interruptions are considered for all downstream loads of the faulted bus. At the same time, all upstream loads of the same faulted bus may experience momentary interruptions due to voltage sags.

The calculation of average system interruption frequency index (***ASIFI***) is based on load outages rather than customers affected, where the voltage sag may cause load outages.

If L_i is the connected kVA load interrupted for each interruption event, and L_T is the total connected kVA load served, the indexes which indicate the reliability level due to load outages can be expressed as [26]:

$$ASIFI = \frac{\sum L_i}{L_T} \tag{18}$$

If ***IMi*** is number of momentary interruptions for each event, ***Nmi*** is number of interrupted customers for each momentary interruption event during the reporting period and ***NT*** total number of customers served for the areas, the index which indicates the reliability level due to customers interruptions can be expressed as [26]:

$$MAIFI = \frac{\sum IMi \times Nmi}{N_T} \tag{19}$$

Another reliability index is the total energy not supply ENS_i is calculated as follows [23] :

$$ENS = \sum_{j=1}^{N_{sag}} \sum_{i=1}^{N_{L,j}} C_{ij} . r_{ij} \tag{20}$$

Where r_{ij} represents the failure duration that can include any required adjustments.

The improvement of reliability level corresponding to the mitigating of voltage sag in distribution systems can be indicated by the calculation of these three indices. The previous developed method of voltage sag mitigation can be evaluated and assessed by using (7) for the total number of propagated sags. In the same manner, the proposed method can assess reliability level improvement by using the reliability indices (18-20). The assessment is done for the base case and before and after optimal placement of USSC.

VI. GENETIC ALGORITHM

GA is a search method based on the natural selection and genetics. GA is computationally simple yet powerful and it is not limited by assumptions about the search space. The most important goal of optimization should be improvement. Although GA cannot guarantee that the solution will converge to the optimum, it tries to find the optimum, that is, it works for the improvement. The GA is basically an evolutionary algorithm, analogous to a part of the physical world. GA is a stochastic optimization technique introduced by [27]. Binary and floating-point representations are used to implement GA, for the sake of comparison. In the binary implementation, each element of a string (or chromosome) vector was coded using the same number of bits and each occupied its own fixed position. The minimization process in the binary representation used is characterized by the following.

The implemented GA starts by randomly generating an initial population of possible solutions. For each solution a value of power generation units is chosen between 0 and a maximum limit, fixed by the planner on the ground of economical and technical justifications; then, a different size of USSC are randomly chosen until the total amount of power installed reaches the facts device penetration level assigned. At this point, the objective function is evaluated verifying all the technical constraints. In Figure 3 the block diagram of optimization problem has been shown.

Parameters used for the GA with binary representation include:

Population size 30, String length 10 bits, Reproduction rate 40% for the first preferred string; 30% for the second preferred string; 20% for the third preferred string.

Crossover rate from exp (0.10) to exp (0.86), Mutation rate from exp (0.500) to exp (0.005), Maximum number of generations is 1500.

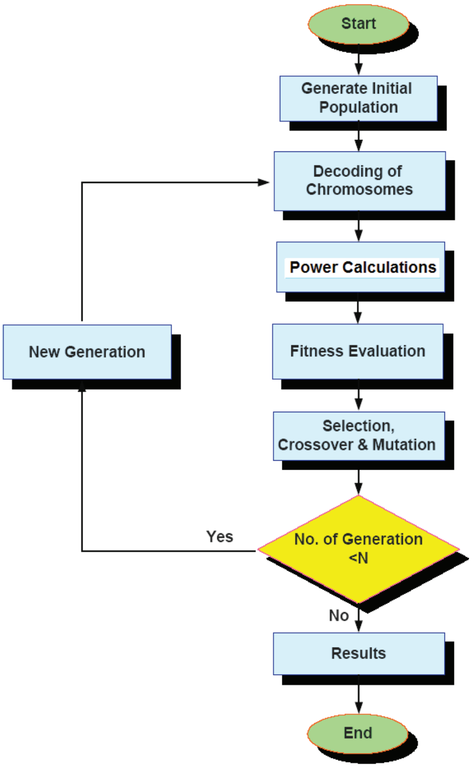

Figure 3: Block diagram of optimization problem

VII. WEAK AREA ANALYSIS FOR FAULT POINT LOCATION USING ETAP SOFTWARE

The fault analyses were performed for all buses of distribution system. Following three phase fault in bus number 1 of system, the voltage magnitude for all buses of distribution system will be calculated using ETAP and so this procedure will be repeated for all buses of system from bus number 1 to N_{sys}.

