Techno-Economic and Environmental-driven planning for Active and reactive power management in distribution network with AHP

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Abstract

This paper presents an approach for optimal placement and sizing of distributed generators (DG) and capacitors units in a radial distribution network. Both fixed and switching capacitors are considered for reactive power compensation at different load levels. Two types of DGs are considered for power generation namely unity power factor and 0.90 lagging p.f. The formulated multi-objective problem comprises of technical performance, economic and environmental (TEE) indices for grid active power reduction, peak power loss, energy loss, reactive power loss, environment impact reduction index. The appropriate weighting factors for different indices have been decided by Analytic Hierarchy Process (AHP). Scenarios are formed for different weighting factors using AHP and simulation results are compared for these scenarios. Four different cases of DG and capacitor operation are considered in the problem and case wise simulation is carried out. Worth of scientific approach for weighting factors has been proven better than uniform weighting factors.

Keywords: TEE, AHP, economic saving, benefits, weighting factors, environmental benefits.

I. Introduction

Economical, reliable and clean electric supply is the prime attempt of distribution system planners in the current global and competitive world. Distribution system has to be designed in such a way that it operates at lowest investment and highest benefit with least emissions. The proper distribution network planning results in power losses reduction, reduction in installation cost, reduces burden of existing feeders, maximization of system stability and improvement in voltage profile etc. The distribution companies consider and tests number of latest upgraded technologies, FACTS devices and optimization programs which results in optimal power flows and cost savings as well. The cost of interruptions reduces as well as quality and reliability of power supply also improves and finally cost of power generation reduces.

The optimal placement of DG with capacitors plays a key role in power loss minimization with reduced loading of feeders. It results in reduction of real and reactive power losses with voltage profile improvement and meets the load demand satisfactorily at each instance of time. Power factor of the network improves and

saves the cost of poor power factor penalty. A large number of technical, economic and environmental (TEE) benefits can be exploited with optimal inclusion of DG along with capacitors.

Based on the various methods available for DG and capacitor placement in a distribution network, the literature can be grouped in analytical methods, numerical programming methods, heuristics approach, artificial intelligence methods and multi-dimensional methods.

Analytical approach for capacitor placement for reactive power management is used as to reduce the computation procedure and simple methodology. Salama *et. al* [1] proposed modified analytical formulae for varying load with end-load conditions for optimal location of capacitor placements in distribution network. Lee and Grainger [2] developed an analytical approach for optimum placement of fixed and switching capacitors in distribution system to minimize energy and power losses. Optimal placement of shunt capacitors for reactive volt-ampere control and loss reduction has been proposed by cook [3] by placing shunt capacitor (fixed and switching) bank at 2/3 (Reactive load factor). Mohamed *et. al.* [4] given an analytical power stability index formula for optimal sizing and placement of capacitors in distribution network. Haque [5] proposed method of minimizing the loss associated with the reactive component of branch currents by placing shunt capacitors. While, Cho and Chen [6] given formula to minimize peak load loss, energy loss and shunt capacitor cost by optimal placing the fixed and switching capacitors in the network.

Numerical programming approach-based problems for optimal capacitor placement and sizing are solved by arithmetic operations with iterative procedure. Grainger and Lee [7] presented new generalized procedure for optimum size and location of shunt capacitors for reduction of losses on distribution feeders with equal area criterion principle. Duran [8] developed a dynamic programming based approach for evaluating the number, size and location of DG in radial distribution system. Baran and Wu [9] proposed nonlinear programming approach for optimal placement and sizing of capacitors and solved it in two phases. Jasmon and Lee [10] given a method for reducing a radial network into a single line equivalent has been developed which simplifies lengthy calculations of an unreduced network.

Optimal capacitor placement with DG in distribution network using heuristic methods where 'rules of thumbs', or hints/suggestions are invented by intuitions, experience and judgement which reduces the exhaustive iterations and saves the time. Shark Smell Optimization (SSO) algorithm for optimal size and location of shunt capacitors with the objective of minimizing cost due to energy loss and reactive power compensation of distribution system is proposed Gnanasekaran *et al.*[11]. Hamouda and sayah [12] used node stability indices approach for optimal sizing and siting of DG and capacitors placement in order to reduce cost of power loss and capacitors placement in distribution network. Novajan *et. al.* [13] presented MINLP based approach for optimal placement and sizing of DG with capacitors to minimize the costs related to power losses and capacitor investment. Khodabakhshian and andishgar [14] investigated a new optimization algorithm, named intersect mutation differential evolution (IMDE) to optimally placement and sizing of DGs and capacitors in distribution networks simultaneously in order to minimize the power loss and loss expenses providing that the bus voltage and line current remain in their limits. Muthukumar and Jayalalitha [15]

developed Harmony search and particle artificial bee colony algorithm (HSA-PABC) approach for optimal placement of capacitors in distribution network for minimizing the power losses and maximizing voltage stability for different load models.

