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A Customer-Oriented Approach for Distribution System Reliability Improvement Using Distributed Generation and Switch Placement

P. Salyani, J. Salehi *

Department of Electrical Engineering, Azarbaijan Shahid Madani University, Tabriz, Iran.

Abstract- *The reliability of distribution networks is inherently low due to their radial nature, consequently distribution companies (DisCos) usually seek to improve the system reliability indices with the minimum possible investment cost. This can be known as system-oriented reliability planning (SORP). However, there can exist some customers that are not satisfied by their reliability determined by adopting the SORP and they may be eager to have a higher level of reliability. Therefore, other planning in addition of SORP is required to concern the customer viewpoint reliability. This paper introduces the customer-oriented reliability planning (CORP) in medium voltage network which is an innovative approach in the context of load point reliability. To this end, first a SORP is conducted to improve the distribution system reliability index. Then the strategy is revised and the CORP is adopted by DisCo considering involving the results obtained in SORP and the customers that have declared to reduce their expected energy not supplied (EENS). Since the surplus investment cost stem from the planning revision is received from the requestor customers, CORP can provide a proper and acceptable mechanism to fairly allocate the surplus cost to those customers. Furthermore, this problem is studied under the probabilistic nature of distribution network. Simultaneous placement of distributed generators (DGs) and automatic sectionalizing switches is implemented too with a new defined load shedding mechanism in order to enhance the reliability level for both mentioned planning frameworks.*

Keyword: Automatic Sectionalizing Switches, Customer-Oriented Reliability Planning, Distributed Generators, Reliability, System-Oriented Reliability Planning.

NOMENCLATURE

β	Risk aversion parameter
$PP^{\max}$	Penetration percentage of DG
CC_{as}	Capital cost of automatic sectionalizing switch ($)
CC_{DG}	Capital cost of automatic sectionalizing switch ($)
$ENS_{i,\omega}^{CORP}$	EENS of customer i obtained in CORP and in scenario ω (kWh)

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$\mathrm{E}_{\omega}\{\cdot\}$	Expected function
$EENS_i^{SORP}$	EENS of customer i obtained in SORP (kWh)
g_{ω}	Load growth rate in scenario ω
$G_{i,j}, B_{i,j}$	Conductance and susceptance of the section between bus i and bus j (℧)
MC_{DG}	Maintenance cost of DG ($/kWh)
$I_{\ell,t,\omega}$	Current in section ℓ, year t and scenario ω (A)
MC_{as}	Maintenance cost of automatic sectionalizing switch ($/yr)
N_i^{Cus}	Number of low voltage customers in bus i
N_{max}^{DG}	Maximum number of DGs that can be utilized in the network
$N_{\max}^{as}$	Maximum number of available automatic switches
OC_{DG}	Operation cost of DG ($/kWh)
$PP^{\max}$	Penetration percentage of DG
PW_t	Present worth factor in year t
P_i^{DG}	Active power of DG i
$P_{i,t,\omega}^{L}$	Selling energy price ($/kWh)
rt	Repair time of feeder (hr)
$Q_{i,t,\omega}^{L}$	Load of bus i in year t and scenario ω (kW)
r_{ℓ}	Resistance of section ℓ (ohms)

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*Corresponding author:
E-mail: j.salehi@azaruniv.ac.ir (J.Salehi)
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$\mathrm{Res}\{.\}$	Restitution function
$SAIDI_{tar}$	Target SAIDI (cus/hr)
T_h	Total number of hours in a year
$V_{i,t,\omega}$	Voltage in bus i, year t and scenario ω (V)
X_ℓ	Binary variable that is 1 if any switch is installed in section ℓ
ρ^{MP}	Market energy price ($/kWh)
$\Gamma_{i,\omega}$	EVC of customer ($)
ζ_i	Decision variable that is 0 if the ENS of customer i in scenario ω exceed the $EENS_i^{SORP}$ otherwise is 1
ρ^{SP}	Selling energy price ($/kWh)
$\lambda_{\ell,\omega}$	Failure rate of section ℓ in scenario ω (fr/km.yr)
γ_i	VOLL of customer i ($/kWh)
$\theta_{i,j}$	Angle between bus i and j (rad)
$\tau_{\ell,i,t,\omega}$	Outage time of load point i in year t and scenario ω that is effected by failure occurrence in section ℓ (hr)
$\Lambda(.)$	Covariance function
$\Upsilon(.)$	Variance function

1. INTRODUCTION

Evolving from monopolized structure into a restructured environment implies the replacement of public utilities with private companies. Considering the technical constraints, investment with the lowest possible cost to reach the acceptable system indices is the main objective of these companies. Distribution sector because of its low degree of protection and also aging problems accounts for more than 90% of failures in power system. This problem has negative effect on customer satisfaction and makes the reliability issue of importance. Typically when the reliability level of system is low, DisCos are obliged by independent system operator (ISO) to enhance the reliability of system otherwise they will face up to inconveniences and discontent growth.

Moreover the probable nature of the failures implies the trade-off between the cost and risk of investment on reliability which can be handled by applying the asset management principles. Investment on reliability as a subset of distribution system planning includes the fields such as placement of sectionalizing switches or sizing and allocation of distributed generators (DGs).

As the earliest studies on reliability improvement in distribution system and in the field of switch placement, Roy Billinton et al. in Ref. [1] have solved the optimal switch placement problem with the objective of reducing the system unsupplied energy. In references [2] and [3], the distribution network is automated by equipping the system to the automated and remote-controlled sectionalizing switches reduce the customer outage duration, however the last term has mathematically modelled the problem through mixed-integer linear programming. Also the authors in Ref. [4] have modelled the switch placement problem by mixed-integer nonlinear programing (MINLP) which determined the type of switch too.

Also, Ref. [5] determines the set of manual switches to be upgraded to remote controlled switches in a smart distribution system. In Ref. [6], manual switches are utilized as tie switches and are combined with automatic switches that is cost effective and results in reduction of system energy not supplied (ENS). By solving the optimal switch placement problem as a multiobjective optimization, it is proposed to minimize both number of switch and number of customers not supplied in Ref. [7] and Ref. [8]. Differential search algorithm is used in Ref. [9] to find the optimal allocation of remote-controlled switches and reliability improvement with multiobjective approach. Also optimal reliability based switch placement and feeder reconfiguration along with reactive power control with capacitor bank is discussed in Ref. [10].

Bus failure and the probabilities of switch operation whether manual or automatic are added to the reliability analysis of distribution network in Ref. [11]. Moreover some control sequences also are introduced in order to best operation of joint automatic and manual sectionalizing switches in a coordinated manner. In Ref. [12], multiobjective switch placement is applied in order to optimally improve the two reliability indices, system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI). Also switch allocation problem in the presence of DG units is conducted in Ref. [13] by implementing the fuzzy multiobjective approach.

In the field of DG placement and from the reliability point of view, segment concept is applied for DG allocation in Ref. [14] in which optimal locations of DGs is compared for two objectives of reliability and efficiency enhancement. In references [15-19], optimal placement of DG units is performed with the aim of increasing the profit and system reliability enhancement. DG and sectionalizing switch placement considering the system reliability, system security and its loading is addressed in references [20-21]. Reliability improvement is taken into account in Ref. [22] which proposes an optimal multiobjective sizing and allocation of DG units from the viewpoints of DG owner and DisCo. Also simultaneous placement of DG units and tie switches is performed in Ref. [23] to increase the loadability of system and to improve its efficiency in terms of voltage quality and power loss. In Ref. [24], multiobjective planning of microgrid is performed in order to reduce the network ENS. Optimal location of switches is determined along with optimal site and size of DGs to have a best partitioning of distribution network into inter-connected microgrids.