The results of this procedure will be set as three dimension matrix, where the X-axis represents the number of system buses, Y-axis represents the fault locations and Z-axis represents the bus voltage magnitudes read according to the degree of darkness. The voltage sag distribution on all system buses for three phase fault with zero fault resistance Z_f will be obtained. These results could be depicted as a surface that the greatest darkness points of voltage sag distribution (Z-axis) shows the sensitive buses in propagating voltage sag throughout the system. Therefore, this group of buses is considered as a weak area in the system. Among the weak buses, the weakest bus that leads to the propagation of voltage sags to most number of system buses will be considered for occurring fault as the worst point in system [28-29].

So the three phase fault will be occur in the worst point and best locations and sizes of USSC with considering investment coast and interruption cost for minimize sagged bus numbers will be optimized.

VIII. SIMULATION AND DISCUSSION

The case study considers a 15-node distribution network, connected to the transmission grid by a substation with 30 MVA, 115/10 kV. The feeders of the lines are 3X1X400Al, using a double circuit for trunk lines and simple circuit for branch lines. The topology of this distribution network is shown in Figure 4.

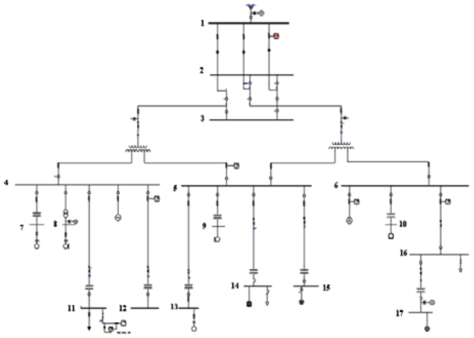

Figure 4: Topology of the distribution network of 15 nodes

The system includes two large induction motors that are connected to buses of numbers 9 (50 kw) and 13 (75 kw) respectively.

The load point data of test system is listed in Table II.

Table II Load and customers at respective load point

Load	Total_Load (MW)	No. of Customers
4	120	10
5	145	30
6	120	25
7	250	60
8	240	40
9	130	50
10	145	60
11	130	30
12	100	40
13	145	50
14	50	40
15	90	50
16	80	30
17	90	20
18	90	30

Also there DC loads rectified using converter are connected to buses 4, 11 and 14 that as a result they generate flickers and harmonics and insert them to network. So in order to mitigate flickers and harmonic instead of design an independent active power filter (APF), the USSC is considered to mitigate other power quality phenomena too. Of course, the selecting of USSC is implemented based on considering economic and reliability indices in distribution system.

The fault analyses were performed for all buses with rated 11kV voltage level except the main substations.

Figure 5 represents the three dimensions figure, where Y-axis represents the fault locations, the X-axis represents the number of system buses and Z-axis represents the bus voltage magnitudes.

The voltage sag distribution on all system buses due to a three phase fault (LLL) without any fault impedance (Zf=0) is depicted in Figure 5. It is clear from the voltage sag distribution on Z-axis that buses 4, 5, 6, 9 and 14 are the most sensitive buses in extending voltage sag throughout the system. So, this group of buses is considered as weak points in the system to propagate voltage sag. Between the weak buses (15 in number), bus 5 is considered as the weakest bus in the system, because in case of occurring fault in this bus, the voltage sag can be easily extent to the most buses of system.