Elsheikh *et al.* [16] presented loss sensitivity factors to identify the buses requiring compensation and then a discrete particle swarm optimization algorithm (PSO) to determine the sizes of the capacitors to be installed in radial distribution system. It includes improvement of the system power factor, improvement of the system voltage profile, increasing the maximum flow through cables and transformers and reduction of losses due to the compensation of the reactive component of power flow. Ali *et al* [17] proposed an Improved Harmony Algorithm (IHA) for optimal allocations and sizing of capacitors in various distribution systems. Power loss index (PLI) method is implemented for identification of candidate buses for capacitor placement. Optimal sizing and placement of capacitors is calculated in order to reduce the total cost and losses and consequently, to increase the net saving per year. Pradeepa *et al.*[18] identified a priority list of DG and capacitor unit allocation for minimization of losses and improvement in voltage magnitude will be evaluated by Genetic Algorithm. Voltage stability index has been measured as security parameter.

Sultana and Roy [19] proposed teaching learning based optimization (TLBO) approach to minimize power loss and energy cost by optimal placement of capacitors in radial distribution systems. Numerical experiments are included to demonstrate that the proposed TLBO can obtain better quality solution than many existing techniques like GA, PSO, direct search algorithm (DSA) and mixed integer linear programming (MILP) approach. It is a metaheuristic optimization algorithm conceptualized using the shark's hunting ability. Kannan *et al.* [20] presents new techniques for capacitor placement in radial distribution feeders in order to reduce the real power loss, to improve the voltage profile and to achieve economical saving. Power loss and node voltage indices are used as inputs to the fuzzy expert system and the output is sensitivity index which gives the weak buses in the system where the capacitor to be placed. The sizing of the capacitors is modeled by an objective function to obtain maximum savings using Differential Evolution (DE) and Multi Agent Particle Swarm Optimization (MAPSO). Mehdi Rahmani-andebili [21] investigated the reliability and economic-driven capacitor allocation approach in electrical distribution system for a definite planning horizon considering several technical and economic aspects. The aim of this study is minimizing total cost of the system including system power loss cost, system risk cost, investment cost and maintenance cost. Sajjadi *et al.*[22] proposed memetic algorithm based approach for optimal DG and capacitor placement considering the cost based analysis of various technical factors into distribution system. Its impact on voltage stability has been also analyzed.

Segura *et al.* [23] presented a heuristic approach for optimal capacitor placement in radial distribution system and compared the results with metaheuristic methods for the similar configuration. The objective function contains conflicting cost parameters as capacitor installation cost and operation losses cost and solved it using non-linear programming method. Tabatabaei and vahidi [24] developed novel methodology with fuzzy decision making approach for minimizing cost of peak power, reducing energy losses and improving voltage

profile with optimal capacitor placement. Bacterial foraging approach has been used for solving objective multi variable optimization problem.

From the above literature, it may be observed that, the various single and multi-objective formulations have been developed for optimal allocation of DG and capacitors units simultaneously. Many multi-objective problems have been converted into single objective problem by giving equal weightage to all the objectives. A scientific and logical technique for weighing factor selection requires further study, as the selection of weighing factors decides the quality and optimality of the obtained solution as per priority of particular index. Also, the reduction of GHG emission due to DG placement is also an issue of concern around the globe. This issue has not given due consideration in the existing literature.

Therefore, the proposed work aims to determine the optimal placement and sizing of DGs and capacitors considering to technical, economic and environmental benefits. An Analytic Hierarchy Process (AHP) technique is used in this multi-objective problem for the selection of weighting factors using multiple criteria multi decision process. The weights are mathematically driven and tested by Consistency Ratio Test (C.R. Test). GA based approach had been used to achieve an optimal solution for the developed formulation. The proposed methodology has been applied to a 34-bus test radial balanced distribution system. The obtained results by the proposed method have been also compared with equal weighting factors formulation. The obtained results reveal the effectiveness of the proposed scientific methodology for weighting selection in terms of cost benefit.

This paper is organized as follows, Section-1 present introduction; Section-2 explains the proposed methodology. Section-3 illustrates the AHP for calculation of weighting factors, Section-4 elaborates the optimal sizing of DG units using GA and Section-5 elaborated results and discussion. In the end, Section-6 summarizes the conclusion.

II. Problem Formulation

The following assumption of distribution network has been considered to develop the proposed formulation.

i. The distribution network under study is radial and balanced.
ii. Grid is 100% reliable.
iii. The distribution fed at substation only and substation node is numbered as 1.
iv. The magnitude of substation voltage is always maintained at a constant value equal to 1pu.
v. The susceptance and shunt conductance of the distribution lines are negligible.

1) DG modelling: In this paper, deterministic output of DG has been considered and it can deliver controllable out as per load requirement. DG Type can be classified into two types as controllable and uncontrollable output sources. Controllable DG has been considered in this work such as diesel generator, small gas turbines,

converter based DGs equipped with energy storage devices. Following type of dispatchable DG units are considered sources:

Type 1: DG capable of injecting P only such as Photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters.

Type 2: DG capable of injecting P with specified power factor.

2) Load modelling: For optimal allocation of DG and capacitors, modelling of load plays a crucial role. Load variation is continuous phenomenon and it varies in a range every hour. Load modelling has been carried out for conversion of continuous pattern into several steps such as load duration curve (LDC) shown in Fig.1. Accuracy of solution increases with number of steps used in the LDC. Typically, high, medium and low load levels are considered for yearly load demand.

