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A Comparative analysis of Various Power loss minimization techniques for Distribution Network

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Abstract-

In an Electrical power system, Power losses become very significant due to high R/X ratio, high current and low voltage. High amount of distribution losses affects the distribution efficiency. Distribution companies (DISCOMs) have an economic inducement to get these losses reduced. Generally, this inducement is the difference between actual losses and standard one in terms of cost. Hence, in case where actual losses are lesser than standard one, the DISCOMs can benefit monetarily or when the opposite happens, they gets penalized. Therefore, it is always recommended to reduce the losses as much as possible. Several methodologies have been published in literature for losses reduction such as capacitor allocation, feeder reconfiguration, grading of cables, DG (Distributed generation) placements, DSTATCOM allocation.

The presented article provides a comprehensive review or comparative analysis of various methodologies for loss reduction. It presents reconfiguration techniques simultaneous with loss reduction and reliability too.

Keyword: Distribution loss, DG allocation, Network reconfiguration, reliability

NOMENCLATURE:

BGSA- Binary Gravitational Search Algorithm
BBBC- big bang-big crunch
BFOA- Bacteria Foraging Optimization Algorithm
GWO- Grey wolf optimizer
CSA -cuckoo search algorithm
SSA- Salp Swarm algorithm
KEPC -Korean electric power corporation
ACO -Ant colony optimization
PSO- Particle swarm optimization
GA- Genetic Algorithm
TS -Tabu search
BA -bat algorithm
ALO-Antlion optimization
HAS- Harmony search algorithm
SAIFI System Average Interruption Freq. Index
SA- Simulated Annealing
FWA -Firework algorithm
ABC- Artificial bee colony
ANN- Artificial Neutral Network
SOS- Symbiotic organisms search algorithm
T&D -transmission and distribution
PGSA- plant growth simulation algorithm
DP- Dynamic programming
TLBO- teaching and learning-based algorithm
WOA- Whale optimization algorithm
EP -evolutionary programming
CSO- cat swarm optimization
AENS- Average Energy Not Supplied

SAMBA -Self Adaptive Modified BA

(1)Introduction:

In any power system, Transmission and distribution (T&D) system losses contributes the largest portion of losses [1]

Because of exponential rise in demand of electricity, environmental concern and competitive energy market environment, power system especially T&D system frequently experiences overloaded conditions. Hence, distribution losses have become a great concern.

In distribution system because of the high-current low-voltage level, distribution losses(I^2R) losses are significant, technical losses in distribution systems are generally because of heat dissipation resulting from current passing through conductors (Joules effect), transformers core losses, mal functioning of the equipment's used in transmission and Distribution line and transformers.

Power losses in distribution system can also be given as per below expression

$$P_{Loss}(Z) = \sum_{j=1}^{Nbr} R_j \times \left(\frac{P_j^2 + Q_j^2}{V_j^2}\right)$$

Here the position of the tie switches is presented via Z, number of branches are shown by Nbr, R_j is the resistance of the jth branch, active power is represented by P_j, and Q_j shows the reactive power. The ending voltage is represented by the V_j.

Distribution losses occur throughout the distribution conductors. Therefore, these losses account in very large amount, which is about 13% of the total power generated and 70% of the total losses [2]. Whereas transmission and sub-transmission line losses are sum up to 30% of the total power losses. Thus, power loss minimization is the only promising alternative in order to achieve greater efficiency and monetary benefit.

As per the report of Energy Information Administration (EIA), the growth of electricity is expected to rise annually by 0.5%, 0.8% and 0.9% in residential, commercial and industrial sectors respectively. This increased demand can be compensated to some extend by applying effective power loss minimization methods.

Conventionally, the loss minimization techniques have been focused on reconfiguration of distribution network and capacitor placements to get reactive power support. Since advent of DG, it become very much significant to achieve greater efficiency, stability and environmental concerns with the added advantages of small generations.

In this article, selected papers from reputed journals and conferences such as IEEE transactions, Power & Energy systems, international journal of power system research, energy etc. have included for review with significance technical advantages and drawbacks.

(2) Methodologies for power loss minimization

Several methods exist for power loss minimization. But some of them are most popular like (1) network reconfiguration (2) DG allocation (3) Capacitor placement

(a) Network reconfiguration: Network reconfiguration is the most promising technique for power loss reduction in radial distribution system. NR is the process of altering the normally open (Tie switches) and normally closed (sectionalized) switches which varies the topological structure.