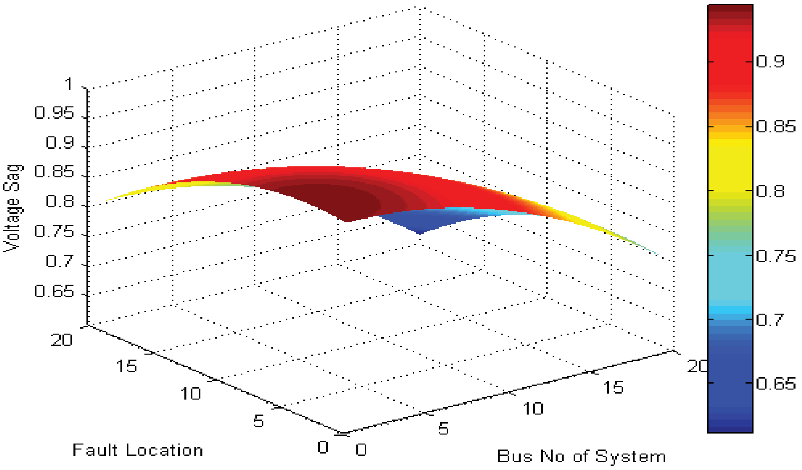

Figure 5: Sag distribution in terms of system buses due to three phase fault at various fault locations

Short circuit analysis is performed using ETAP software; on all of buses of system .Figure 6 indicates the simulation model of system in ETAP for this purpose.

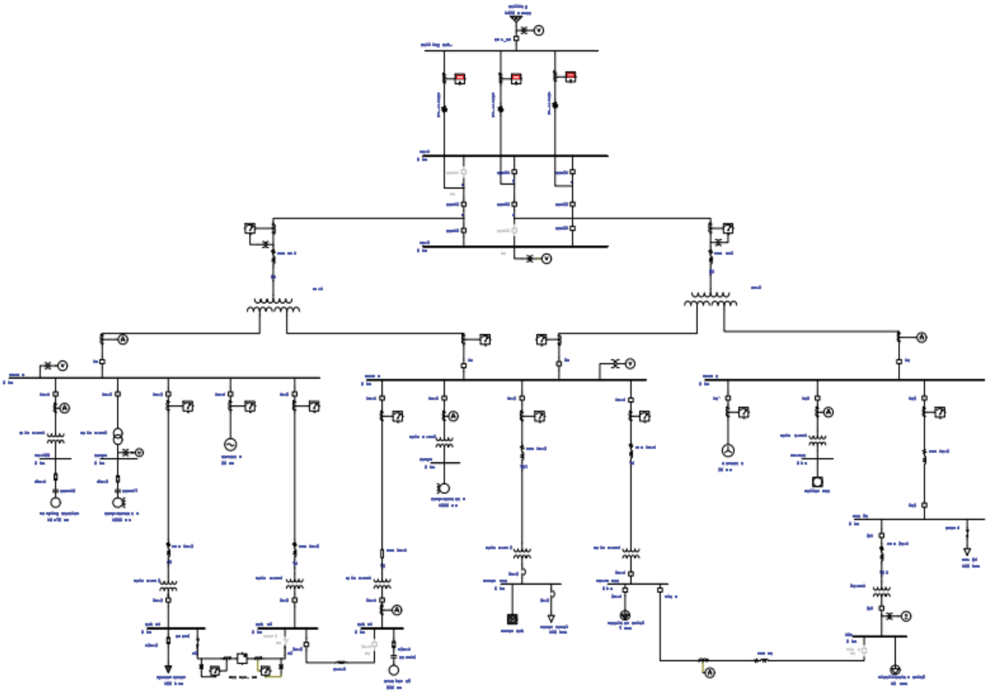

Figure 6: Etap (Power Station) model of studied distribution network

Figure.7 represents the distribution of voltage sag because of three phase fault at bus in compared with base case voltage profile of the system. From this figure it is obvious that the voltage magnitudes of all buses of system are within standard limits during base case load flow but in case of considering three phase fault in bus 5, it causes voltage sag propagation at the most buses of system.

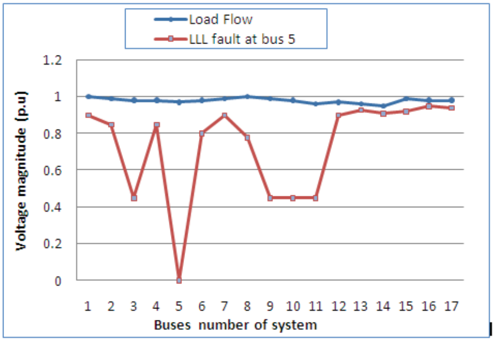

Figure 7: Voltage magnitudes of system buses at base case and During three phase fault at bus 5

It is notable that determination of the weak area is a main step in the voltage sag assessment and mitigation because it gives adequate information to optimize optimal placement and sizing of the studied system using the GA algorithm as an optimization tool. Figure 8 shows the convergence of the GA algorithm to minimize the total costs including capital cost and interruption cost as objective function (7) and determine optimal placement and sizing of USSC.

