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Service restoration in power system:A Review

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ABSTRACT- In the power industry customer satisfaction and service reliability are of primary concerns. Several studies on power utilities experience suggest that customer satisfaction is closely correlated with service interruption frequency and interruption duration, service restoration is performed to avoid such problems. The main objective of service restoration is to restore as many loads as possible (i.e., minimize loads in out-of service areas) .In process of Service restoration back up feeders are found for restoring the supply in out of service area by choosing the best combination of switches which gives the optimal solution . It can also be understood as a temporary network configuration until the cause of the problem is cleared. In this paper various issues regarding service restoration and comparative study of various methods to achieve service restoration is being discussed.

Keywords—service restoration; multi-objective ; optimization; microgrids;

I. INTRODUCTION

After a blackout restoration is an essential task in a power system. The restoration process returns the system back to normal operation after any combination of system components. In general restoration is a decision making process in which various set of actions are executed by system operator to the outage . Fast service restoration has multiple benefits. For example, it reduces the inconvenience and the cost of the outage to customers; it enables the utility to resume earning revenue for energy sales; it enables the utility to provide enhanced service to priority customers such as hospitals, police stations, fire departments, customers who

may have contracts with the utility for reliable power delivery, etc. The main objective in service restoration procedures is to restore as much load as possible by transferring de-energized loads in the out-of-service areas via network reconfiguration to other supporting feeders without violating operation and electrical constraints. In practice, distribution dispatchers need to restore service to the outage areas as quickly as possible with a minimal number of switching operations. A minimal number of switch operations is required because of switch life expectancy concerns and manpower limitations since all switches in the network are not currently automated from .

An overview of service restoration process is given in fig.1. In a typical restoration procedure, the stages of the

restoration process are summarized as follows, in the first stage, the system status is assessed, initial cranking sources are identified and critical loads are located. In the following stage, restoration paths are identified and subsystems are energized.

These sub systems are then interconnected to provide a more stable system. In the final stage, the bulk of unserved loads is restored. In [1,2] policies of restoration during power failure isbeen discussed .In[3] how restoration after black-out in Sweden was achieved is discussed. However, for service restoration, there may exist many solutions restoring power to the out-of-service areas. In an effort to address challenges of service restoration, and to reduce the duration and cost related to service interruption, several forms of automation and analytical tools have been used in the literature. Heuristic techniques [4,5,6] and expert systems [7,8,9] have been developed for quickly determining restoration plans. After that more advanced meta-heuristic approach was developed which includes artificial intelligence techniques such as evolutionary techniques.. In [10-11] instead of switching factor method integration of distributed generators in distribution system is emphasized.
The remainder of this paper is as follows, in part II various issues related to power system is discussed. In part III objectives and constraints is being discussed. In part IV different methods to achieve service restoration is being discussed. In part V some other methods are discussed to achieve service restoration. and in part VIII comparison between various methods is done in tabular form.

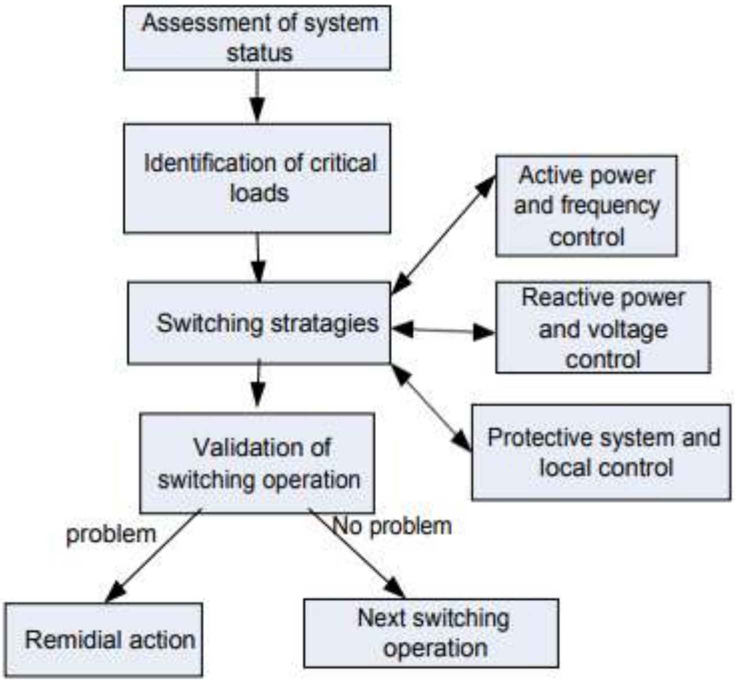

Fig.1 overview of service restoration

II. CHALLANGES DURING SERVICE RESTORATION

Over the years, restoration has been performed by set of guides and common practices developed by utilities . Adibi [12-13] has explained various problems of service restoration and the way to deal it. Issues during transmission such as phase angle reduction, protection scheme and limitations of reactive power in synchronous machines are discussed in detail in [14- 16].

