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Optimal Capacitor Placement and Sizing: An Overview

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Abstract— ***Optimal shunt capacitor placement and sizing or optimal capacitor configuration for distribution system has received considerable attention for researchers from last three decades. In this paper, an overview of previous published work for understanding of different simulation methods, assumptions made by authors and brief description of the simulation methods are presented. While studying the optimal capacitor configuration problem there is a need to consider a single phase as well as three phase loads with voltage unbalance conditions, proper power factor control, power quality issues like series and parallel resonance, harmonic issues and reliability indices in distribution system network. Review of published research literature on distribution system reliability addresses the various aspects such as maintenance strategies as well as the use of capacitor. However, in recent years many researchers have focused on optimal placement of capacitors for enhancement of reliability. Lot of research work is reported in published literature on optimal capacitor placement with the conventional objective function considering total cost of losses and investments.***

This study is useful for researcher those are working with the similar problem formulated in their research work. Various optimal capacitor placement methods in literature are discussed in this paper.

Keywords— Optimal capacitor placement, Reliability indices, particle swarm optimization, genetic algorithm, simulated annealing.

I. INTRODUCTION

Energy is always transferred from source to distribution via transmission and consuming active and reactive power losses. Major Losses are due to reactive power losses and can be controlled by proper reactive power management. To avoid the reactive power loss, local reactive power compensation by placing appropriate capacitor is most powerful method employed throughout the world. Benefits of capacitor placement are minimizing active and reactive power losses, improving power factor, maintaining appropriate voltage profile and releasing capacity of feeders and transformers. Apart from these benefits, if capacitor are not selected with appropriate size and not placed in appropriate place then system may become vulnerable and behaves in abnormal way and voltage may increase beyond limits, unacceptable power factor and series and parallel resonance issues. Considering this in mind many researchers are working for the best simulation process for optimal capacitor placement and sizing. Optimal capacitor placement problem has been the topic of many research works. Some of most recent published papers on this topic have solved the problem using ant colony direction, graph search algorithm, genetic algorithm, particle swarm optimization (PSO) and fuzzy Evolutionary programming. Besides, the cost per kVAR varies from one size to another. In general, capacitors of larger size have lower unit prices. Since the capacitor placement is not an online action for distribution systems, its computational solution 2time is not a significant issue. However, in order to avoid excessive computational times for large feeders, the following measure can be considered to reduce the computational time. At first, in order to find the sensitive buses to capacitor placement, the problem is solved with a low population size and a small value for maximum number of iterations while the solution vector includes all buses of the system. Sensitive buses are referred to those buses of the distribution feeder for which placing a constant size of capacitor results in more reduction in the value of overall defined cost function. Capacitors can supply reactive loads, reduce losses improves voltage profile, power factor, and hence optimum capacitor placement is a need as per today’s complex integrated network. An algorithm is proposed to solve the optimum capacitor placement problem to determine capacitor size and location. ECOST is calculated to determine the acceptable level of reliability for customers. Conventional objective function and reliability based objective function is evaluated separately. However, the proposed method considers only overhead line and cables for capacitor placement. It is a need to find out such locations other than overhead line and cables in the distribution system. Failure rate is considered with linear relationship to the percentage of compensation, in real practice these failures is never in linear, so it is need to develop a method for nonlinear solution of such objective functions.

II. PROBLEM DESCRIPTION

Problem can be described for optimal capacitor placement and sizing as, developing an objective function or multi-dimentional objective function to minimize power losses, minimize reliability cost losses, minimize cost of capacitor for constraints like voltage profile, power factor enhancement, harmonic voltage limits.