Network reconfiguration permits the loads to be shifted from greatly loaded feeder to the lighter loaded feeder which reduces the system overall power losses.

Network reconfiguration have following advantages:

1. Provide service restoration during fault period.
2. Bus voltage enhancement
3. Loss reduction
4. Network maintenance through outage planning. [3-4].

Network reconfiguration algorithms are based on two type of configuration

Branch exchange and loop cutting configuration, in former configuration the switches are operated to gain feasible radial configuration. Whereas, in latter the algorithm is going to open the switches to get the radial configuration for mesh configuration. [5]

The evaluation of reconfiguration technology for loss minimization has been summarized in table 1.

Table.1 Evaluation of reconfiguration techniques for power loss minimization

Author	Year	Reconfiguration approach	Optimization techniques	Objective Function	Network
Merlin and Back[6]	1975	Switches made closed initially, then open one by one	Exhaustive search method	Power loss minimization	Urban Radial distribution system
Shirmohammadi and Hong,[7]	1988	Initially closed all the switches and then opened till the optimal structure is reached	Heuristic method	Power loss minimization	Real time Distribution system for Taiwan
Civanlar S. et al. [8]	1988	Switch exchange and determination of loss due to it	Load flow method	Power loss minimization	Actual two and Three feeder systems
Baran and Wu[9]	1989	Applying branch exchange method	Heuristic method	Power loss minimization	33 bus distribution system
Taylor and David [10]	1990	Decision tree is to be setup for representation of various available switching options.	Heuristic method	Power loss minimization	59 bus distribution system

Kim et al.[11]	1993	ANN based optimization techniques	ANN based Method	Power loss minimization	33 bus distribution system
Sarfi et al[12]	1993	The system is partitioned In to sub systems and then perform optimization..	Dynamic Programming	Power loss minimization	meshed distribution network
Ji-Yuan Fan et al.[13]	1996	Switches are operated iteratively	Heuristic method	Power loss minimization	16 Bus distribution system
Taleski et al.[14]	1997	oriented element ordering, summation method for power flow, numerical representation for variations of loads,	Heuristic method	Energy loss minimization for daily hrs.	Two feeder Distribution system
Young-Jae Jeon et al.[15]	2002	Cost function also augmented in to operation condition of distribution system.	Simulated Annealing (SA)	Power loss minimization	32- Bus distribution system
McDermott et al.[16]	1999	Originally, at every step make the switch open, then they are closed in order to get minimum operating function	Heuristic nonlinear constructive method	Power loss minimization	33- Distribution system
Ching-Tzong Su et al.[17]	2005	Based upon ant colonies searching for the food.	Ant colony search algorithm	Power loss minimization	Real Distribution system
C. Wang et al[18]	2008	To get the feasible solution, switches are categorized in to four state	Plant growth simulation algorithm (PGSA)	Power loss minimization	
Abdelaziz et al[19]	2009	The method is based on swarm behavior searching for food	Particle swarm optimization (PSO)	Power loss minimization	16,32,64 node radial distribution system
Rao et al [20]	2011	Algorithm is based on musical instruments trying to develop a node for harmony	Harmony search algorithm (HSA)	Power loss minimization	Practical 119 distribution system
Sathish Kumar et al.[21]	2012	Algorithm is based on bacterial frogging	Bacterial Frogging Optimization	Power loss minimization	33 bus distribution system

			Technique (BFOA)		
Thuan Thanh Nguyen et al. [22]	2015	The algorithm is based on obligate brood parasitism of some species of a cuckoo which uses other host birds' nests for Laying eggs.	Cuckoo search algorithm (CSA)	Power loss minimization	33 and 69 Bus distribution system

(b) DG Allocation: Distributed generation or embedded generation is term referred as a generation of electrical power at consumer end. DG reduces power flow through long distribution lines resulting in to reduction in active power losses. These are small scale generators up to 100MW. Inappropriate allocation of DG units create adverse effect in power distribution system. Hence, research have been emphasized on proper allocation of DGs.

The literature relating to loss minimization by using DG allocation are included in this section and presented in table.2. Researchers have investigated and implemented several methodologies/ techniques which are summarized here.

In recent years, dispersion of DGs in to distribution system has grown rapidly, it is estimated that DG will contribute more than 25% of total power generation in near future [23].

(c) **Capacitor placement:** capacitor allocation is preferably used in high voltage distribution system for loss minimization. The capacitor is a reactive power source that reduces the inductive reactance of line loading. Capacitor is used for voltage stability improvement.