III. SERVICE RESTORATION PROBLEM FORMULATION

Due to some fault on a bus blackout occurs and power supply is interrupted. A load dispatcher restores the power supply by changing the status of sectionalizing switches. Thus, the aim of the service restoration problem is to find an optimal combination of status of the sectionalizing switches for restoration .For small distribution system this is quite easy but for large distribution it is difficult to achieve restoration because there are multiple combination of switch status and constraints which must be satisfied. Considering above explained challenges number of constraints and objectives can be formulated for service restoration problem.

A. Constraints

• Radiality should be maintained in the network after service restoration since it allow substantial saving in the number of protection devices and circuit breakers, it allows ease in fault location and proper relay coordination.[6,29, 34,37, 42,43,48,45]

• avoid component overloading,[6,39,60,38,63]

• Areas which are serviced before restoration must not be blacked out after restoration.

• Voltage drop in the system should be in specified range i.e voltage limit should not be violated.[6,35,39,48,69]

• Current limit in power system should not be violated.[6,48,38,69]

• Priority customers should be supplied with continuous power[48]

• Reliability.[76]

• Speed of finding restoration solution.

• Restoration cost.[35,38]

• switching time.[26]

B. Objectives of service restoration

• minimize out of service area.[48,38]

• minimize the number of switching operation.[6,34,39,48,45,53,63]

• minimize the losses.[48]

• Maximize quantity of restored power in out of service area. [6,54,55,69]

IV. TECHNIQUES TO DEAL SERVICE RESTORATION

PROBLEM

A. Arya et.al in [17] had given a broad

classification of techniques which are applied for Service restoration problem .Various methods have been implemented some of which are classified as-

- Expert systems
- Analytical methods
- Heuristic Techniques
- Meta-heuristic methods.

A. Expert systems in service restoration

These methods are useful for problems that involve logic reasoning and human knowledge and where traditional algorithm programmes have not been successful. Expert systems deals in three major factors- fast and effective generation of restoration procedures, the ability to deal with unexpected events or faults, flexible operation for future development. These approaches give the solution very efficiently and also in these techniques, weighting factors are not required. However, acquisition of the knowledge base of the operators for this purpose is often a very difficult task. As a result, there is no guarantee of getting optimal solution. In [7] expert system is implied for service restoration. In[8] loss reduction was given priority in service restoration around 180 rules were given which can be used by operators in planning a restoration scheme. In more recent work, Men Shen Tsai [9] developed an expert system by utilizing its fast reasoning mechanism and object-oriented features. The feeder component and configuration data are organized in a hierarchy way using the object-oriented programming paradigm. Service restoration procedure proposed in this paper takes load variation into consideration. In [18] Adibi et.al has discussed the requirements of an expert system. The paper [19] presented a practical restoration aid ES for 154 kV distribution substations. The proposed ES had a topology based simple structure and it utilized basic rules suggested by Korea electric power company.

1) Real time knowledge based restoration: This is mainly used for bulk power system .In this a real time expert system is used which requires continuous intelligent monitoring, diagnosis and control. In [20] a method which reduces distribution networks by merging selected nodes is applied to address real-time service restoration. Hotta et.al in [21] uses an expert system for real time service restoration. Thomas Brunner et al. [22] implemented a real-time ES as part of a supervisory control and data acquisition (SCADA) system for the public utilities board of Singapore, controlling its 22kV distribution network

B. Analytical methods

Techniques based on analytical approaches represent the system by a mathematical model and produces an algebraic expression that can be used to evaluate optimization. These techniques offer the advantage of providing desired solutions with less computing time. Though, these techniques suffer

from a major drawback that they are very difficult to implement while analyzing complex systems. In[23]an analytical approach is implemented by using a delayed exponential model for load and thermodynamic model for transformer. Mixed integer programming combined with fuzzy set ,ranking based methods, interior point method, are some of analytical tools commonly used. In[24] graph theory was used to identify the out of service area. In[25] ranking based method is used. It provides an effective and quantitative evaluation model for evaluating restoration plans. This propose a quantitative evaluation framework for ranking restoration plans with their performance indexes, using the analytical hierarchy process-based fuzzy-grey approach.. Graph trace theory(GTA) was implemented by Thi et.al[26] in which branch-and-bound algorithm was adopted to solve the problem. It maximizes the restored loads in distribution by using the DG availability. The objectives were to reduce the consequences due to a major blackout in terms of the out-of service load volume, and the duration of restoration process.