A. Objective Function

First Objective function is developed for reliability cost as given below,

$$ECOST = \lambda_i \ \ Ci \ \ L(a)_i \qquad (1)$$

Where,
ECOST - Reliability Cost
λ_i - failure rate

Ci - customer composite damage function

$L(a)_i$ - average load

Eq. 1 represents evaluation of reliability cost based on Failure rate (denoted by λ_i). Failure rate can be decreased with strengthening power system by means of (i) proper reactive power management and control (ii) maintaining power factor towards unity and (iii) improving voltage profile. Now, second objective function is to evaluate capacitor cost (CC) is formulated by,

$$CC = x_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T \quad (2)$$

Where,

x_i - 0/1, 0 means no capacitor installed at bus_i

C_{0i} - Installation cost

C1i - per kVAr cost of capacitor bank

Q_{ci} - Capacitor bank size in KVAr

B_i - Number of capacitor banks

C_{2i} - operating cost of per bank, per year

T - Planning period (years)

Then energy loss (El), active power loss (Ploss) and reactive power loss (Qloss) are given below,

$$El = T_i P_{Li} \quad (3)$$

where, P_{Li} is the combination of Ploss and Qloss. Now the multi-dimensional objective function can be stated as follows,

$$min_f = ECOST + \sum_{i=1}^{N_{bus}} (x_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T) + C_2 \sum_{l=1}^{N_{load}} (T_l P_L^l) \quad (4)$$

Where,

Nbus	-	No of bus candidate
Xi	-	0/1, o means no capacitor installed at bus i
C0i	-	Installation cost
C1i	-	per kVAr cost of capacitor bank
Qci	-	Capacitor bank size in KVAr
Bi	-	Number of capacitor banks
C2i	-	operating cost of per bank, per year
T	-	Planning period(years)
C2i	-	Cost of each kWh loss in Rs/kWh
L	-	load levels, maximum, average and minimum
Tl	-	Time duration, in hours, of load level l
PLl	-	Total system loss at load level l

B. Constraints and Possible Assumption

$$Vmin < V < Vmax$$
$$PFmin < 0.90$$
$$VTHD < 5\%$$

Here Vmin = 0.95 and Vmax = 1.05. Assumptions considered in the development of the objective function

(a) Balanced network considered for simplicity,

(b) Capacitors are available in step size and

(c) Capacitor placement affects only the flow of reactive power in the feeder.

III. Intelligence Tools

A. Genetic Algorithm

GA is a search algorithm based on the mechanic of natural selection. Basically, a GA makes a population that evolves through time using reproduction and mutation process. Only individuals representing good solutions of the capacitor placement problem will survive longer, and their genetic information will be present in the next generation. At the end, after several generations, the interaction between these high quality individuals will produce a final population which represent the best solutions set of the problem. The main parameters to determinate if a chromosome is a very good solution depends of two factors: The objective function and technical restrictions of generation and transmission costs. Technical restrictions embrace all possible solutions that even having a good value for objective function involve an unacceptable increase or decrease of some parameters of the system. The most important parameters can be characterized as follows.

1. Magnitudes of the voltage on system's nodes: Nodal voltages must be in a range between 0.95 and 1.05 pu. It means that for all transformers connected to the nodes will be at least a minimal value that assures a good voltage value in secondary network. This range can be fixed if the system does not require a tolerance too close respect to feeder voltage.
2. Current flow by conductors: Given a capacitor placement structure by GA, none of the branches current circulating around system can be higher than maximal current supported by conductors.

3. Maximum reactive power provided by capacitors: Let's total reactive power demand of the distribution system be Qt. Then the result of sum of every capacitor connected on nodes cannot be higher than Qt. It implies that never will be a current flowing toward feeder at peak load.

Here is a brief description for how the mechanisms of reproduction and mutation are simulated by GA. In reproduction process, firstly, we randomly select a pair of chromosomes, with the same structure. In the next step, chromosomes are treated separately; one for binary part and another for integer part. In binary part, for a given position, if two parents share value, the chromosome produced by reproduction will keep it. If values are different, the result for new chromosome is selected at random. In integer part, for a given position, result will be the average of values found in the parents. If result is not an integer value it will be approximated until closer value at random. In mutation process, chromosome structure is modified. This change is performed at random, but there is a difference between binary and integer part.