Employing demand response programs and reliability improvement of network is considered in Ref. [25] with the aim of optimal allocation and sizing of energy storage units and in Ref. [26] for purpose of distribution network expansion planning. In Ref. [27], simultaneous allocation of sectionalizing switches and DER units with the reliability and supply security point of view is conducted.

The preferable level of reliability from the utilities viewpoint is usually different from what the customers expect. DisCos seek to achieve the acceptable reliability indices of system with the lowest investment cost as it is possible. The reliability based planning in this perspective can be known as system-oriented reliability planning (SORP) which means that DisCo invests on reliability enhancement of the system irrespective of customer choices. This project is usually performed on the networks with poor reliability and considerable interruptions. By this way the reliability level of entire customers within the network would be improved too.

On the other hand electricity interruptions have different impacts on customers. Customers like residential loads can put up with interruptions whereas for some others like commercial or industrial loads it results in monetary loss and causes dissatisfaction with their existing service quality. This difference can be modelled by a parameter named value of lost load (VOLL) that reflects the effect of interruptions on any type of customers. But what is important for DisCo in SORP is the effect of these interruptions on the entire network and usually VOLL is ignored. Now DisCo comes up with a main problem that is to find out a solution for situations that any customer is willing to have a higher level of reliability. In other word, the SORP may not meet the preferable level of reliability for some of the customers in the network. In addition from the economical point of view, the SORP is the cost effective and optimal planning for DisCo and accordingly further investment on reliability increases the planning cost which is undesirable for the owners of the companies.

This paper discusses about a novel strategy in the perspective of reliability based planning in the distribution network named as customer-oriented reliability planning (CORP) to enhance the load point reliability index ENS. In this regard customers who are interested in reliability enhancement can fill in a questionnaire and give a request to the DisCo. This means that they should make a contract with DisCo to pay an extra money and DisCo is responsible of reducing their ENS, otherwise a restitution should be paid to the customers based on the agreed contract. Applying this method can result in the customer acquisition for DisCo in the case of handling the problems mentioned in the following sections.

The paper is organized as follows: In sections 2 and 3 the objective functions and other respective equations are discussed. In section 4, optimization methods and algorithms are briefly discussed and in section 5 the simulation is done on the test system to validate the effectiveness of the proposed method and the obtained results are represented. Finally conclusion is given in section 6.

2. PROBLEM DESCRIPTION

The main purpose of DisCo in SORP is to customer servicing with the lowest cost and in an acceptable level of network reliability. Usually in SORP the system indices are important for these utilities and they attempt to set these indices to an acceptable level. However the fact here is that customer viewpoint on reliability is not considered in this type of planning. Even though the interruptions lead to different losses for various consumers due to their VOLL but DisCo does not obligates itself to compensate their loss.

Now suppose that a DisCo aims to provide the opportunity of reliability enhancement for customers that are dissatisfied with their electricity interruptions and consequently the loss imposed on them. Moreover the load point reliability index that customers are interested to be improved, is the expected energy not supplied (EENS). Load point EENS denotes the expected amount of energy that could not be delivered to a certain customer in a year due to interruptions. To execute the mentioned proposition, following difficulties should be dealt.

(1) Is it basically possible for customers to determine their EENS and force DisCo to reduce their EENS to a specified value? To comprehend more exactly the

problem, suppose that n load points in the network declare to reduce their EENS to the values $EENS_1$, $EENS_2$,… and $EENS_n$ respectively.

First, it must be noticed that load point reliability is a quantity that may not take any desirable value. Because the reliability enhancement methods are performed with respect to the network topology and the parameters like equipment failure rate, load growth and such factors that have direct impact on reliability. Therefore in a planning, it cannot be expected to achieve any desirable value of load point reliability that is requested from DisCo.

Other one is that when the load points are located in a joint feeder and customers declare their desired EENS value, DisCo cannot meet all the requests. As a matter of fact, customers are interested in a specific value of EENS and the planner aims to reach these values by investment on the system (switch placement and other methods). Whereas this is almost impossible and the planner can just reduce their EENS to a value less than that of requested from DisCo. Its reason is that when a section is equipped with a switch, all the load points are influenced by its operation. Hence DisCo cannot attain the specified value of EENS defined by requestor customers.

Of course the EENS of these load points must be equal or less than the specified value. This has a negative impact on the pricing mechanism and defining the amount of payment for each customer. Because in this situation, there isn't any specific criteria for DisCo to exactly define that for what amount of EENS reduction, the payment must be received from these customers (the amount of this payment for each customer is a problem too).

(2) The second problem which is so important and covers the previous case is that companies basically are not interested in additional investment for load point reliability enhancement without receiving any payment from customers. Now as an outstanding point, is this payment economical for the customer? For instance, a commercial load declares to reduce its EENS by 1000 kWh. Definitely this will result in monetary loss reduction and a raise in the income of customer, which is the main reason for request too. But does necessarily the amount of money that customers must pay to DisCo is less than their surplus income resulted from their EENS reduction. In other word, is the declaration for reliability enhancement is economical from the financial perspective. Because as an example, if the monetary loss reduction be 0.5 million $ and the payment amount to the DisCo be 0.6 million $, then this declaration is not economical for this customer.

(3) It must be noted that reliability enhancement costs a definite amount for requestor customers and this amount is written in the contract to be paid every month in addition of their regular consumed energy cost. Whereas reliability has uncertainty nature and is inherent to risk. For this reason, risk management and considering the probabilistic behaviour of the network is necessary to ensure that the customers will experience a warranted reliability extent within an acceptable level of risk.

In Ref. [28], optimal planning problem of distribution network is studied by employing customer choice on reliability (CCOR) strategy. In this paper, without considering the additional investment cost imposed on DisCo and based on a predefined price, a payment is received from customers for their reliability enhancement. In addition to the abovementioned points that are disregarded, any explanation about the electricity price curve for customers adopted the CCOR strategy and that how it is extracted is not presented. Additional investment cost (cost surplus) is the amount that is incurred by Disco in order to have reliability enhancement for customers adopted CCOR.

The authors in Ref. [29] have proposed a game theory-based method for customer damage function (CDF) reduction of customers that are willing to reliability enhancement. The reliability enhancement is performed by optimally placement of additional sectionalizing switches. Using the game theory and Karush-Kuhn-Tucker (KKT) condition, the problem is optimized in a bi-level model in which the customers submit their preferable level of CDF to the distribution system operator (DSO) and consequently DSO allocates the additional cost between these customers. This allocation of cost directly depends on the parameters defined by DSO which their determination is not clearly explained. Furthermore as well as previous paper, the authors have not considered the first difficulty mentioned above that occurs when the CDF of customers interested in reliability enhancement become less than the declared value. However the second difficulty is roughly resolved and the third one can be included in the project.

What is proposed in this paper is to employ a customer-oriented based planning of distribution network or CORP as a proper solution for the abovementioned problems. As a brief explanation, first a SORP is carried out by the planner for the sake of reducing the reliability indices like SAIDI or SAIFI under the mandated level in a minimum investment cost. It must be noted that the total investment cost and the EENS of each customer as the two gotten results of SORP are required for CORP.

Then considering these results and the customers that have declared to EENS reduction, the planning strategy is revised and a new planning based on customer-orientation is employed. The purpose of this planning is to increase the net profit of customers that are interested in EENS reduction. It must be mentioned that both of the SORP and CORP elaborated below are based on method of simultaneous DG and switch placement (SDGSP) with a new defined load shedding mechanism which leads to automation of network and will be fully discussed later.