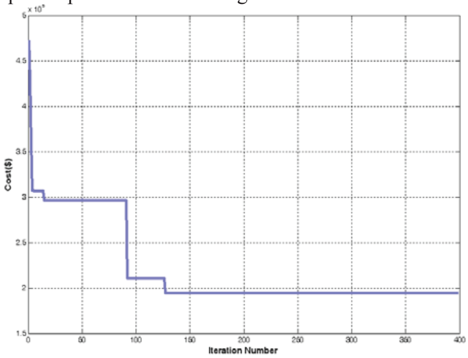

Figure 8: Convergence characteristics of GA for optimal placement Of USSC fitness function

The optimum size and placement can be selected by the algorithm within the range 0-1MVA.

Table III gives this result.

Table III The optimum size and placement of USSC

USSC Location		Capacity (MVA)
Beginning Feeder	Ending Feeder	
5	13	0.3642
4	11	0.5255

The voltage sag distribution on all system buses for three phase fault with zero fault resistance (Zf=0) in presence of USSCs in optimal locations in comparison without any USSC is shown in Figure 9.

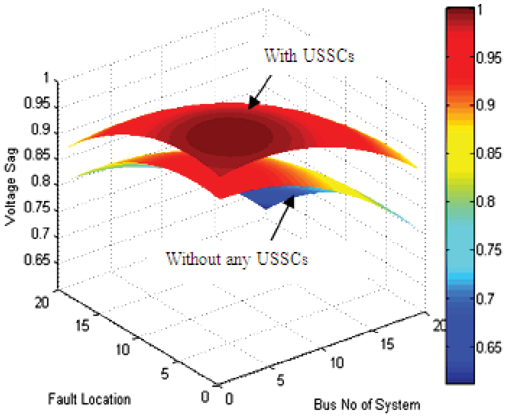

Figure 9: Improvement of sag distribution in terms of system buses due to three phase fault at various fault locations after USSCs placement

Figure 10 shows the simulation results of short circuit analysis due to a fault at bus 5 along with the base case voltage profile after optimal placement of USSC. An improvement in the number of healthy buses can be observed as compared with the results of pre USSC installation.

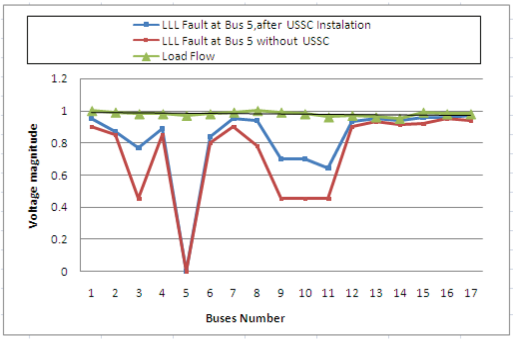

Figure 10: Voltage magnitudes of system buses at base case and during three phase fault at bus 5, after optimal placement of USSC

Table IV gives the improvement system indices using USSC in placement with optimal size.

Table IV USSC installation assessment

Item	Before USSC Placement during Fault	After USSC Placement during Fault
Sagged Bus during fault in weakest bus with suppose Vcrit=0.86 p.u	10	4
Load Point Outage	10	4
ENS Index (kW/yr)	258	126
Interruption Cost ($/yr)	145	98
ASIFI Index	0.83540	0.38460
MAIFI Index	1.84847	1.13630

As seen in table IV, by USSC, the number of sagged buses of system, during fault in weakest point, decease from 10 buses to 4 buses. Therefore the more little load point will be interrupted, so this reduce interruption cost from 145 [$/yr] to 98 [$/yr].

In order to analyze the validation the obtained results, the sensitivity analysis is done based variation of capacity USSC on reliability parameters of system. In order to investigate the effect of capacity of USSC on ASIFI index of system, the variation of capacity in terms of MVA to achieve ASIFI Index as per unit between 0 to1 is indicated in Figure 11. Figure 12 shows the similar variation of MAIFI versus of capacity of USSC. It seen that the convergence of result is very good.