A problem of choosing a optimum location and size of shunt capacitors in three- phase distribution system with non linear and unbalanced load is presented (Carpinelli, G. et al.) and G. Carpinelli et al. (2005). The objective of capacitor placement of procedure is not only to minimize the power loss along distribution feeders but also to make sure that there capacitor will have the minimum possible impact of harmonic distortion of bus voltages in the system. Furthermore the distribution system can operate at under unbalanced loading condition. Hence, optimization will have to account for any unbalance in the system and proposed optimization program according to the authors successfully solves the problem. Results obtained by simulation of a distribution test system under various operating conditions are presented to validate the proposed solution methods. However, the proposed work other solution based on optimization method such as Genetic Algorithm for optimal placement and sizing are not compared with proposed optimization program and does not addresses the effect optimal placement and sizes of shunt capacitor on distribution system reliability improvement considering the other objective functions including the voltage profile as a constraint.

When applying the genetic algorithm to optimize the shunt capacitor placement and sizing problem, an important aspect is the coding of the potential solution. The coded variables are the number of capacitor units and their sizes for placement. (Biswas, S. et al.) developed an algorithm for system modelling to achieve loss minimization, power quality issues in voltage and power factor constraint. (Hamid Reza Esmaeilian et al., 2014) uses Backward -forward power flow and GA algorithm for optimal capacitor placement of capacitors and DGs. In (M. A. S. Masoum et al., 2004) capacitor placement is considered as planning problem and computational time for genetic algorithm is compared with other tools. Power quality limit for THD_v is also evaluated. Cost of harmonic current is included in the objective function rather than considering it as constraint. Appropriate place and appropriate size of capacitor is important to ensure that system power loss and total capacitor bank cost is to be reduced. (Deepti Sharma et al., 2013) presents an objective function to minimize net saving in miminizing in net annual active power loss and cost of shunt capacitor using genetic algorithm. However power quality issues and reliability indices are not addressed. (Calderaro et al., 2013) formulate optimization of capacitor placement for Wind Farm Power Plant. Cost function includes energy cost and cost of capacitor in well defined voltage constraint as it is supposed that the voltage of wind farm is voltage due to transmission system operator. So voltage constraint is not applicable in case of off peak period. The most relevant advantage of genetic algorithm is to not require differentiability and continuity of the cost function and to reduce the risk to be trapped in local minima compared with other optimization tools. Reconfiguration and optimal capacitor placement for losses reduction using genetic algorithm is discussed by (Montoya, D.P. et al.).

The author focuses on strategies of reconfiguration and capacitor allocation using 33 bus systems. Initialization, crossover, mutation is developed with the help of minimal spanning tree algorithm. Genetic algorithm which is population based search method is utilized to evaluate power loss in IEEE 33 bus for the optimal placement of capacitor (Neha Goyal et al., 2014). Genetic algorithm is utilized for voltage control and optimal capacitor configuration in presence of photovoltaic system. Acceptable voltage limit is applied as discussed in (Soleimani et al., 2014). The results indicate that the PV system power factor optimization reduces the total amount of required capacitor and power losses. (Mahmoodianfard, F et al.) placed capacitor optimally on transmission and sub-transmission Zanjan's network for loss reduction. Reproduction, Crossover, Mutation and Population is defined to understand genetic algorithm. Genetic algorithm treatment was given by (W. A. dos et al., 2009) for multi objective capacitor allocation problem to achieve smallest possible cost in placement for capacitor dimension. Result analysis represents comparative study with graphical representation. Genetic operators and genetic parameters are well defined in (Srinivasan Sundhararajan et al., 1994). Objective function is formulated for loss minimization and cost of capacitor. However it is observed including this paper, many researchers had not touched reliability parameter in objective function.

B. Fuzzy Logic

Optimal reactive power compensation is a radial distribution system requires the determination of best setup location for capacitors of minimum sizes, the total cost of compensation should be the least and must yield the maximum energy loss reduction accounting for various load levels.