3. MATHEMATICAL FORMULATION

3.1. Objective function and associated constraints

A) System-oriented reliability planning of distribution network

In this planning with respect to ISO policies, DisCo is responsible of reducing the SAIDI of distribution network up to a target value or less than it. SAIDI is an index that can appropriately evaluate the performance of DisCos on reliability of the system. Since it is difficult to model the SAIDI with the investment cost in a single objective function, bi-objective optimization seems to be suitable. Also three parameters of system are assumed to have probabilistic behaviour that are load growth, failure rate of feeders and their repair time respectively [30]. So the problem is evaluated in scenario generation framework and the objective functions of expected cost and SAIDI shown by $\mathrm{E}_{\omega}\left\{Cost_{\omega}^{SORP}\right\}$ and $\mathrm{E}_{\omega}\left\{SAIDI_{\omega}^{SORP}\right\}$ are aimed to be minimized in Eq. (1) and Eq. (2).

The cost function is quantified in terms of sectionalizing switch cost, DG cost, cost of energy purchasing from transmission sector and ENS cost. Switch cost consists of just the capital cost and maintenance cost shown in Eq. (3). The total cost related to the DG is the summation of capital cost, maintenance cost and operation cost that are formulated in Eq. (4). The utilized DGs are supposed to be dispatchable like micro turbines and non-dispatchables like PV and Wind Turbine are disregarded.

$$\mathrm{E}_{\omega}\left\{Cost_{\omega}^{SORP}\right\} = Cost^{sw} + Cost^{DG} + \sum_{\omega\in\psi_S} \pi(\omega).\left(Cost_{\omega}^{Epur} + Cost_{\omega}^{ENS}\right) \tag{1}$$

$$\mathrm{E}_{\omega}\left\{SAIDI_{\omega}^{SORP}\right\} = \sum_{\omega\in\psi_S} \pi(\omega).SAIDI_{\omega} \tag{2}$$

$$Cost^{sw} = \sum_{\ell\in\Omega_\ell} X_\ell.CC_{as} + \sum_{t=1}^{N_Y}\sum_{\ell\in\Omega_\ell} X_\ell.MC_{as}.PW_t \tag{3}$$

$$\begin{aligned} Cost^{DG} &= \sum_{i\in\Omega_L} \zeta_i.P_i^{DG}.CC_{DG} \\ &+ \sum_{t=1}^{N_Y}\sum_{i\in\Omega_L} \zeta_i.P_i^{DG}.OC_{DG}.T_h.PW_t \\ &+ \sum_{t=1}^{N_Y}\sum_{i\in\Omega_L} \zeta_i.P_i^{DG}.MC_{DG}.T_h.PW_t \end{aligned} \tag{4}$$

$$Cost_{\omega}^{Epur} = \sum_{t=1}^{N_Y} \rho^{MP}.\left[\sum_{i\in\Omega_L}\left(P_{i,t,\omega}^L - \zeta_i.P_i^{DG}\right) + \sum_{\ell\in\Omega_\ell} r_\ell.I_{\ell,t,\omega}^2\right].T_h.PW_t \tag{5}$$

$$Cost_{\omega}^{ENS} = \sum_{t=1}^{N_Y} \rho^{SP}.\sum_{i\in\Omega_L}\left(\sum_{\ell\in\Omega_\ell} \lambda_{\ell,\omega}.\tau_{\ell,i,t,\omega}\right).P_{i,t,\omega}^L \tag{6}$$

$$SAIDI_{\omega} = \sum_{t=1}^{N_Y}\sum_{i\in\Omega_L} \frac{\left(\sum_{\ell\in\Omega_\ell} \lambda_{\ell,\omega}.\tau_{\ell,i,t,\omega}\right).N_i^{Cus}}{\sum_{i\in\Omega_L} N_i^{Cus}} \tag{7}$$

$$P_{i,t,\omega}^L = P_{i,0}^L.\left(1+g_\omega\right)^t \tag{8}$$

$$PW_t = \left(\frac{1+\inf\_r}{1+\mathrm{int}\_r}\right)^t \tag{9}$$

By installing the DGs in the system, portion of demands are supplied by these units. Other portion in the network is provided by buying the active power from the subtransmission substations. This active power itself is decomposed into consumed active power in the buses and dissipated power in the feeders. The expected cost of buying active power from subtransmission substation is computed in Eq. (5). $I_{\ell,t,\omega}$ is the current of section ℓ in planning year t and in scenario ω.

In the case of last term the expected ENS cost, it must be mentioned that by electricity interruption occurrence in the network, DisCo is not capable of selling its energy to the customers. Therefore unlike the energy purchasing cost that market price is considered, energy selling price to the customers is used in Eq. (6). The parameter $\tau_{\ell,i,t,\omega}$ refers to the average outage time of load point i in planning year t and in scenario ω that is effected by fault occurrence in section ℓ.

The formula for total SAIDI in the planning period is given in Eq. (7). As it is shown this index is independent of load in the buses but is effected by number of low voltage customers in the buses. The load of buses has an indirect influence on the restoration time which is caused by load restoration and load shedding mechanism. Finally SAIDI in the planning period and network load growth in each scenario and also present worth factor are calculated through Eqs. (7-9). Load growth rate, inflation rate and interest rate are represented by g_{ω}, Inf_r and Int_r respectively.

Also if $\pi_g=\left[\pi_{g1},\pi_{g2},...,\pi_{gn}\right]$ be the discrete probability distribution of network load growth related to set ψ_g, $\pi_{\lambda}=\left[\pi_{\lambda1},\pi_{\lambda2},...,\pi_{\lambda n'}\right]$ be the discrete probability distribution of feeder failure rate related to set ψ_{λ} and $\pi_{\tau}=\left[\pi_{\tau1},\pi_{\tau2},...,\pi_{\tau n''}\right]$ be the discrete probability distribution of feeder average repair time related to set ψ_{τ}, then set of possible produced scenarios with the associated probability relationship are given in Eq. (10) and Eq. (11) respectively.

$$\psi_S=\psi_g\times\psi_{\lambda}\times\psi_{\tau} \tag{10}$$

$$\sum_{\omega\in\psi_S}\pi_g.\pi_{\lambda}.\pi_{\tau}=1 \tag{11}$$

The required constraints for optimization and solving the problem are shown in Eqs. (12-18). $SAIDI_{tar}$ is the target value that DisCo is responsible to reduce the expected SAIDI to an amount less than it and is ensured by (12). Other constraint represents the voltage limitation of network buses in each scenario and during the planning horizon. Equalities (14) and (15) represent the power flow constraint related to active and reactive power injection to bus i in each scenario. The Eqs. (16-17) express the maximum number of installed DGs and maximum number of available sectionalizing switches for DisCo that are restricted due to budget inadequacy. And last inequality denotes the maximum penetration percentage for total DG capacity in the network.