3) AHP for calculation of weighting factors (Proposed Approach): The AHP is suitable to quantitative outcome of the decision in the strategic area. To solve such problems, it requires classified and clear information along with expert knowledge and experience for handling the decision makings. A logical and systematic decision-making approach further need to foresee and implement to achieve the optimal solution of significant weight [24].

Multi Criteria Decision Making (MCDM) method based on the pairwise comparison of alternatives. It is a decision supporting tool to create a priority vector of relative performance measure from multiple actors, to create various scenarios. If the comparison matrix created is not consistent, then it also provides a mechanism for improving *C.R.* For the given alternatives and decision criterion, a decision matrix is formed based on relative importance scale. For a multi-objective problem in which the selection of weighing factor is very crucial in the optimization, which must be handled precisely. The values of weighing factors indicate the performance of the indices considered in the objective function and accordingly affected. The strategic decision for the selection of such priority's weights is decided by MCDM in AHP.

For simplicity and clear explanations of weight and decision making, the systematic process is given below. Following are the steps involved in AHP:

Step 1: Problem is divided into a hierarchy of targets, criteria, sub-criteria and alternatives. It is a fundamental decision-making step for creating relationships.

Step 2: Information received from experts in terms of opinion for hierarchical structure is gathered such as equal, marginally strong, extremely strong.

Step 3: Based on different criteria's defined in the previous step, pairwise comparison is carried out to form a square matrix. The coefficients at position (j, i) will be reciprocal of values at position (i, j) and the element value is unity for position $i = j$.

Step 4: Comparison matrix is formed on various relative comparisons, containing principle eigen values and normalized right eigenvectors with respect to criteria and sub-criteria give the value of the weights.

Step 5: Order of matrix (n) is determined to check the consistency of the matrix. If matrix

constituted is inconsistent i.e. Consistency index (*C.I.*) is greater than 0.10 , then it is re-examined to achieve required consistency level. (*C.I.*) is given as:

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \tag{17}$$

Where, $\lambda_{\max}$ is the maximum eigenvalue of the matrix.

For Consistent matrix, the consistent Ratio (*C.R.*) is given as:

$$\frac{C.I.}{R.I.} < 0.1 \tag{18}$$

Step 6: The weight multiplied with ratings of each criterion provides the final rating values.

Table 1: Values of RI

R.I	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 2: Scale of relative importance for AHP

Level of comparable status	**Definition**	**Description**
1	Identical status	Equal contribution of both activities with the objective
3	Marginally weak	Marginal favor of activity over another
5	Strong	Strongly favor of activity over another
7	Very strong	Strong favor and dominance over other activity
9	Extremely strong	Highest possible order of affirmation over another
2,4,6,8	In-between values among two decisions	As negotiation needed
Reciprocal of non-zero values	The value of activity (i, j) reciprocal of activity (j,i)	-

The detailed flow chart of the AHP to calculate the weighting factors is given in Fig. 3

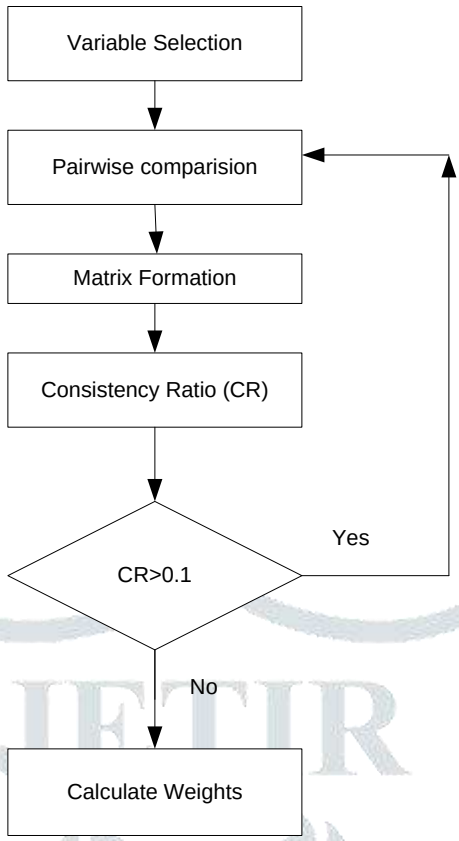


Fig. 1 Flowchart of AHP for calculation of weighting factors

4) Scenario Formulation: Based on the multiple choices and decision variables for priorities, AHP results in unique weighting factors in a scientific way. Different scenarios are formed in which highest weighting factor value to particular index indicates the priority for it. In general the values for weighting factor are chosen equal and it lacks priority for any index. The objective function *F* in equation (1) contains total nine indices but five benefit related indices are considered for AHP related exercise because these parameters gives cost benefit. The weights w_1, w_2, w_3, w_4, w_5 are given to indices *BIPI*, *BELI*, *BPPLI*, *BQLI* and *BEEI* and a base case having equal weighting factors. Five scenarios are formed and weights are calculated corresponding to benefit indices as shown in Table 3.