Other control such as transformer taps, reconfiguration options and existing reactive power sources must be considered while searching for the optimal solutions. Optimal selection of few based sites from among a large set is a problem of high combinatorial order and difficult to solve using conventional optimization techniques. Optimal sizing is a problem of continuous nature. A single dynamic data structure for an evolutionary programming algorithm that handles the problem of optimal location and sizing of new shunt capacitor simultaneously while considering transformer tap, existing reactive power sources and reconfiguration option counting from different load levels and time duration is proposed (B. Venkatesh et al., 2006). A fuzzy model of objective function is developed for optimization in the EP frame work. The proposed fuzzy EP method is tested on two cases of a 69-bus radial distribution system. The overall problem has objectives of minimization of total cost of new capacitor and the minimization of power loss in lines while obtaining the satisfactory voltage profile. The proposed work needs to be extended for distribution system reliability enhancement point of view with wider objective functions.

(Joyal Isac, S. et al.) discusses fuzzy logic tool for optimal capacitor placement problem implemented on IEEE 34 bus system. Triangular membership function is selected for power loss index. For voltage constraint, apart from triangular membership function trapezoidal membership function can be used. the decision matrix is developed using 25 rules, which is framed for desired output. However simulation by fuzzy method for optimal capacitor placement problem is not compared with other intelligent tools. Fuzzy deferential evaluation tool is selected for optimal capacitor placement by (Saranya, S.G. et al.). Triangular membership function for power loss index and sensitivity index is selected whereas trapezoidal membership function is used for voltage constraints. In (Saranya, S.G. et al.) it is discussed that fuzzy logic tool is used for only capacitor placement whereas 8capacitor sizing based on objective function is carried out by PSO. (Anwar S Siddiqui et al., 2012) reduced losses 10 bus radial distribution system by capacitor placement with the help of fuzzy logic tool. Fuzzyfier and inference engine is nicely used to solve the cost function. However use of fuzzy logic for load flow study carried out by author is rare. ETAP software introduces optimal capacitor placement module for OCP simulation using genetic algorithm as discussed by Pravin Chopade et al. (2011). Losses are compared for before and after OCP simulation. (M. Ladjevardi et al., 2008) and (B. A. D'Souza et al., 2004) proposes a hybrid approach for placement and sizing of capacitor in radial network. Genetic algorithm can be utilized for capacitor placement due to it's biological evolution and population genetic to search ability whereas Fuzzy logic can be used for sizing objectives due to it's inference engine technology and capability of simulation selection approach. (M. A. S. Masoum et al., 2004) introduces fuzzy approach for OCP in presence of harmonics.

C. Particle Swarm Optimization

The Particle swarm optimization was introduced by Kennady and Elbert in 1995. It was developed through simulation of a simplified social system and has been found to be robust in solving contineous non linear optimization problem (James Kennedy et al., 1995) (Xiaohui Hu et al., 2004) (Yuhui Shi et al., 1999). The information links are redefined randomly with each iteration: each particle informs K others chosen randomly. We note that it means that the group of informants corresponding to a particle has an average size slightly less than K, owing to the fact that the same information receiver can be selected several times. In the same way, it means that the 9average size of the groups of informants is also slightly less than K, though that is a little less obvious. The exact formula and the manner of finding it are given at the end of the chapter, for the benefit of mathematical amateurs.

It is enough for us to note that the smaller the swarm, the lower the average number of informants of a given particle in respect of K. For example, for a swarm of 20 particles, with K = 3 one finds that the average size of the group of informants is 2.85, whereas it is 2.71 for a swarm of 10 particles. This is relevant when one decreases the size of the swarm in the hope of reducing the total number of evaluations needed to achieve the goal. With fewer particles, the swarm is certainly a little less ready to explore the search space, but there is a kind of automatic partial offsetting by the correlative reduction of the average size of the groups of informants. As we have seen and will examine further, this reduction actually encourages exploration by increasing diversity. Note that, for the moment, we are interested only in continuous problems with real variables. In practice, it is not desirable that too many particles tend to leave the search space as early as the first increment, or for that matter later. We will see below what occurs in this case, but, for the moment, let us be satisfied with deriving at random the values of the components of each velocity, according to a uniform distribution in:

$$[\ (x_{min} - x_{max})/2\ ,\ (x_{max} - x_{min})/\ 2] \qquad (4)$$

Its current velocity is v(t). The best position found up to now by this particle is given by a vector p(t). Lastly, the best position found by informants of the particle is indicated by a vector g(t). In general, we will write simply x, v, p, and g. The d^{th} component of one of these vectors is indicated by the index d, for example xd. With these notations, the equations of velocity and position of a given particles are formulated by,

$$V_d = C_1V_d + C_2(pd- xd) + C_3(gd- xd) \qquad (5)$$
$$x_d = x_d + v_d \qquad (6)$$