Now after optimization and getting the Pareto frontier solutions, the best point should be selected among other

$$\mathrm{E}_{\omega}\left\{SAIDI_{\omega}^{SORP}\right\}\le SAIDI_{tar} \tag{12}$$

$$V_{\min}\le V_{i,t,\omega}\le V_{\max} \tag{13}$$

$$P_{i,t,\omega}^{L}-\zeta_i.P_i^{DG}= V_{i,t,\omega}.\sum_{j\in\Omega_L}V_{j,t,\omega}\left(G_{ij}.Cos\left(\theta_{ij}\right)+B_{ij}.Sin\left(\theta_{ij}\right)\right) \tag{14}$$

$$Q_{i,t,\omega}^{L}-\zeta_i.P_i^{DG}.pf_i^{DG}= V_{i,t,\omega}.\sum_{j\in\Omega_L}V_{j,t,\omega}\left(G_{ij}.Sin\left(\theta_{ij}\right)-B_{ij}.Cos\left(\theta_{ij}\right)\right) \tag{15}$$

$$\sum_{i\in\Omega_L}\zeta_i\le N_{\max}^{DG} \tag{16}$$

$$\sum_{\ell\in\Omega_\ell}X_{\ell}\le N_{\max}^{as} \tag{17}$$

$$\frac{\sum_{i\in\Omega_L}\zeta_i.P_i^{DG}}{\sum_{\omega\in\psi_S}\sum_{i\in\Omega_L}P_{i,0,\omega}^{L}}\le PP^{\max} \tag{18}$$

solutions. Naturally the optimum and best solution from the decision maker point of view is the minimum cost solution within an acceptable SAIDI level or in other word the solution with an expected SAIDI close to the target value. This can be due to asset management principles and the fact that reaching to an acceptable SAIDI level (but not necessarily the best level) can serve the goal of DisCo.

B) Customer-oriented planning of distribution network

Previous planning was in the context of system reliability improvement and was in the scope of DisCo’s responsibility. Now suppose that DisCo has provided a questionnaire for customers to recognize that if any customer is willing to reduce its EENS and hereby declare its request. Of course their expected unsupplied energy (EENS) that they will experience by applying SORP is given in this questionnaire. But this is just a declaration and the amount of EENS reduction is not known and will be determined by decision maker. Here DisCo revises its planning strategy and employs a new planning (CORP) by regarding the output results obtained in previous stage. In fact if there were not any customer interested in EENS reduction, previous planning SORP would be implemented by DisCo. It must be noted that EENS reduction refers to get an EENS value lower than that of obtained by SORP. Nevertheless the main purpose of DisCo from the implementation of CORP is defined in the following framework.

The ultimate goal of DisCo from this planning is to increase the economic value of customers declared for EENS reduction. Economic value for customers known as EVC is the difference between customer’s perceived benefit and the customer’s perceived cost [31]. Here the perceived benefit is the benefit stem from EENS reduction and the perceived cost refers to the cost that must be paid to the DisCo due to their EENS reduction.

To further understand the issue, suppose that a customer has a VOLL equal to 100 $/kWh. So if the EENS of this load point has 1000 kWh reduction, then the customer is perceived 100000 $ benefit because of this loss compensation.

It is worth mentioning that the SORP gives the minimum investment cost for DisCo and hence DisCo incurs a cost surplus by implementation of any other planning. This cost surplus will be received from customers declared to reliability enhancement. Due to existence of uncertainty in the system and the fact that there is a direct relation between the investment cost surplus and the cost inflicted to customers that must be paid to DisCo, applying risk management methods seems to be inevitable. As commented before the customers are allowed to just declare their interest in reliability enhancement (EENS reduction), but the amount of EENS is determined by optimization in a way that an optimal EVC be obtained for them. This can be most fairly than that of CCOR strategy, either for customers or DisCo.

The proposed single objective function for CORP is represented in Eq. (19). This objective is based on mean-variance method [32] and its application is mostly in electrical engineering and the portfolio theory [33]. In this method, depending on the risk aversion parameter, in addition of increasing portfolio profit, the variance of portfolio is decreased too. As this parameter increases, the expected profit of portfolio and also the risk of perceiving this profit decrease. Z is introduced as the objective function of the problem that must be maximized and consists of expected function and risk function. The main goal from maximizing Z is to increase the EVC of each load point that has declared to

$$
\begin{aligned}
Z &= \sum_{i\in\Omega_{RL}} \mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\} - \beta.\sum_{i\in\Omega_{RL}} \Re_{\omega}\left\{\Gamma_{i,\omega}\right\}, \\
&= \left(1-\beta\right).\sum_{i\in\Omega_{RL}} \mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\} - \beta.\sum_{i\in\Omega_{RL}} \Re_{\omega}\left\{\Gamma_{i,\omega}\right\} \\
&= \left(1-\beta\right).\sum_{i\in\Omega_{RL}} \mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\} - \quad ,\forall\beta\in\left[0,1\right] \\
&\beta.\sum_{i\in\Omega_{RL}}\left(\Upsilon\left(\Gamma_{i,\omega}\right) + \sum_{\substack{j\in\Omega_{RL}\\ j\neq i}} \Lambda\left(\Gamma_{i,\omega},\Gamma_{j,\omega}\right)\right)
\end{aligned}
\tag{19}
$$

$$
\begin{aligned}
&\mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\} = \\
&\sum_{\omega\in\psi_S} \pi\left(\omega\right).\Big[\xi_{i,\omega}.\gamma_i\left(EENS_i^{SORP} - ENS_{i,\omega}^{CORP}\right) \\
&-\Phi_{i,\omega} + \left(1-\xi_{i,\omega}\right).Res\left\{\Delta ENS_{i,\omega}\right\}\Big],\ i\in\Omega_{RL}
\end{aligned}
\tag{20}
$$

$$
\Phi_{i,\omega} = \frac{\xi_{i,\omega}.\left(EENS_i^{SORP} - ENS_{i,\omega}^{CORP}\right)}{\sum_{j\in\Omega_{RL}} \xi_{j,\omega}.\left(EENS_j^{SORP} - ENS_{j,\omega}^{CORP}\right)}.\Delta Cost \quad ,\ i\in\Omega_{RL}
\tag{21}
$$

$$
\begin{aligned}
&Res\left\{\Delta ENS_{i,\omega}\right\} = \\
&\gamma_i.\left(EENS_i^{SORP} - ENS_{i,\omega}^{CORP}\right),\quad i\in\Omega_{RL}
\end{aligned}
\tag{22}
$$

$$
\Delta Cost = \mathrm{E}_{\omega}\left\{Cost_{\omega}^{CORP}\right\} \text{-} Cost_{Exp}^{SORP}
\tag{23}
$$

EENS reduction. Following equations are given as the explanation of objective function.

To elaborate the objective function, DisCo aims to increase the EVC of requestor customers by lowering their EENS. EVC of each customer is calculated by Eq. (20). This equation constitutes three terms. First term is the benefit attained from EENS reduction of customers in each scenario. Because EENS reduction results in monetary loss reduction depending on VOLL of each customer, it must be mentioned that EENS reduction stands for the difference between EENS value obtained in SORP and CORP. Second term presents the cost that each customer must pay to the DisCo in order to reduction of their EENS.

Amount of this payable cost in each scenario is calculated through Eq. (20). As it is seen, the cost allocation for customers in each scenario is defined based on EENS reduction and the cost surplus that is incurred by DisCo because of planning revision.

This cost surplus that is shown by $\Delta Cost$ is the difference between the expected costs of both planning. Indeed the customer with more EENS reduction must pay more money to the DisCo or in other word high percentage of cost surplus is assigned to that customer.

Third term relates to the restitution that must be paid to the requestor customers. In each scenario if ENS of any load point exceeds the $EENS_i^{SORP}$, DisCo is bound by an agreement to pay restitution to that customer according to relationship (22). Restitution is defined due to the amount of loss increment for each customer. Binary decision variable $\xi_{i,\omega}$ is used in that if such a condition occurred, just the restitution be considered by getting $\xi_{i,\omega}$ to 0, so the customer don't pay any money to DisCo, otherwise $\xi_{i,\omega}$ is 1.