Table 3: Weighting factor values for scenarios

Scenario description	**Weighing factor values**	***C.R.* (<0.10)**
Base case	$W_1=0.2$, $W_2=0.2$, $W_3=0.2$, $W_4=0.2$, $W_5=0.2$	-
Scenario-1 (*BIPI*)	$W_1=0.5322$, $W_2=.0864$, $W_3=.1288$, $W_4=0.1831$, $W_5=0.0695$	0.0033
Scenario-2 (*BELI*)	$W_1=0.0799$, $W_2=0.5338$, $W_3=0.1632$, $W_4=0.0982$, $W_5=0.1248$	
Scenario-3 (*BPPLI*)	$W_1=0.0823$, $W_2=0.0939$, $W_3=0.5290$, $W_4=0.1324$, $W_5=0.1624$	0.0986

Scenario-4 (*BQLI*)	$W_1 = 0.0707$, $W_2=0.1824$, $W_3 = 0.1156$, $W_4 = 0.5284$, $W_5 = 0.0929$	0.0993
Scenario-5 (*BEII*)	$W_1 = 0.0823$, $W_2 = 0.1636$, $W_3= 0.0823$, $W_4 = 0.2561$ $W_5 = 0.4158$	0.0717

5) Objective Function: A multi-objective problem has been formulated in terms of different cost indices related to various performance measuring parameters such as technical, economic and environmental factors. The indices are categorized into two categories namely benefits and expenses indices. Overall saving or benefit may be written as difference of benefit and expenses.

$$Objective\ Function\ F = (w_1 * BIPI + w_2 * BELI + w_3 * BPPLI + w_4 * BQLI + w_5 * BEII) - (CICI + CMCDI + COCDI + CIDI) \quad (1)$$

a) Cost due to installation of fixed and switching capacitors index $(CICI)$

$$Capacitor\ installation\ cost\ \ CICI = Cost_{CF_i} \times n_{C_{Fi}} \times CF_i + Cost_{CS_i} \times n_{CS_i} \times CS_i \quad (2)$$

Here $Cost_{CF_i}$ & $Cost_{CS_i}$ are the costs of ith-fixed and switching capacitors in the distribution network. $n_{C_{Fi}}$ & n_{CS_i} are number of fixed and switching capacitors, $Cost_{CF_i}$ & $Cost_{CS_i}$ are capacity of fixed and switching capacitors. The total cost of installation in fixed and switching capacitors is calculated using above expression. The switching capacitors contain step size of 100kVARs step size. The total size of capacitors to be included into the network is limited by budgetary constraints.

b) Cost due to Installation costs of DGs Index $(CIDI)$

$$CIDI = \sum_{i=1}^{NDG} \sum_{k=1}^{kDG} \text{cost}_{installation_{ik}} \quad (3)$$

c) Cost due to maintenance of DG Index $(CMCDI)$

$$CMD = \sum_{j=1}^{Nl} \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} \cos t_{Maint,ik} \times DG_{j.ik} \times T_j \quad (4)$$

$$CMDI(CMD) = CMD \times \sum_{t=1}^{T} \left(\frac{1+InfR}{1+IntR}\right)^t \quad (5)$$

Where $\cos t_{Maint,ik}$ is maintenance cost of ith-DG. $InfR$, $IntR$, T and T_j are the inflation rate, interest rate, total planning period and time duration at j^{th}-load level related to maintenance cost of DG. Equation (5) gives

the cost of maintenance for DG installed which is directly proportional to number of DGs incorporated in the distribution network.

d) Cost due to operation of DG Index $(CODI)$

$$COD = \sum_{j=1}^{Nl}\sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}} T_j \times DG_{j.ik} \times CG_{ik} \tag{6}$$

$$CODI(COD) = COD \times \sum_{t=1}^{T}\left(\frac{1+InfR}{1+IntR}\right)^t \tag{7}$$

Here CG_{ik} is operation cost of DGs incorporated into the distribution network and $DG_{j.ik}$ is the capacity of power generated by i^{th}-DG at j^{th} -load level.

e) Benefit due to reduction in active power demand from grid Index $(BIPI)$

$$PT_{N_{DG,j}} = PD_j + Loss_{NDG,j} \qquad PT_{N_{DG,j}} = PD_j + Loss_{NDG,j} \tag{8}$$

$$PT_{DG_j} = PD_j + Loss_{DG,j} - \sum_{j=1}^{Nl}\sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}} DG_{j,ik} \tag{9}$$

$$BIP = \sum_{j=1}^{Nl} C_{Mwh,j} \times \Delta PT \times T_j \qquad BIPI(BIP) = BIP \times \sum_{t=1}^{T}\left(\frac{1+InfR}{1+IntR}\right)^t \tag{10}$$

$PT_{NDG,j}$ and $PT_{DG,j}$ are active power demand purchased from central grid before and after DG inclusion into the distribution network. $\Delta Loss_j$ is the reduction in real power losses and ΔPT is reduction in active power demand. $C_{Mwh,j}$ is the energy market price at j^{th}-load level (\$/MWh). $BIPI$ gives benefit achieved due to reduction in active power demand from grid at different load level.

f) Benefit due to reduction in reactive power loss index $(BQLI)$

$$BQL_1 = C_R \times (Q_0 - Q_1) \qquad BQLI = BQL_1 \times \sum_{t=1}^{T}\left(\frac{1+InfR}{1+IntR}\right)^t \tag{11}$$