C_1, C_2 and C_3 are the confidence coefficients or learning factors depending on random variables r_1 and r_2 (0 to 1) is selected to each step improvement in evaluation up to the last iteration. Optimization techniques have been applied to power system in a wide range of problem. A particle swarm optimization (PSO) as a tool for loss reduction study is presented (A. A. Ahmed et al., 2005). The proposed application consists of using a developed optimal power flow based on loss minimization function by expanding the original particle swarm optimization. The study is carried out in two steps; first, by using the tangent vector technique, the critical area of the power system is identified under the point of view of voltage instability. Second, once this area is identified, the PSO technique calculates the amount of shunt reactive power compensation that takes place in each bus. The proposed approach is examined and tested with promising numerical results using an IEEE 118-bus system. The proposed approach presents good results for loss reduction. These results were compared with those reported in the literature confusing the potential of the method. However the proposed work needs to be extended for evaluation of optimal placement and sizing of capacitor in a distribution system for reliability enhancement for a wider range of objective function.

The positive impact of capacitor placement on reliability can be considered as a failure rate reduction of distribution feeder components. The conventional objective function which consists of cost of losses and cost of capacitor has two objectives. The one objective function considers only cost of reliability. The second objective function considers the cost of reliability and investment. The third one is a comprehensive objective function which consists of three terms: cost of reliability (ECOST), cost of losses and capacitor investment cost (A. H. Etemadi et al., 2008). The number of parameters to be optimized is equal to the number of load buses. Considering the real world capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size. Since capacitor banks are added in discrete step the objective function is non differentiable and capacitor placement problem is mixed individual nonlinear program. However, most of the conventional optimization algorithms need so for is unable to generate optimal solution for this type of problem. Optimal capacitor placement problem has been the topic of many research works. Some of most recent published papers on this topic have solved the problem using ant colony direction, graph search algorithm, genetic algorithm, particle swarm optimization (PSO) and fuzzy Evolutionary programming. Besides, the cost per kVAR varies from one size to another. In general, capacitors of larger size have lower unit prices. Since the capacitor placement is not an online action for distribution systems, its computational solution time is not a significant issue. However, in order to avoid excessive computational times for large feeders, the following measure can be considered to reduce the computational time.

At first, in order to find the sensitive buses to capacitor placement, the problem is solved with a low population size and a small value for maximum number of iterations while the solution vector includes all buses of the system. Sensitive buses are referred to those buses of the distribution feeder for which placing a constant size of capacitor results in more reduction in the value of overall defined cost function. Capacitors can supply reactive loads, reduce losses improves voltage profile, power factor, and hence optimum capacitor placement is a need as per today's complex integrated network. An algorithm is proposed to solve the optimum capacitor placement problem to determine capacitor size and location. ECOST is calculated to determine the acceptable level of reliability for customers. Conventional objective function and reliability based objective function is evaluated separately. However, the proposed method considers only overhead line and cables for capacitor placement. It is a need to find out such locations other than overhead line and cables in the distribution system. Failure rate is considered with linear relationship to the percentage of compensation, in real practice these failures is never in linear, so it is need to develop a method for nonlinear solution of such objective functions. Newly developed Bacterial Foraging Optimization algorithm (BFOA) is effcient swarm intelligence based stochastic method used for optimal distributed generation and capacitor placement for the objectives to minimize power loss. Author focused on sensitivity analysis is must in capacitor placement. However importance of reliability cost is not mentioned in (Imran, A.M. et al .).