In this way the EVC of each customer is defined in the objective function but EVS enhancement of customers implies a minimized investment cost.

Because the additional cost imposed on DisCo will be totally received from these customers. So total planning cost is embedded in the objective function however it is not modelled directly in the objective function.

As mentioned before, unlike the reliability that is concerned with uncertainty, customers must pay their cost regularly each month. Hence they should be ensured to fulfil the amount of EVC that DisCo has offered them. For this reason, objective function is modelled based on mean-variance method. Risk aversion parameter β exhibits average risk aversion degree of customers. This parameter is limited between 0 and 1 in order to have a better and easy understanding of being risk taker or risk averse.

According to this method, the risk function is composed of variance and covariance functions for EVC of each customer. The variance concept is clear and for EVC probability distribution is calculated by Eq. (24). It measures the spread of values for a random variable. The main point must be considered is that the overall risk is not limited to the EVC volatility of each individual requestor customer and their EVC is in relation with each other. Because as mentioned before, any change in ENS of each customer can influence on ENS of other customers and hence can result in EVC change.

Therefore covariance is used to measure the extent of moving together for EVC of any pair of customers. In other word to maximize the total expected EVC of customers, the overall associated risk should be reduced. Covariance is a measure of how the EVC of two customers move in relation to each other which is calculated through Eq. (25). When the covariance between EVC of two customers is negative, it means that to have increase in the EVC of one customer, there will be a decrease in EVC of other customer. So existing of negative covariance can reduce the inherent risk and volatility.

$$\Upsilon\left(\Gamma_{i,\omega}\right)=\mathrm{E}_{\omega}\left\{\left[\Gamma_{i,\omega}-\mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\}\right]^{2}\right\} \tag{24}$$

$$\Lambda\left(\Gamma_{i,\omega},\Gamma_{j,\omega}\right)= \mathrm{E}_{\omega}\left\{\left[\Gamma_{i,\omega}-\mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\}\right].\left[\Gamma_{j,\omega}-\mathrm{E}_{\omega}\left\{\Gamma_{j,\omega}\right\}\right]\right\} \tag{25}$$

However to have a better measurement on co-movement of EVC for any pair of customers, correlation is commonly used as defined in Eq. (26) and is a degree between 0 and 1. This is because of that covariance is not able to give the strength of mutually relationship among the EVC of customers. As well as covariance, positive correlation indicates that there is positive inter-

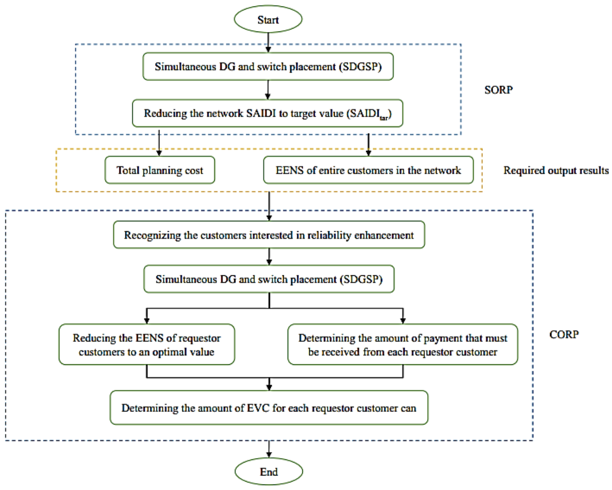

Fig. 1. Flowchart of general procedure for the proposed strategy

-action between EVC of both customers. Negative correlation expresses that EVC of two customers move in opposite direction.

$$\Lambda\left(\Gamma_{i,\omega},\Gamma_{j,\omega}\right)= \mathrm{E}_{\omega}\left\{\left[\Gamma_{i,\omega}-\mathrm{E}_{\omega}\left\{\Gamma_{i,\omega}\right\}\right].\left[\Gamma_{j,\omega}-\mathrm{E}_{\omega}\left\{\Gamma_{j,\omega}\right\}\right]\right\} \tag{26}$$

The constraints that must be fulfilled in CORP are almost the same as what was discussed in SORP. As well as inequality (12), network expected SAIDI must not exceed the target value specified to the DisCo that is shown in Eq. (27). Constraint (28) ensures that the ENS of customers in each scenario should be less than the value obtained in SORP, otherwise $\xi_{i,\omega}$ is set to zero.

Other aforementioned constraints like voltage limitation of medium voltage buses, power flow equation, number of available DG and switch and the penetration percentage of DG units must be fulfilled in this planning too. To have an explicit view, a flowchart is represented in Fig. 1, which gives the general procedure of proposed strategy in this paper.

$$\mathrm{E}_{\omega}\left\{SAIDI_{\omega}^{CORP}\right\}\leq SAIDI_{tar} \tag{27}$$

$$ENS_{i,\omega}^{CORP}<EENS_{i}^{SORP}\ ,\qquad i\in\Omega_{RL} \tag{28}$$

3.2. Load shedding procedure

By implementing SDGSP and using remote controlled and automatic switches, the smart degree of distribution system can have a dramatic increase. Also because of automatic fault detection and removing the manual operation, the restoration time is close to few minutes. Due to the smart feature of network and presence of DG units, islanding after fault occurrence and load shedding are performed to reduce the number of failed customers.

When a fault occurs in a radial network, first the breaker at begin of the feeder operates and all the load points located in the feeder will be de-energized. Then the load points above the faulted section are restored by operation of the best sectionalizing switch. If there exists any sectionalizing switch to isolate the de-energized load points from the faulted section of the feeder, in the presence of DG units an island can be created and operate till the fault in the section be cleared. So it is possible to take place a number of islands in the fault condition. In the island mode of operation, an opportunity is provided for these de-energized loads to be supplied in the fault condition of network through the DGs. It must be noted that sectionalizing switches must operate in a way that the certain islands include maximum number of de-energized customers.

But to take place an island, power balance between supply and load must be provided too. If the overall active power of a certain island is less than the whole capacity of DGs within the island, DGs have the capability of matching its produced power to the load amount of island. In the case that the total load of island be greater than the total capacity of sited DGs in the island, the system will be faced up to frequency drop problem. To overcome this difficulty, load shedding mechanism is applied in which some load points must be remained interrupted in order to reduce the island demand less than its DG capacity. However other loads within the island will be restored and energized. To determine which buses must be shed, it is common to select the buses with low degree of importance.

Two different mechanisms of load shedding is introduced in this paper for both of the aforementioned planning. In SORP and about shedding, the priority is for the buses with lower consumption. In the case of load equality, the bus further from the faulty portion is prior to being shed i.e. if there are some buses with an equal amount of load, the buses with higher distance from the beginning bus of the island have low importance relative to others.

In CORP, the above classification of load points is applied with the main difference that the customers declared to EENS reduction include a higher degree of importance with respect to others. For example a requestor customer with consumption of 100 kW has a higher degree of importance in relative to an ordinary customer with consumption of 200 kW. Its reason is that the decision maker is willing to lower the EENS of requestor customers and increase their EVC as it is possible.