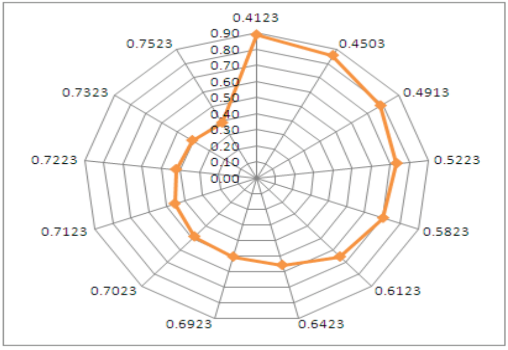

Figure 11: The variation of MVA of USSC versus the per unit value of ASIFI Index

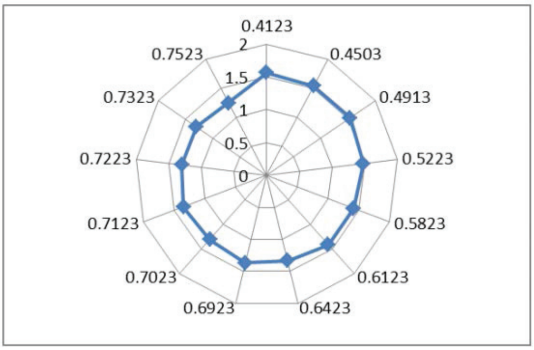

Figure 12: The variation of MVA of USSC versus the per unit value of MASIFI Index

IX. CONCLUSION

In this paper, reliability enhancement with considering installation cost of distribution flexible ac transmission (DFACTS) device in distribution system has been investigated. The reliability improvement is investigated by optimal placement and sizing of unified series shunt controller (USSC) as a voltage sag numbers reduction approach in order to minimizing interruption cost and capital costs. The simulation results indicate that the proposed technique is efficient to improve reliability of distribution network. The reliability assessment indices such as EENS, ASIFI & MAIFI are evidences of benefits of the proposed method. The main reason in selection of USSC as voltage sage mitigation device in this study is related to many capabilities of this device in mitigation various power quality phenomena in respect to other facts devices. Of course, this study focuses on voltage sag mitigation using USSC and so the optimal placement and sizing of this DFACT is considered and analyzed. The optimization is performed based on minimizing total cost including capital cost for USSC installation and interruption costs for considering reliability improvement due to sagged buses reduction and therefore reduction of outage load points.

REFERENCES

[1] Singh, B., K. Al-Haddad and A. Chandra, 1999, a review of active filters for power quality improvement, IEEE Trans. Ind. Elect, 46: 960-971.

[2] Crow, M.L., 2004. Power quality enhancement using custom power devices. IEEE Power Energy Magazine, 42: 50-56.

[3] Ramirez, J.M., Gonzalez and M.L. Crow, 2007. Steady state formulation of FACTS devices based on ac/ac converters. IET Generat. Transmission Distribut., 1: 619-631

[4] Zarghami, M. and M.L. Crow, 2007. The existence of multiple equilibria in the upfc power injection model. IEEE Trans. Power Syst., 22: 2280-2282.

[5] Pohjanheimo, P. and E. Lakervi, 2000. Steady state modeling of custom power components in power distribution networks. In: IEEE Power Engineering Society Winter Meeting, pp: 2949-2954.

[6] Parle, J.A., M. Madrigal and E. Acha, 2001. Trends in power quality monitoring. IEEE Power Eng. Rev., 21: 3-21.

[7] Oliver, J.A., R. Lawrence and B.B. Banerjee, 2002, How to specify power-quality-tolerant process equipment, IEEE Ind. Appl. Magazine, 8: 21-30.

[8] Shin, Y.J., E.J. Powers, M. Grady and A. Arapostathis, 2006. Power quality indices for transient disturbances, IEEE Trans, Power Delivery, 21: 253-261.

[9] Enslin, J.R., 1998. Unified approach to power quality mitigation, In: Proceeding of IEEE, International Symposium on Industrial Electronics (ISIE '98), 1998, pp: 8-20

[10] Olimpo, A.L and E. Acha, 2002. Modelling and analysis of custom power systems by PSCAD/EMTDC. IEEE Trans. Power Delivery, 17: 266-272.