Capacitor placement has following advantages.

1. Control of power flow
2. Reduction of Power losses
3. Voltage stability improvement
4. Power factor correction [23-24]

Capacitor placement in distribution system perform some additional task such as better voltage regulation and power factor correction along with loss minimization . Several research work are available in literature towards capacitor placements which reveals that for practical utilization of capacitor placements for distribution network, varying nature of load should be considered.[25]

Table 2. Evaluation of different reconfiguration techniques for DG placements considering loss minimization

Author	Year	DG type	Optimization techniques	Objective Function	Network	Merit	Demerit
Rau and Wan[26]	1994	Renewable	Analytical approach	Power loss	Six-bus 25-kV distribution Network.	Easy to apply	Computational time is more. Therefore, not suitable for large system

Willis [27]	2000	Conventional	Analytical approach	Power loss	Radial distribution system	Easy to apply	Method may not work for variable load conditions
Acharya et al. [28]	2006	renewable	Analytical approach	Active & reactive power loss	16,33,69 bus radial distribution system	Calculation of losses is fast and	Limited for small or medium network
S. Ghosh et al.[29]	2010	conventional	Conventional	Power Loss Minimization OF = C(PDG)+W × E	6 bus, 14 bus and 30 bus distribution system	Impressive results had achieved	Good while assigning Weightage for each objective
A. Casavola [30]	2011	Renewable	Quadratic programming	Power loss & voltage regulation	14 bus distribution system	Attractive results for certain loading conditions	Applicable for certain loading conditions
M. M. Aman et al [31]	2012		Analytical approach	Power loss reduction & voltage profile enhancement	12-bus, 69-Bus distribution system	Computation time is very less	Convergence characteristics need to explained
Abu-Mounti and Elhawary [32]	2011	Conventional	Artificial bee colony Method	Power loss	69- Bus system	Tuning is required for less parameters	Effectiveness depends upon the tuning of parameters
Kansal et al.[33]	2013	Conventional	PSO	Power loss minimization	33- bus and 69- bus system	May be useful for different types of DG sources	Parameters tuning is an issue
Yuvaraj et al.[34]	2015	Conventional	BAT algorithm	Power loss minimization	69 bus distribution system	Lesser requirements for tuning	Convergence characteristics are not shown
Sultana et al.[35]	2016	renewable	Grey wolf optimizer (GWO)	Power loss minimization	69- bus system	Less parameter tuning is required. Hence, useful for solving complex combinational problem	More computation time
Das B. et al.[36]	2016	renewable	Symbiotic organisms search (SOS) algorithm	Power loss minimization	33- bus and 69- bus distribution system	Parameter tuning is not required	Computation time per iteration is high
Tanvar et al.[37]	2017	Renewable	PSO	Power loss Minimization	51 bus system	to be effective for renewable	Results are not properly compared and validated.

						DG allocation	
Reddy et al.[38]	2018	Conventional	Whale optimization (WOA) algorithm	Power loss minimization and Voltage profile	33 bus, 69 bus and 85-Bus system	Reduced power losses, Voltage profile improvement.	Convergence characteristics was not shown and comparison is also absent
Sanjay et al,.[39]	2018	Conventional	Hybrid grey wolf optimizer (HGWO)	Minimization of power loss and voltage profile	33 bus, 69 bus and 85-Bus system	Loss demission or voltage profile is achieved on different DGs	Algorithm has not been tested on mathematical standard

(3) Simultaneous reconfiguration considering power loss and reliability

Distribution systems are usually designed or operated in radial structure in which consumer have a single source of supply. Distribution system is the prime source of power outage in the power system, as per the report in literature about 80% of power outage happens because of problem with distribution system which includes over loading, equipment's failure. These kind of power outages affect consumers and power utility companies both. It is also predicted that power interruption may occur more severe in near future. Hence, it became essential to consider reliability criteria for planning and operation of distribution system [51].

Conventionally, network reconfiguration technique has been utilized to attain certain targets such as the reduction of active power loss, load balancing or voltage stability and the impact on reliability indices have not been included. This section is aimed to present the review of different methodologies with the objective of finding the optimal configuration which reduces the losses and enhances reliability too. Comprehensive review of different methodologies simultaneously for losses reduction and reliability has been presented in Table.3.

Table. 3 Network reconfiguration techniques considering loss and reliability.