Inequality (29) represents the required condition to have a proper operation of an island in year t and scenario ω. $\Omega_{Is,j}$ denotes the set of load points belong to the island j in the network and N_{ℓ}^{Island} is the total number of created islands by fault occurrence in the section ℓ. Unless the constraint M_2 is fulfilled, the inequality (30) is considered to be satisfied.

$$\mathrm{M}_1: \sum_{i\in\Omega_{Is,j}} \zeta_i.P_i^{DG} - \sum_{i\in\Omega_{Is,j}} P_{i,t,\omega}^{L} \geq 0 \quad , \ \forall j=1,2,\ldots,N_{\ell}^{Island} \tag{29}$$

$$\mathrm{M}_2: \sum_{i\in\Omega_{Is,j}} \zeta_i.P_i^{DG} - \sum_{i\in\Omega_{Is,j}} x_{i,t,\omega}.P_{i,t,\omega}^{L} \geq 0 \quad , \ \forall j=1,2,\ldots,N_{\ell}^{Island} \tag{30}$$

Where

$$\mu_{i,t,\omega} = \begin{cases} P_{i,t,\omega}^{L} + 1/d_{ik} & i\in\Omega_L \\ \hbar_i.P_{i,t,\omega}^{L} + 1/d_{ik} & i\in\Omega_{RL} \end{cases} \tag{31}$$

$$\begin{aligned} &\textit{while } \mathrm{M}_2 < 0, \\ &\quad [\sim,\alpha] = \min\left(\vec{\mu}_{t,\omega}\right), \ \ x_{\alpha,t,\omega}=0, \ \ \mu_{\alpha,t,\omega}=\inf \\ &\textit{end} \end{aligned} \tag{32}$$

Relationships (31) and (32) show the load shedding strategy in general case. Parameter d_{ik} is the distance from bus i to bus k as the initial bus of the island and $\hbar$ is a sufficiently large constant about 100. So if this customer declares to reliability enhancement, it will have a higher degree of importance $\mu_{i,t,\omega}$ in comparison with ordinary customers. If it is an ordinary customer, the importance degree will be defined due to its amount of load. About the conditional loop shown above, it must be said that α is an index that gives the bus number with the lowest degree of importance in the case of constraint M_2 dissatisfaction. Then it alters the binary variable $x_{i,t,\omega}$ of that bus to 0 and sets its importance degree $\mu_{i,t,\omega}$ to infinite. This binary decision variable defines that which load point must be shed (when it is equal to 0) and is initially set to 1 for all the buses within the island.

4. OPTIMIZATION METHODS

With respect to the planning strategies explained in previous section, a bi-objective function is used in SORP while a single objective function is implemented for CORP. Due to these objective functions, the modified non-dominated sorting genetic algorithm (NSGA-II) is used to optimize the SORP and single objective genetic algorithm is used to optimize the

CORP. At first, the single objective genetic algorithm and then NSGA-II are briefly discussed as follow.

4.1. Genetic algorithm

The proposed optimization method in this paper to optimize the CORP is genetic algorithm. Genetic algorithm is based on evolutionary search and population reproduction. Each solution produced in genetic algorithm is named a chromosome which is constructed of genomes. Based on implementation of SDGSP method to reliability enhancement of network, these genomes are codified according to Eq. (33) for this problem.

The chromosome structure φ_i for the i th solution is constructed of four parts. First part is the binary vector $\bar{B}$ with the length equal to $N_{\max}^{DG}$ (total number of DGs permissible to be installed) and decides whether DG should be installed or not. Vector $\bar{Y}$ represents the selected capacity of DG units nevertheless it depends on the corresponding decision vector $\bar{B}$. The location of these DGs in the network is determined by vector $\bar{D}$ and finally binary vector $\bar{U}$ defines that if section ℓ is equipped with sectionalizing switch or not.

$$\begin{aligned}
&\varphi_i = \{\bar{B},\bar{Y},\bar{D},\bar{U}\}\\
&\bar{B} = [b_1, b_2, ..., b_n], \quad n = N_{\max}^{DG}\\
&\bar{Y} = [y_1, y_2, ..., y_n], \quad n = N_{\max}^{DG}\\
&\bar{D} = [d_1, d_2, ..., d_n], \quad n = N_{\max}^{DG}\\
&\bar{U} = [u_1, u_2, ..., u_m], \quad m = |\Omega_\ell|
\end{aligned} \tag{33}$$

After randomly creation of population, crossover and mutation as reproduction mechanisms are applied to this population over a specific number of iterations. Selection of chromosomes among the population as a parent is performed by Roulette Wheel mechanism. Complete explanations about genetic algorithm can be observed in Ref. [34].

4.2. NSGA-II

In SORP it was aimed to reduce the expected SAIDI of network to a value lower than that of specified by ISO. In this paper NSGA-II as a multiobjective evolutionary algorithm (MOEA) is employed to find the optimal solution within Pareto frontier [35]. The chromosome structure is same as SORP and does not have any change. But selection methods and sorting of solutions in each iteration is different from what was used in genetic algorithm. In genetic algorithm solutions are sorted in an ascendant form. However in NSGA-II, the obtained solutions in each iteration are sorted due to domination concept. The solutions with respect to their domination degree are located in number of frontiers.

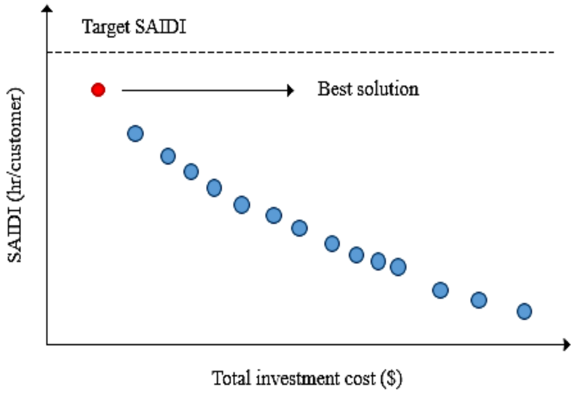

Fig. 2. Pareto frontier solutions

Pareto frontier contains the solutions with higher domination relative to others that are known as non-dominated solutions.

These are fully discussed in Ref. [36]. After achieving the Pareto frontier, it is necessary to select a point as the final optimal solution. There are various methods to make a decision about selection of optimum point such as fuzzy decision making. But it must be reminded that the main purpose of DisCo by applying this planning is to reduce the SAIDI with the lowest cost. Therefore the best solution for decision maker is the point with minimum planning cost or in other word the point with a SAIDI close to the target value. This issue is demonstrated in the Fig. 2 in which the best solution among other solution is specified by red colour.

5. NUMERICAL RESULTS

In order to validate the proposed strategy the problem is tested on the IEEE 33 bus test system. The related data containing line impedance and load of buses can be found in Ref. [37] and network schematic is depicted in Fig. 3. Table 1 represents the associated data about probabilistic parameters of network, load growth, feeder failure rate and its repair time. However these data are assumptive for this test system. Using these data, set of scenarios and their probability can be obtained. Table 2 represents the required data for solving the problem and number of low voltage customers in each bus is given in Table 3.