$BQLI$ is index for benefit due to reductions in reactive power losses. Reactive power compensation plays an important role in benefits and expenses calculations.

g) Benefit due to reduction in energy loss index $(BELI)$

$$EL_{i,j} = T_{i,j} \times R_i \times I_i^2 \qquad EL = \sum_{j=1}^{n} E_j \qquad CEL = C_e \times EL \tag{12}$$

$$BELI_1 = CEL_0 - CEL_1, \qquad BELI = BELI_1 \times \sum_{t=1}^{T}\left(\frac{1+InfR}{1+IntR}\right)^t \tag{13}$$

CEL_0 , CEL_1 are the cost of energy loss before and after DG inclusion into distribution network. $BELI$ gives the benefits due to reduction in energy losses in the network for the given planning period.

h) Benefit due to reduction in peak power loss index $(BPPLI)$

$$PL = P_{Loss,0} - P_{Loss,1} \quad BPPL_1 = C_d \times PL \qquad BPPLI = BPPL_1 \times \sum_{t=1}^{T} \left(\frac{1+InfR}{1+IntR}\right)^t \tag{14}$$

Benefit due to reduction in peak power loss is calculated at peak load hours. The reduction in peak load power losses increases the current carrying capacity of feeders and reduces the burden on the lines.

i) Benefit due to environmental impact reduction index ($BEII$)

$$EI = r_1 * (P_{GSS}^{NDG} - P_{GSS}^{DG}) - r_2 * P_{RE}^{DG} \tag{15}$$

$$BEI_1 = C_{EV} * EI \quad \text{and} \quad BEII = BEI_1 * \sum_{t=1}^{T} \left(\frac{1+InfR}{1+IntR}\right)^t \tag{16}$$

The environmental impact reduction due to simultaneous placement of DG and capacitor in the distribution network has been calculated in terms of cost by $BEVI$. The CO_2 emissions due to centralized power generation i.e. grid and DG are calculated and net reduction in emission after DG and capacitor placement is converted in cost by using above written equations. The overall impact is analyzed for prescribed planning period.

6) Constraints: Equality constraints

Power flow constraint

$$P_{i+1} = P_i + PD_j - Loss_{DG,j} - R_{i,i+1} \times \frac{\left(P_i^2 + Q_i^2\right)}{|V_i|^2} \tag{19}$$

$$Q_{i+1} = Q_i + QD_j - Loss_{DG,j} - X_{i,i+1} \times \frac{\left(P_i^2 + Q_i^2\right)}{|V_i|^2} \tag{20}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2\left(R_{i,i+1} \times P_i + X_{i,i+1} \times Q_i\right) + \left(R^2_{i,i+1} + X_{i,i+1}{}^2\right) \times \frac{\left(P_i^2 + Q_i^2\right)}{|V_i|^2} \tag{21}$$

DG power factor

$$\cos\phi = \frac{P_{DG}}{\sqrt{P_{DG}{}^2 + Q_{DG}{}^2}} \tag{22}$$

DG penetration level

$$PL = \frac{S_{DG}}{S_{Load}} \times 100 \tag{23}$$

Inequality constraint

DG penetration limit

$$\sum_{i=1}^{DG} S_{DG,i} \leq 0.65 \times S_{load} \tag{24}$$

Reactive power compensation limit: The limit for maximum reactive power compensation using shunt capacitors may not be greater than total reactive load demand and it may be written as:

$$\sum_{i=1}^{ncap} Q_{c,i} \leq total\ Q \tag{26}$$

Voltage magnitude limit constraint: The upper and lower voltage limits for the peak load and off peak load operation are confined to 1.05 p.u. and 0.95 p.u. for the network under consideration.

$$V_i^{\min} \leq V \leq V_i^{\max} \tag{27}$$

Where, V_{min} and V_{max} are minimum and maximum limits of voltages (p.u.) of the system.

Branch current constraint: The limits for maximum branch current capacity of DG are fixed and it should not be beyond thermal limit. It provides the improvement in reserve capacity of the conductors.

$$I_i^{DG} \leq I_i^{rated} \qquad \text{For } i=1,2,3\ldots, B_r\text{-}1 \tag{28}$$

Where I_i^{DG} are branch currents with DG and IC_i maximum branch current carrying capacity of conductors.

Budgetary constraint

The total cost of investment for installation of DGs and capacitors should be less or equal to predefine budget for the overall planning.it may be given as below.

$$C_{cap} + C_{DG} \leq B \tag{29}$$

Here, B is the maximum allowable budget.