[11] Neha Bajpai and S.Gupta, Simulation of Unified Series Shunt Compensator for Power Quality Improvement, Special Issue of International Journal of Computer Applications, on Electronics, Information and Communication Engineering - ICEICE No.2, Dec 2011.

[12] S. Asha Kiranmai M.Manjula A.V.R.S.Sarma, Mitigation of Various Power Quality Problems Using Unified Series Shunt Compensator in PSCAD/EMTDC, 16th National power systems conference, 15th-17th december, 2010.

[13] M A Hannan, A Mohamed and A Hussain, Dynamic Phasor Modeling and EMT Simulation of USSC, Proceedings of the World Congress on Engineering and Computer Science 2009 Vol I , WCECS 2009, October 20-22, 2009, San Francisco, USA.

[14] Arnez, R.L. and L.C. Zanetta, 2002. Unified power flow controller (UPFC): Its versatility in handling power flow and interaction with the network. In: IEEE/PES Asia Pacific Transmission and Distribution Conference and Exhibition, pp: 1338 -1343

[15] Hingorani, N.G. And L. Gyugyi, 2000. Understanding FACTS Concept and Technology of Flexible AC Transmission System. IEEE Press, New York.

[16] Su, C. And G. Joos, 2000. Series and shunt active power conditioners for compensating distribution system faults. In: Procedding of the Canadian Conference on Electrical and Computer Engineering, pp: 1182-1186.

[17] Jin Nan, Tang Hou Jun, Yao Chen, Wu Pan, Topology and Control of Chopper Type Dynamic Voltage Regulator, International Review of Electrical Engineering (IREE), February, 2011, vol.6, no.2, part A, pp.160-168.

[18] [18] Hendri Masdi, Norman Mariun, S. M. Bashi, Azah Mohamed, Voltage Sag Compensation in Distribution System due to SLG Fault

Using D-STATCOM, International Review of Electrical Engineering (IREE) ,December, 2010,vol.5,no.6,part B,pp.2836-2845.

[19] M. A Hannan and A Mohamed, Unified Series-Shunt Compensator Modeling and Simulation, 2004 IEEE, National Power & Energy Conference (PECon) 2004 Proceedings, KuaIa Lumpur, Malaysia.

[20] [20] M.A. Hannan, A. Mohamed, A. Hussain and Majid al Dabbay , Development of the Unified Series-Shunt Compensator for Power Quality Mitigation, American Journal of Applied Sciences 6 (5): 978-986, 2009.

[21] M. A. Hannan and Azah Mohamed, PSCAD/EMTDC Simulation of Unified Series-Shunt Compensator for Power Quality Improvement, IEEE Transactions on power delivery, vol. 20, no. 2, april 2005.

[22] Gyugyi, L., K.K. Sen and C.D. Schauder, 1999. The interline power flow controller concept: A new approach to power flow management in transmission systems. IEEE Trans. Power Delivery, 14: 1115-1123.

[23] Peng Wang and Roy Billinton,Reliability Cost/Worth Assessment of DistributionSystems Incorporating Time-Varying Weather Conditions and Restoration Resources, ieee transactions on power delivery, vol. 17, no. 1, january 2002.

[24] Lijiun Cai, and Istvan Erlich, “Optimal choice and allocation of FACTS Devices using Genetic Algorithms,” ISAP Intelligent Systems Application to Power Systems, 2003lemnos, Greece, August 31-September 3, 2003.

[25] http://www.siemens/td.com/trancSys/pdf/cost/ effectiveReliabTrans.pdf.

[26] IEEE_Std.1366, "IEEE Guide for Electric Power Distribution Reliability Indices," IEEE Std 1366-2003 (Revision of IEEE Std 1366-1998), ed. New York: IEEE, 2004.

[27] D.E. Goldberg, Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley, Reading, MA, (1989).

[28] Nesrallh salman, Azah mohamed, Hussain shareef, Reliability Improvement in Distribution Systems by Optimal Placement of DSTATCOM Using Binary Gravitational Search Algorithm, Electrical Review), R. 88 NR 2/2012.

[29] Perttu Parkatti, Heikki Tuusa, Experimental Comparison of Current Source and Voltage Source Active Filters with and without the Series-Connected Capacitor, International Review of Electrical Engineering (IREE), December, 2011, vol.6, no.1, part a, pp.149-159.