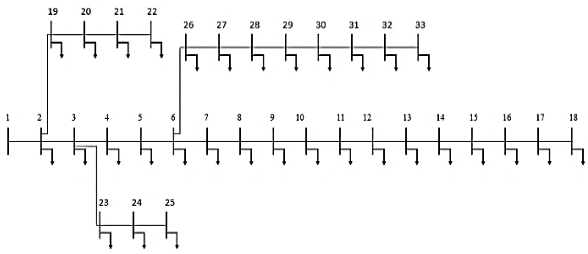

Fig. 3. IEEE 33 bus network schematic

Table 1. Probabilistic parameters of system
(Exp: Expected, Prob : Probability)

Load growth		Failure rate (fr/km.yr)		Feeder repair time (hr)	
Exp	Prob	Exp	Prob	Exp	Prob
0.07	20%	0.12	30%	2	28%
0.05	38%	0.15	50%	2.5	34%
0.04	25%	0.20	20%	3	22%
0.03	17%	-	-	3.5	16%

Table 2. Required data for solving the problem

Parameter	Value	Parameter	Value
DG installation price ($/MW)	700000	Automatic switch installation price ($)	4700
DG operation price ($/MWh)	33	Automatic switch maintenance price ($/yr)	90
DG maintenance price ($/MWh)	8	Market energy price ($/kWh)	0.06
Inflation rate	0.09	Selling energy price ($/kWh)	0.08
Interest rate	0.125	Planning period (year)	5

The simulation for both the SORP and CORP are performed in a notebook Laptop with 4GB RAM and in MATLAB software. SORP is optimized through NSGAII with population size of 100, maximum iteration of 150 and in elapsed time of about 95 minutes. Similarly for the CORP that is optimized by genetic algorithm with population size of 120, maximum iteration of 150 and in elapsed time of about 140 min.

Available number of automatic sectionalizing switches is 15 and all the buses and sections are candidate to install the DG and switch respectively. Two types of planning with different strategies are employed in this network that the first one is SORP and second one is CORP that their associated results are discussed below.

4.3. Stage 1- System-oriented reliability planning

In the first stage by applying the SORP, DisCo is responsible for reducing the SAIDI to less than the target value equal to 15 (hr/customer) in the planning horizon. To get the solution, the problem is solved in a multiobjective framework using NSGA-II. The Pareto front obtained by this method is represented in Fig. 4.

Table 3. Number of low voltage customers in each bus of network
(BN: Bus number, CN: Customer number)

BN	CN	BN	CN	BN	CN	BN	CN
1	76	9	10	17	95	25	70
2	66	10	24	18	67	26	33
3	129	11	86	19	25	27	35
4	86	12	80	20	100	28	126
5	48	13	99	21	80	29	4
6	215	14	87	22	107	30	169
7	207	15	20	23	1	31	5
8	79	16	69	24	2	32	82

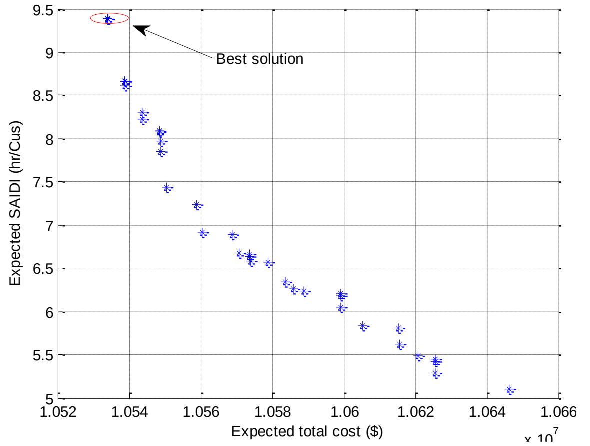

Fig. 4. Pareto frontier solutions related to SORP

Regarding this Figure, investment cost increases as the expected SAIDI decreases. It is clear that DisCo is willing to choose the point with minimum cost from the aspect of asset management policies. This point is shown in the Figure as the best solution. For this point expected SAIDI is approximately 9.4 (hr/customer) and total planning cost is 10.534 million $. Also optimum location and size of DG units in the network is shown in Table 4 and location of automatic sectionalizing switches along with DG location are given in Fig. 5. Green circles and blue squares denote the DG and automatic switch respectively. Therefore by applying this planning, system reliability index SAIDI could be reduced through a minimum investment cost.

Table 4. Utilized DG location and size for SORP

DG location	17	29	31
DG capacity (kW)	500	350	350

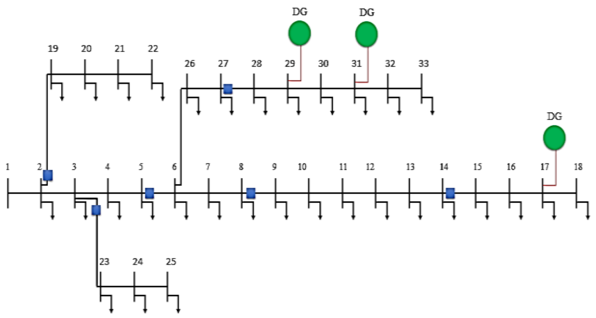

Fig. 5. Optimal location of automatic switches and DGs in the network obtained in SORP

4.4. Stage 2- Customer-oriented reliability planning

Once the SORP is applied, the planning strategy is revised and the CORP strategy is adopted in the network. In order to employ this planning, it is assumed that load points {11, 14, 18, 24, 29 and 32} have declared to reduce their monetary loss due to electricity interruptions. The VOLL of these customers is considered to be {30, 50, 40, 80, 40 and 60} ($/kWh) too. This planning is verified for two values of β .

In the first value of β that is equal to 0.001, customers are risk taker and for the second one, β is 0.999 means that requestor customers are risk averse. The main goal from assessment of these cases is to verify the validity of results and to see that if the following condition is fulfilled. This condition states that from the DisCo point of view as the customers are risk taker, the total customer loss compensation must increase and their total payment to the DisCo must decrease.

4.4.1. Case 1: $\beta = 0.001$

In this case the requestor customers (customers have declared to EENS reduction) are assumed to be economically risk taker. Table 5 represents the expected EVC that requestor customers can attain by strategy revision and employing CORP in distribution network.

A comparison between EENS of requestor customers obtained in SORP and CORP is given in Table 6. Their expected loss compensation and payment to the DisCo are represented in this Table. It can be observed that the cost payment of each customer is less than its amount of loss compensation which satisfies one of the main purpose of the customers and DisCo.

Optimal location and size of DG units for this case are shown in Table 7. Fig. 6 demonstrates the location of automatic sectionalizing switches and DG units in the network. The results are different from what was obtained in SORP strategy and number of sectionalizing switches has increase.

Table 5. Expected EVC of customers that have declared to EENS reduction in $\beta = 0.001$

Bus number	11	14	18
EVC ($)	23940	76670	33140
Bus number	24	29	32
EVC ($)	141060	69720	11060

Table 6. EENS comparison and amount of payment for requestor customers in $\beta = 0.001$ (BN: Bus number, ES: EENS in SORP-kWh, EC: EENS in CORP-kWh, ELC: Expected loss compensation-k$, PY: payment-$)

BN	11	14	18	24	29	32
ES	946.8	1839.1	1087	3873.1	2183	2127.5
EC	27.8	174	167	2018.4	249.4	163.7
ELC	27.57	83.26	36.78	148.38	77.37	117.83
PY	3635	6585.7	3636	7321	7650	7767

Table 7. DG size and location for $\beta = 0.001$

DG location	14	18	32
DG capacity (kW)	400	300	500

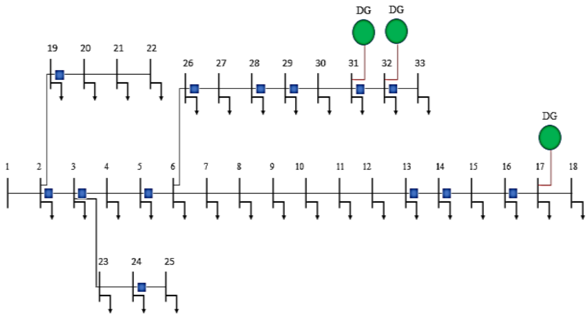

Fig. 6. Optimal location of automatic switches and DGs in the network obtained in CORP for $\beta=0.001$