Authors/years	Reconfiguration Approach	Objective function	Merit	Demerit	Network used
Richard E. Brown 2001[40]	Improved Simulated annealing algorithm	Power loss considering reliability	Results are effective, efficiency improves with size of system, can be used for large systems	Comparison are not shown	16 bus distribution system
Ching-Tzong Su 2002[41]	Modified Genetic Algorithm	Total costs and reliability (The total cost including the apparatus investment cost and the system	Simple to implement and Useful for planning and Operation	Computational time is little more	Real network of Taiwan

		interruption cost)			
A. Coelho et al. 2004 [42]	Simulated Annealing.	Loss Reduction and Reliability	Low computational cost	Comparison of results are absent	Standard 64 bus distribution system
A. Skoonpong et al. [43]	Simulated Annealing.	Reliability enhancement by minimizing total interruption cost	Computational speed is good	Impact on other parameters (Loss, voltage) have not shown	Roy billionton test system
R. M. Vitorino et al.2009[44]	Improved genetic algorithm	Power loss and reliability	Convergence characteristics are good	Useful for limited network	69 bus distribution system
R. Arya et al.2012 [45]	Coordinated aggregation particle swarm optimization (CAPSO)	Reliability	Shows good convergence characteristics and presented technique is more effective than PSO.	considered customer oriented and energy based reliability indices	33 bus distribution system
B. Amanulla et al.2012[46]	Binary particle swarm optimization (BPSO) search algorithm	Reliability and power loss	Effective for planning and operation purpose	Monte Carlo method is used which takes Larger computational time	33-bus and 123-bus radial distribution system
N. Gupta et al. 2014. [47]	Genetic Algorithm	Power quality and Reliability	Multi objective optimization deals with many parameters, provides the flexibility to decision maker to select one set of solutions	Problem formulation for large network becomes complicated	69 bus and 73 bus distribution system
Abdullah Kavousi-Fard,2014 [48]	Self-adaptive Modified Bat Algorithm	Reliability considering SAIFI, AENS and total power loss	Multi objective approach considering SAIFI, AINS and total cost	-	64 bus distribution system
H. Shareef et al. 2015 [49]	Firefly algorithm Optimization	Power quality &l. reliability	Most suitable for the objectives specified	-	33 bus distribution system
Juan Camilo López 2016 [50]	Mixed-integer second-order conic programming (MISOCP)	Reliability indices improvement with reduction of loss	Flexible and decision making approach (trade off is found where loss in minimum and reliability is a loss)	Computational time is more	136-bus distribution system

(4) Comparative analysis of loss reduction techniques:

Although apart from above illustrated techniques also can be used for loss reduction of distribution network such as grading of cables, minimization of cable resistance. However, following are the most popular techniques who have brought the attention of researchers.

A comparative analysis for these technology with respective merits and drawback has been presented in Table.4.

Table.4. Comparative analysis for NR, DG allocation and Capacitor placement

Network reconfiguration	DG allocation	Capacitor placement
1. Normally applicable in low voltage network 2. Provide isolation under faulty condition 3. Beneficial for line loss reduction and load balancing 4. Most economic but limited payback 5. Problem formulation becomes difficult and requires extensive numerical computation time while solving for complex network 6. Does not properly coordinated with protective devices, especially for large networks	1. Provide interconnection of network 2. Useful for line loss reduction and voltage profile 3. Less environmental effect 4. Improves system efficiency 5. Reduces transmission & distribution congestion 6. Adversely affects if improperly placed. 7. Reversal of power flow causes adverse effect on system performance 8. It faces hurdles with respect to implementation and installation	1. Normally applicable in high voltage network 2. Applicable for loss reduction, power factor improvement, voltage profile improvement 3. Financial cost involved 4. Stability improvement 5. Source of reactive power

Conclusion.

This paper has presented the comprehensive review of network reconfiguration and DG allocation techniques has been utilized for loss reduction in power system network. Methodologies have been illustrated with respective merits and demerits, which will surely help the researchers for future research. Some approaches which involve more than single objective also have been reviewed which provides flexibility to the decision maker to pick any one set of solutions under normal and contingency conditions.

Each and every approach summarized in this paper have been utilized for solving the problem subject to satisfying various and limited objective constraints.

Several techniques which have been discussed are leading following conclusion.

1. Network reconfiguration technique claimed to be most economic and most suitable for low voltage distribution system. Whereas, presence of various candidate switching combination leads to be a combinatorial complicated, non-differentiable, constrained based optimization problem which necessitates huge mathematical computation.
2. DG allocation is more suitable for integrating small generators. However, for effective implementation and installation, it requires effective techniques.

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