The overall flowchart of problem formulated is given as shown below:

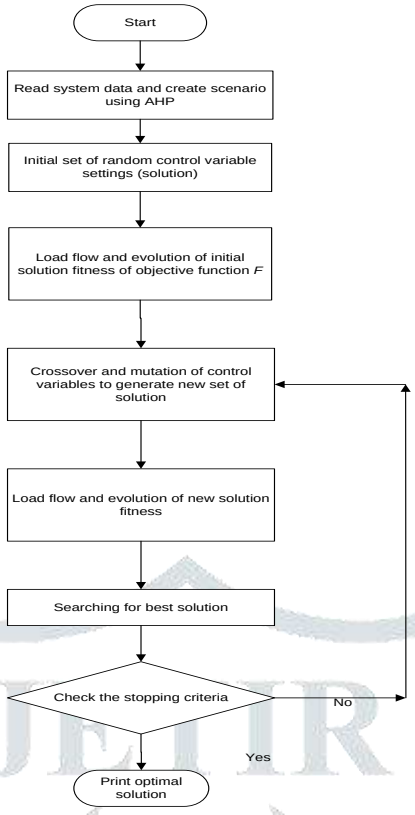


Fig 2: Flowchart of overall proposed problem.

III. Proposed Algorith Using Genetic Algorithm (GA)

John Holland (1975) defined GA as "A method for moving from one population of "chromosomes" to a new population by using a kind of "natural selection" together with the genetics−inspired operators of crossover, mutation, and inversion". GA utilizes population of points instead of single point which helps it to get rid of local minima and provides multiple optimal solutions. GA has capability of handling non differential functions, discontinuous functions and multimodal functions effectively. GA find their usage in vast range of applications like search, optimization, decision making, machine learning, robotics and many more. The steps used for implementation of proposed algorithm are as following.

Step 1. Initialization and Structure of Individual

Read the values of various parameters and technical data such as distribution network, costs, load levels and constraints data at beginning. The values of weighting factors for various scenarios have been calculated and objective function. Generate random population of n chromosomes – each chromosome being the potential solution.

$$X_i = x_{i1}, \dots \dots \dots, x_{in} \tag{30}$$

Step 2. Updating the population

Applying crossover operator: Mate the selected chromosomes as per given crossover probability to form new off springs.

Mutation: Mutate new chromosomes as per given mutation probability.

Step 3. Selecting new population

Evaluating fitness of every chromosome: Fitness of every chromosome is evaluated while running the problem. All the constraints must be satisfied.

Applying selection process: The offspring population created by selection, recombination, and mutation replaces the original parental population. Many replacement techniques such as elitist replacement, generation-wise replacement and steady-state replacement methods are used in GA.

Step 4. Checking stopping criteria: In this step the improvement values in the fitness of the chromosomes of the old and new population is checked. If there is no significant improvement in it than optimization process must be stopped, otherwise it must continue to *step 2*.

Step 5. Saving the outcomes: The optimization process has ended with all constraints fulfilled. The results obtained as optimal sizing and placement of DGs with capacitors are recorded and published for each scenario

IV. Results and discussions

In this work, five scenarios based on AHP are formed and developed formulation has been implemented in MATLAB environment. 11 kV, 34-bus radial and balanced distribution network has been used to test the proposed methodology for optimal placement and sizing of selected renewable DG and capacitor units. The single line diagram of this test system is shown in Fig.2. The network has total demand of 2520+*j*1562 kVA, 3202+*j*1985kVA and 2974+*j*1876kVA at low, medium and high load-levels. The total base case power losses are (225.14+*j*74.97) kVA. Thereafter, optimal sizing of DG and capacitors has been calculated by simulating the developed objective function based on the cost corresponding to various technical economic and environmental indices for different scenarios obtained by AHP. Simulated results are stored and compared with results obtained from objective function *F* with equal weighting factors.

The line diagram of 34-bus radial distribution system is shown as below in Fig.3

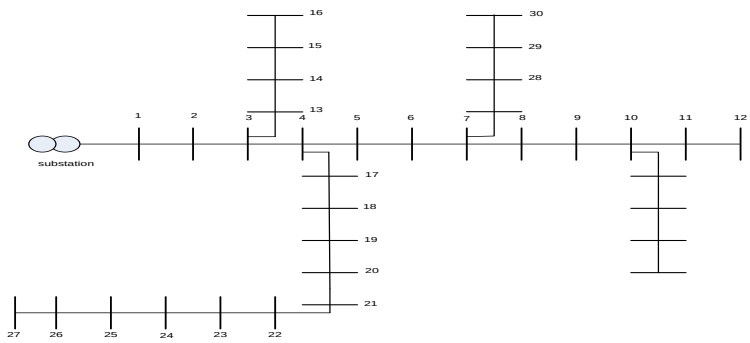


Fig. 3. 34-bus radial distribution system

Load Variation and electricity price table

The annual load schedule of test distribution system is been modeled for one year and it has been categorized into three load level.

Table 4: Load and electricity price of Test system

Serial number	Load level	Time duration in a year	Market price ($/MWh)
1	Light load	2190	35
2	Medium load	4745	49
3	High load	1825	70

To demonstrate the effectiveness of the proposed algorithm, two cases based on combination of DG and capacitor installation are considered for the test system:

Case 1: Placement of only DGs at unity power factor.

Case 2: Placement of only DGs at 0.90 lagging power factor.

In this work, four distributed generation units with the capacity of 300kW and ten capacitors are used.