(Khalil, T.M. et al.) proposed a simple modification in to the binary PSO to search in a selected space. The proposed system had been implemented on three feeder distribution system and Taiwan power Distribution Company for reconfiguration and loss minimization. Branch current and node voltage is selected as constraint. However current may not be the constraint as load current is not in the hand of utility. The feature of PSO algorithm is the ability to control the speed of convergence process using the number of particles in the swarm and the inertia factor (Trach, I. et al.). A set of solution is formed, where each m particle corresponds to the n- dimensional vector. This combined approach is used till the best solution is selected for optimal capacitor placement. (Nasim Ali Khan et al., 2013) and (Afaghzadeh, H. et al.) introduces BPSO algorithm for optimum sitting and sizing of shunt capacitor in a radial distribution system. discussed as IEEE 10 bus and IEEE 69 bus system. Convergence characteristic of loss minimization had been evaluated for feasibility of the test system. Improved binary particle optimization is presented and discussed to minimize power losses in distribution network reconfiguration and capacitor placement in Mostafa Sedighizadeh et al. (2014).

The minimum power losses and maximum voltage profile is achieved using BPSO. (Khalil, T.M. et al.) Introduces selective particle swarm optimization (SPSO) for 27 bus power system. From simulation results, it was observed that the optimal capacitor placement using SPSO reduces power loss as well as improve the voltage profile. Particle swarm optimization based optimal capacitor placement and sizing is discussed for IEEE 13 bus unbalanced system in (Razak, M.A.A. et al.). Harmonic constraint is also considered. Power loss against computational iteration and total cost against computational iteration is also discussed. (El-Fergany et al., 2014) discusses heuristic approach for multi objective capacitor placement problem. Active power loss as well as reactive power loss is addressed. Acceleration of particles to achieve the targeted velocity and desired position is briefly discussed. Algorithm is tested on 10 bus,22 bus, 28 bus, 30 bus, 33 bus, 34 bus, 69 bus and 118 bus system in a radial distribution feeder. Simulation of optimal capacitor placement and sizing problem for TABRIZ distribution system was carried out using sensitivity analysis after PSO application. Author also consider the voltage and THD constraint. However reliability constraints and reliability cost is not addressed in (Dehkordi et al., 2012). (Saeid Jalilzadeh et al., 2012) introduces shuffled frog leaping and PSO for optimal capacitor placement problem simulation in IEEE 45 bus radial bus system. convergence analysis is also carried out. Result analysis indicate that shuffled frog leaping algorithm is more better than PSO. (A. E. Eajal et al. part-I, 2010), (A. E. Eajal et al.part-II, 2010), (Eajal, A.A. et al.part-III) and (Eajal, A.A. et al.) introduces system modeling and harmonic power flow studies, PSO solution method with Pseudo code, numerical results of loss reduction of 13 bus system in voltage and harmonic constraint. Total harmonic distortion is reduced with novel equations developed. However reliability parameters are not address in these papers. Hybrid PSO technique is explained in (Hakimi, S.M. et al.). DIgSAILENT software is used to simulate 9 bus IEEE bus system for optimal capacitor placement. Evolutionary PSO and PSO programs are developed and compared by (Naing Win Oo., 2008) for capacitor placement problem in radial distribution system. results indicate that EPSO method is more better than PSO in number of iteration and fitness test. However EPSO is more computationally intensive due to additional evaluations like selection and developing movement rules for particles.

IV. REVIEW OF EXISTING OPTIMAL CAPACITOR PLACEMENT

Review of published research literature on distribution system reliability addresses the various aspects such as maintenance strategies as well as the use of capacitor. However, in recent years many researchers have focused on optimal placement of capacitors for enhancement of reliability. Lot of research work is reported in published literature on optimal capacitor placement with the conventional objective function considering total cost of losses and investments. The optimal capacitor placement problem is solved by various researchers using ant colony direction, graph search algorithm, genetic algorithm, particle swarm optimization and fuzzy evolutionary program. Since the capacitor banks are added in discrete steps the objective function is not differentiable and capacitor placement problem is mixed integer non linear program. Optimal capacitor placement increases the load carrying capacity of the lines which helps to improve the reliability of distribution system.