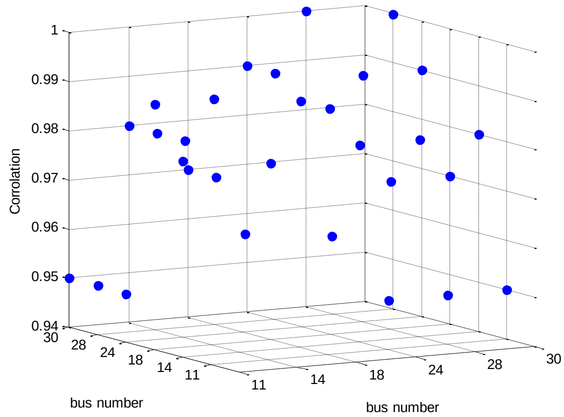

Fig. 7. Correlation between EVC of customers for $\beta=0.001$

Fig. 7 represents the correlation among the EVC of customer pairs that have declared to EENS reduction. As it is seen, all the correlation values are positive means that the EVC of customers move together in a same direction. In other word, EVC of the requestor customers has positive effect on each other and to increase the EVC of any customer, EVC of other customers does not decreases. However their movement has different extent and surely this correlation significantly depends on network topology. This correlation output constructs a diagonal and symmetric matrix.

4.4.2. Case 2: $\beta = 0.999$

Risk aversion parameter is assumed to be 0.999 in this case which shows that the requestor customers are economically risk averse. Table 8 represents the expected EVC that customers declared to EENS reduction can receive by strategy revision and employing customer oriented based planning.

Table 8. Expected EVC of customers that have declared to EENS reduction in $\beta = 0.999$

Bus number	11	14	18
EVC ($)	4560	65310	11310
Bus number	24	29	32
EVC ($)	129650	57580	97920

Table 9. EENS comparison and amount of payment for requestor customers in $\beta = 0.999$

BN	11	14	18	24	29	32
ES	946	1839	1087	3873	2183	2127
EC	721.6	201.0	1036	2018	255	163
ELC	6760	81900	2010	148380	77120	117830
PY	2272	16598	1863	18732	19538	19902

Table 9 compares the EENS of each requestor customer obtained in SORP and CORP strategies and gives the amount of loss compensation by changing the strategy and implementation of customer oriented based planning for these customers. It explicitly presents that the employment of CORP strategy after SORP lessens the EENS of customers interested in reliability enhancement, whilst the expected loss arose from interruptions in the network is reduced for these load points. This reliability enhancement results in payment values for each customer given in last row of the Table.

Table 10 shows the DG location and size for the case that customers are risk averse. In addition optimal location of DG units and sectionalizing switches in this case are represented in Fig. 8. The Change in DG results and switch number increment is to reduce the monetary loss of requestor customers (reduce the EENS).

Table 10. DG size and location for $\beta = 0.999$

DG location	17	31	32
DG capacity (kW)	250	350	450

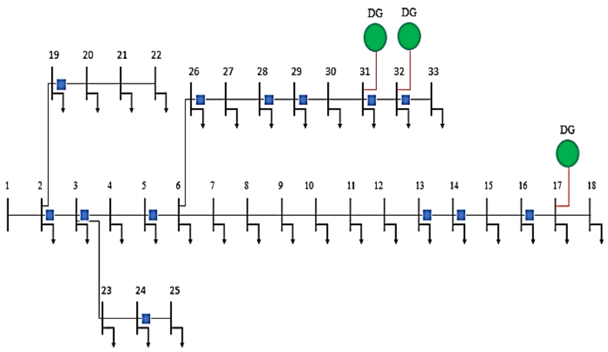

Fig. 8. Optimal location of automatic switches and DGs in the network obtained in CORP for β=0.999

Also the correlation between EVC of these customers is shown in Fig. 9. Paying attention to the results of this Figure, some correlation values are negative (e.g. correlation between customers 11 and 18). It expresses that to increase the EVC of customer 11, the EVC of other customer 18 will decrease.

By evaluating the results of these two cases, in the first case that the customers are risk taker, summation of loss compensation for all the six customers is 491190 $ and their overall payment to DisCo is 36597 $ through

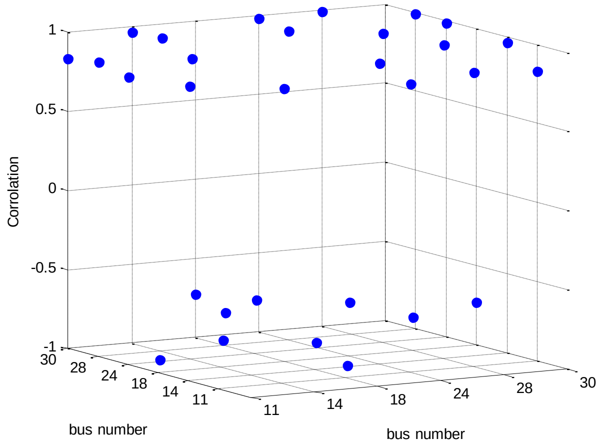

Fig. 9. Correlation between EVC of customers for β=0.999

the planning period. While for second case that customers are risk averse, total compensation of loss is 434000 $ and the overall payment is equal to 78911 $.

This verifies the obtained results and points out that when the customers are risk averse, their loss reduction summation and the overall amount of customers' payment to the DisCo are economically worse than the case in which the customers are risk taker. This is naturally true, since the existing uncertainty in the network acts as a hindrance that exposes the fulfilling of desired result to risk. Hence if the customers participated in CORP have problem with this risk, they must pay further amount to DisCo, albeit the less monetary loss compensation with respect to the condition that customers are risk taker. It must be noted that DisCo has done its duty in the case of increasing the EVC of customers declared for EENS reduction. But about the payment amount of each customer based on their risk strategy, it is beyond the duty of DisCo.

Furthermore by having a precise attention on the correlation results, it can be concluded that in addition to network topology, the risk strategy of customers adopted CORP is a key factor in determining their EVC movement direction. As it was observed, in the risk taking strategy of customers, the correlation among them was all positive, while with a risk averse strategy, the correlation for EVC of some customers changed to negative. However this shows the significant impact of customers risk strategy on the correlation, but its positive or negative effect cannot definitely be expanded to all other networks and different scenarios.

6. CONCLUSION

The conventional planning usually employed by DisCo is economically beneficial from its point of view but does not response to reliability level requirement of customers. For customers that are eager to reliability enhancement, a risk based customer oriented planning was proposed in which DisCo is bound to increase the EVC of these customers by fairly receiving a payment from them. To this end and in a two stage planning, first a SORP was performed to optimally set the SAIDI of network to less than the target value which is determined by ISO. And then using the output results obtained from SORP, the CORP was employed by revision of strategy in order to reduce the EENS of requestor customers.

It was shown that by receiving a fair amount of payment from requestor customers, DisCo could enhance their reliability and increase their EVC by managing the inherent risk. In fact, adopting the CORP has not any beneficial aspect for DisCo but is economical for customers and provides a chance to increase the load point reliability by receiving a payment from customers. Moreover CORP has a positive impact on customer orientation and their satisfaction from DisCo. The risk management was performed through the risk strategy of these customers which inversely effects the total loss compensation of customers as expected but it is beneficial over the planning period for any risk strategy at all. At the end, it must be noted that both of the SORP and CORP were implemented through simultaneous placement of DG units and automatic switches which gives rise to the automation of network. In addition, the proposed load shedding mechanism after unintentional creation of islands was so effective in attaining the lower amount of EENS for customers.

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