Investment Cost table

Serial number	Parameter	Unit	Cost
1	Capacitor investment cost	$/KVar	
	100kVar		400
	200kVar		800
	300kVar		1100
	400kVar		1500
	500kVar		1700
2	DG installation cost	$/MW	3,18,000
3	DG operation cost	$/MWh	29
4	DG maintenance cost	$/MWh	7
5	Active power purchase price	$/MW	1,20,000
6	Average interruption cost per hour	$/MW$_{peak}$	19,100
7	Reactive power purchase price	$/MVar	30,000
8	Annual load growth rate	%	10
9	Interest rate	%	12.5

10	Inflation rate	%	9
11	Planning period	years	4

The cost based analysis of various scenarios for different cases as compared to base case in terms of technical, economic and environmental parameters has been carried out.

Case 1: ***Placement of only DGs at unity power factor***

In this case, only DGs operating at unity power of 300kW capacity are placed in the distribution network. Computation of various parameters related to technical, economic and environmental in terms of cost is processed for base case (equal weights) and five scenarios. Optimal location of DGs is evaluated. Table.5 shows comparative values of benefit, investment, overall benefit, technical parameters and minimum voltages.

Table 5: Cost analysis for Case-1

Parameter	**Base case (Equal Weights)**	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**	**Scenario-5**
BEII	3179936	3189828	3202425	3138157	3117779	3183811
BELI	11199681	12058686	13152712	7571414	5801767	11536212
BQLI	177309.3	177932.8	178760.2	76440.06	76270.56	177594.8
BPPLI	1298.458	1376.477	1488.749	917.1557	784.2232	1359.851
BIPI	161085.6	161586.7	162224.9	158969.1	157936.9	161281.9
CIDI	192652.9	192652.9	192652.9	192652.9	192652.9	192652.9
CODI	307338.7	307338.7	307338.7	307338.7	307338.7	307338.7
CICI	0	0	0	0	0	0
CMDI	8.46863	8.468629	8.46863	8.46863	8.46863	8.46863
Overall benefit ***B***	**14219311**	**15089410**	**16197611**	**10445897**	**8654538**	**14560260**
%- Real power loss reduction	29.27	31.50	34.32439	19.76	15.16	30.14
%- Reactive power loss reduction	28.35	30.07	32.55	20.04	17.12	29.70
%- reduction in peak power losses	27.85	27.95	28.08	12.01	11.98	27.90
%-Energy loss reduction	28.70	30.91	33.71	19.40	14.87	29.57
Minimum Voltage (p.u.)	0.9695	0.9712	0.9736	0.9688	0.9660	0.9698

From the Table.5, it may be observed that scenario-2 (*BEL*) gives maximum overall benefit and these are higher than base case scenario (equal weights). The total benefit increases from 14219311$ to 16197611$. Percentage-reduction in real power losses, reactive power losses, imported active power and peak power losses is highest for scenario-2 as compared to other scenarios and base case (equal weights). It is quite evident that

most of scenario results are better than base case result. Minimum voltage p.u. values for all scenarios are improved and it is better than base case minimum voltage.

Voltage profile

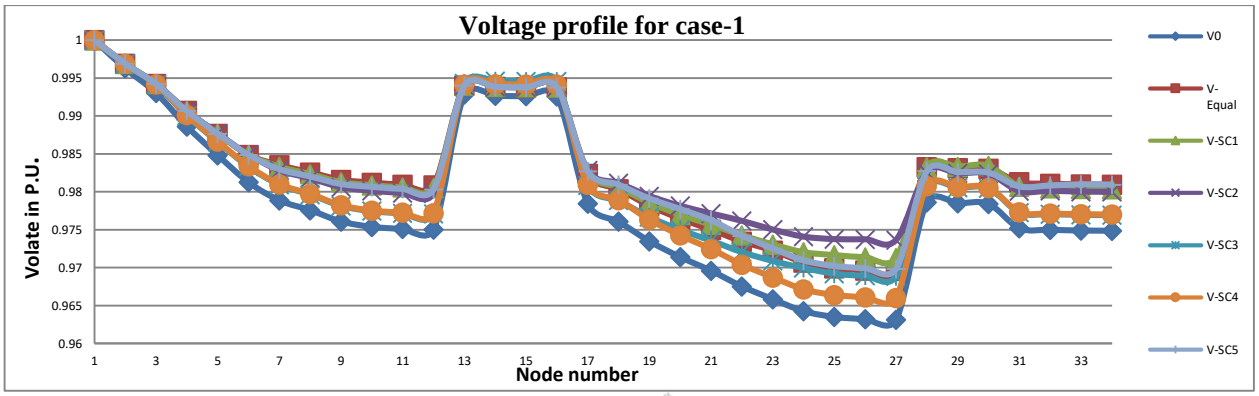


Fig. 4. 34-bus radial distribution system

In radial distribution network, due to voltage drop across the long lines, voltage profile of end user in the feeder drops beyond the acceptable limit. It is necessary to make certain arrangements so that voltage may restored within limits. Voltage profile of the distribution network before and after DG placement has been shown in Fig.4. As compared to before DG placement case, voltage profile in all five scenarios and base case has improved. It is noticeable that voltage profile in scenario-2 has shown highest improved comparatively.

Case 2: Placement of only DGs at 0.90 lagging power factor

In this case, four DGs of 300kW capacity at 0.90 lagging power factor are placed in the distribution network. Proposed formulation is implemented for five scenarios and a base case (equal weights) and it is simulated. Results obtained in terms of cost parameters, technical parameters are represented in Table.6.