The majority of the research works reported on optimal placement of capacitor focuses mainly on loss reduction and investment on the objective function and very less work is reported on optimal placement of capacitors for reliability enhancement considering the wider objective function. Some of the reported work on reliability improvement using capacitor is focused on few objective functions with various assumptions and constraints. The effect of placement of capacitor on voltage profile is not addressed by many researchers.

A firefly algorithm is used for optimal capacitor placement problem for distribution system reliability indices like system interruption frequency index, system average interruption duration index and average energy not supplied as discussed in (Fard, A.K. et al.). Author had tested IEEE 34 bus system problem and tested feasibility and effectiveness of the result. In this reliability indices are the sub part of objective function in addition to cost of capacitor and active power losses. However interruption cost depends on failure rate is modified with old methods which is based on assumptions.

Population based approach using ant colony search algorithm for capacitor placement is discussed in (C. F. Chang., 2008) and (J. P. Chiou et al., 2004). Distribution system of Taiwan power company is considered for case study and the results are compared with genetic algorithm and simulated annealing. However problem is identified for symmetrical network only. (Reza SIRJANI et al., 2012) introduces heuristic optimization technique to determine capacitor placement and sizing in radial distribution network. He compared ant colony, fuzzy logic, genetic algorithm, harmony search, particle swarm optimization, tabu search, simulated annealing, hybrid methods and other optimization methods and concluded that use of particle swarm optimization is widely used due to fast computation and most beneficial results. Author also give comparison of various heuristic optimization techniques (Sirjani, R et al.).

Loss sensitivity factor is used to determine the candidate buses for optimal capacitor placement for maximum benefit due to savings in feeder losses is discussed by (Meng Zhang., 2012). However author assumed balanced network and planning period as one year only.

Reliability of the equipment is not addressed. (A.A.E.Shammah et al ., 2013) presents an effective technique to evaluate optimal capacitor bank in a ring distribution system. Author used Heuristic 17Algorithm as an optimization technique. However paper focuses on to regulate voltages of entire network rather than focussing on power factor and power quality issues in capacitor placement. Optimal capacitor placement implemented practically on Macau medium voltage distribution network for power loss minimization. GUROBI commercial package is used to conduct simulation. NPV analysis had been adopted by (Yan Xu et al., 2013) for cost benefit analysis. Assumptions are absent in the paper, however it looks like the simulation is only for symmetrical network. (El-Fergany et al., 2014)indicates use of differential evaluation (DE) and pattern search (PS) hybrid method for optimal capacitor allocation. Voltage as constraint, reactive power as constraint and line capacity as constraint is considered whereas power factor and power quality issues are not addressed.

Original Firefly algorithm is modified as Adoptive Modified Firefly algorithm (AMFA) by (Olamaei, J. et al.). AMFA is applied for optimal capacitor placement problem of IEEE 9 bus system and results are compared with Fuzzy, PSO and PGSA methods. Overall losses are reduced by 14.106% and cost saving is 12.974%. However reliability cost is not considered. (Rani, D.S. et al.) discusses about Adoptive Harmony search algorithm (analogy with music improvisation process) which generates new solution vectors that improves accuracy and convergence rate of harmony search algorithm for optimal capacitor placement. In this case study, forward/backword sweep power flow method is used for real and reactive power evaluations as a load flow study. An algorithm is tested on radial distribution system and results are compared with PSO and PGSA methods. Biography based optimization technology is discussed by (Tom, T. et al.) for active and reactive power compensation by means of capacitor and DG placement. In addition to voltage constraint power limits and power balance as constraint is also used. Simulation results are shown that BBO technique is also one of the methodology choice for researchers of optimal capacitor placement.

(Mahdi Mozaffari Legha et al., 2013) discussed about artificial Bee Colony (ABC) algorithm for capacitor placement to improve the network efficiency. Penalty factor due to voltage violation is introduced in objective function rather than voltage as a constraint. Power factor and Power quality constraints are neglected in simulation process. In Result analysis, it observers that voltage profile is improved in capacitor placement by using ABC algorithm.