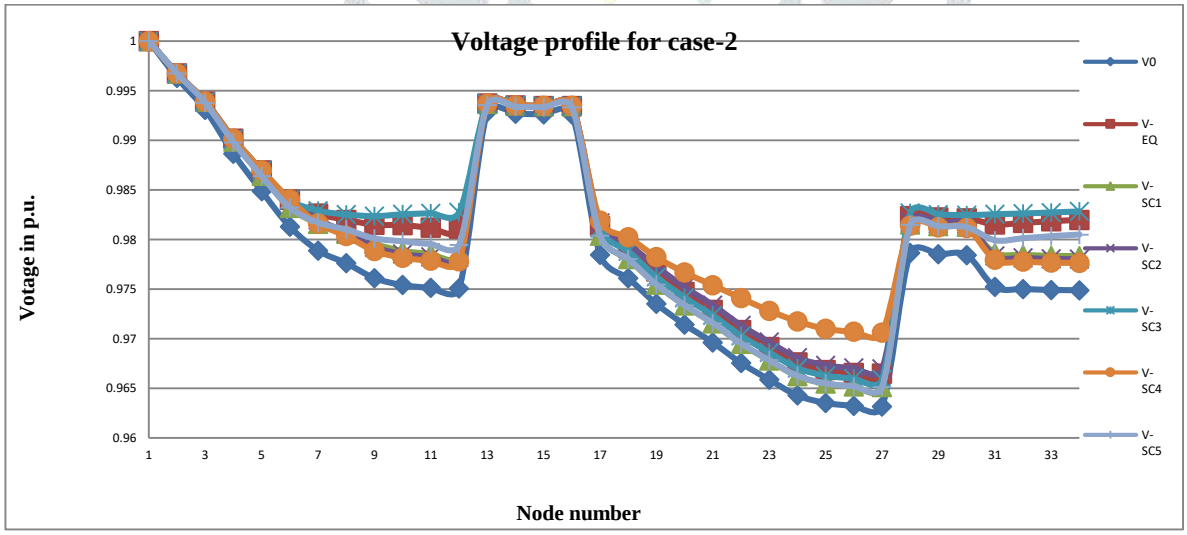
Table.6 Cost analysis for Case-2

Parameter	Base case (Equal Weights)	Scenario-1	Scenario-2	Scenario-3	Scenario-4	Scenario-5
BEII	3114675	3096630	3130534	3106314	3120605	3096461
BELI	5532219	3965074	6909467	4806060	6047194	3950407
BQLI	104716.6	66102.83	105790.2	104196.9	105089.5	73628.22
BPPLI	675.6951	504.0569	806.8118	604.7617	731.7416	491.4434
BIPI	157779.6	156865.4	158583	157356	158080	156856.9

CIDI	192652.9	192652.9	192652.9	192652.9	192652.9	192652.9
CODI	307338.7	307338.7	307338.7	307338.7	307338.7	307338.7
CICI	8.46863	8.468629	8.46863	8.46863	8.468629	8.468629
CMDI	0	0	0	0	0	0
Overall benefit ***B***	**8410067**	**7285168**	**9805173**	**7674532**	**8931701**	**6777844**
%- Real power loss reduction	16.40	10.40	14.77	12.55	18.51	10.36
%- Reactive power loss reduction	16.45	11.22	15.54	13.46	18.46	10.93
%- reduction in peak power losses	16.53	10.38	16.46	16.37	16.64	11.56
%-Energy loss reduction	16.02	11.01	14.43	12.32	18.07055	10.12
Minimum Voltage (p.u.)	0.9664	0.9651	0.9669	0.9659	0.9706	0.9651

In Table.6, it may be observed overall benefit is highest for scenario-2 as compared to base case and other scenarios. Technical parameters such as percentage reduction in real power losses, reactive power losses, imported active power from grid, power losses are recorded and compared.

Fig. 5. Voltage profile for case-2



V. Conclusions

This paper aims to focus on an AHP and GA based multi objective formulation for optimal allocation of DG and capacitors considering technical, economic and environmental performance indices (TEE). A committed multi criteria multi decision making AHP approach has been applied to evaluate the appropriate values of weighting factors. These prioritized values of weighting factors are being used to create various scenarios for DG and capacitors allocation with corresponding priority. Annual load variation is modelled into three load levels. GA approach had been utilized to determine the optimal sizes of DG and capacitors units corresponding to three load levels at UPF and 0.90 lagging power factors. The performance of proposed methodology has been tested on 34-bus test system in terms of real power loss reduction, voltage profile enhancement, reduction of substation injection power, and investment cost savings by DG penetration corresponding to above indices on both the power factors. The worthiness of the proposed method has also been validated and compared with other objective function termed as base case (equal weights) reported in literature. Simulation results revealed and demonstrated that the proposed methodology is a good compromise to acquire the distribution system technical (real power loss reduction, voltage profile enhancement, releasing the burden of the distribution network, i.e. enhancing the power transferring capabilities of the network), economic and environmental (emissions reduction) benefits compared to those methods considered technical and economic parameters with equal weight in objective function.

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