Simplified direct search algorithm to minimize power loss by means of capacitor placement is discussed in (Fitriana Suhartati et al., 2014). Total harmonic distortion as per IEEE standard 519 is considered as constraint, at the same time a component as harmonic power loss is also considered. Harmony search approach in (K. Muthukumar et al., 2012) discusses that in case of unbalanced distribution system, capacitors can be placed. Harmonic constraint is applied to limit the total harmonic distortion within the limit as given by IEEE standard 519. In addition to this equality and In equality constraints are also discussed. Power loss is computed with components, fundamental component and Harmonic component. Looking towards objective function, it seems that cost function is influenced by harmonic component where as other researcher had put the limits while selecting simulation search for the best solution.

(Farahani, V. et al.) developed branch exchange algorithm for network reconfiguration and joint optimization algorithm for energy loss reduction using capacitor placement. Practical implementation of these algorithm was carried out on two feeders of Sirjan distribution network. However CPU time and number of required iterations are much high as compared to other methods. (El-Fergany et al., 2014) used cuckoo search algorithm for capacitor allocation in radial distribution system. Proposed approach identifies sizing and placement and takes the final decision for optimum location within the number of buses nominated with minimum number of effective locations and with lesser injected VArs. Mixed integer conic programming approach to find optimal capacitor placement is discussed by (Abou Jawdeh, S.A. et al.). 34 bus system and 83 bus system is selected for mixed integer conic programming approach. Power losses and cost of capacitor is the part of objective function. Mixed Integer Conic Formulation is a convex optimization problem, which insure that local solution is the global solution. A loss sensitivity factor can be used to calculate the location and fire fly algorithm is used for cost minimization including cost of capacitor and cost of power loss as discussed in (Priyanka Das et al., 2014). (Pushpendra Singh et al., 2014) introduces harmony memory for network reconfiguration and capacitor placement.it is observed the losses are reduced by 24.7%.(Sathya Siva Chandan. G. et al., 2014) introduces objective function to minimize I^2r losses in RDS system with voltage as constraints. Genetic algorithm is implements and results are carried out for comparison study in voltage profile and reactive power loss.

(Neelima, S et al.) introduces differential evolution to reduce dimension of power flow equations. Dimension reducing distribution load flow algorithm is developed as first stage of optimal capacitor placement and differential evaluation based algorithm is used as power loss minimization as discussed in (Neelima, S et al.). IEEE 39 bus system is used and results are compared with fuzzy and genetic algorithm. (Murthy, K.V.S.R. et al.) introduces comparison between conventional, GA and PSO. However methodology is not described briefly. (R. A. Gallego et al., 2001) introduces Tabu search strategy for optimal capacitor placement which is Heuristic strategy to find capacitor locations and size for a given radial distribution system.

V. Need of Optimal Capacitor Placement

There is a need to extend the research work on study of impact on optimal configuration of shunt capacitor bank for distribution system reliability and power quality improvement with additional function such as saving related to reduction in failure rate, improvement in cost reduction of the customer related to reduction in interruption duration, reduction in losses involving optimal location of discrete size of capacitors with minimum investment is achieved to targeted reliability including the voltage profile and voltage distortion as constraints.

Considering the growth of nonlinear load, while deciding optimal capacitor placement for enhancement of reliability with wider objective function, it is necessary to make sure that the configuration of capacitor will have minimum impact on harmonic distortion of the voltage and issues related with series and parallel resonances needs to be addressed.

VI. Conclusion

A survey of optimal capacitor placement for loss reduction in radial feeder in various constraints had been carried out. Most of researchers used particle swarm optimization or it's equivalent as tool to solve the multi dimensional problem. From the results of researcher it was concluded that the optimal capacitor problem was always multi dispensational problem depending on the constraints selected. voltage profile, power factor are the regular constraints used in addition to harmonic as constraint. Many scholars are tried to add cost of harmonic component in cost function. Reliability cost is also required to address while optimal capacitor placement rather than using reliability as different issue.

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