C . Heuristic Methods.

A heuristic search approach is developed for A heuristic search approach is developed for service restoration of a distribution system. To reach a restoration plan which satisfies all practical requirements, a set of heuristic rules are compiled through interviews with experienced operators. A heuristic program uses rules based on previous experience in order to solve a problem rather than using a mathematical procedure**.** In [27] Fiu et.al has proposed a heuristic algorithm to achieve service restoration in an efficient manner. In [28] a major disadvantage of these techniques is discussed that they require significant amount of data for optimal performance, especially in large scale systems, In [29], a heuristic is applied with global network switching. In the present work, only the restoration following a fault on a feeder is considered. Service restoration following a fault on a lateral branches was not considered. Heuristic rules takes significant time to give result so to overcome this problem combination of heuristic and fuzzy logic is being used. . In the reference [6], Miu et .al developed an algorithm for service restoration problem incorporating multi-tier or

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system-wide switching and capacitor control action for large-scale radial distribution systems. The solution algorithm is designed to consider networks with predominantly manual switches. In [30], a heuristic method was applied with several operating constraints. In **[31],** heuristic rules and fuzzy logic are employed to determine the combined problem of service restoration and load balancing. In [9], the authors determine the minimal paths to load points from all sources under various operating conditions in order to deduce switch procedures. In [32] a comparative study of modern heuristic approach is done.

D. Meta heuristic approach

A meta-heuristic technique is an iterative generation process which can act as a guide for its subordinate heuristics to efficiently find the optimal or near optimal of the optimization problem, especially when the information is incomplete or imperfect[33]. Meta-heuristics may make few assumptions about the optimization problem being solved. In some cases, it is seen that global optimal solution cannot be found using these techniques. In simple words it can be said that, meta-heuristics are strategies for search process which efficiently explores the search space to find near optimal solutions. There are many algorithms that adopt meta-heuristic techniques. Some of these algorithms are Tabu search , simulated annealing and evolutionary techniques.

1) Tabu search: This meta-heuristics approach has dramatically changed the way we solve a host of optimization problem. It can be characterized as an iterative technique that explores a set of problem solutions by repeatedly making moves from one solution to another .In [34] multi-objective tabu search is implemented for service restoration for radial networks it has a drawback to require a lot of computational time in creating the solution candidates in realistic problems. In [35] a modified tabu search called as probabilistic TS is used in which computational time is much lesser than conventional tabu search algorithm. In[36] advantages of TS over other metaheuristic is given.In [37] a parallel tabu approach is used .A genetic tabu search(GTS) in [38] was implemented by Shin et.al in which restoration loss cost,reliability were also considered.GTS algorithm is expected to have a faster convergence in a global space than using GA only.

2) Simulated annealing: Simulated Annealing (SA) is a generic probabilistic meta-heuristic technique for the global optimization problem. It points out to locate a good approximation to the global optimum of a given function in a large search space[39].This helps in more realistic problem Can be applied to large-scale distribution systems .Considers a more realistic problem formulation than other conventional meta-heuristic .In[40] Lin et.al proposes fault restoration algorithm based on Simulated Annealing and Tabu Search. When faults appears in the path, the algorithm can calculate a new optimal path with the new network state again.

3) Evolutionary techniques:

a) Genetic algorithm: In[41] Y. Kumar et.al have proposed genetic algorithm .This method is customized to accommodate multi-objective, non-linear and non differentiable optimization problems by using specialized fitness function.GA implies the survival of fittest. In GA the multiple objective optimization problem is combined into a single composite functions by using particular set of weights.The weighting factors depend on the importance of the objective functions as well as on the scaling of the objective functions and constraints. Weighting factors differs from network to network and hence it is tuned for every new network. It has a slow convergence and also it takes large number of iterations for large distribution network. GA is inherently discrete i.e it encodes the design variables into bits of '0' and'1'. In [42,43]a parallel genetic algorithm is developed to generate a service restoration procedure for restoring as much outage load as possible subject to power source limits and voltage and current flow constraints. In [44]
GA and simulated annealing both are applied for achieving service restoration since GA is weak in global optimization. In [45] a hybridized GA is proposed since GA alone is not efficient for non-radial network. In hybridized GA fitness function and genetic operators changes depending on current available power and on the part of string to which it is applied.

b) NSGA-II: This method does not requires weighting factors. It is a generalized methodology to any power distribution network. By ELITE preserving operator its performance is further improved. There is a good spread of solutions in the obtained set of solution called diversity. Diversity in this method is attained by CTSO i.e crowded tournament selection operator that does not require any tunning parameters . Number of iterations is also less than genetic algorithm**.** In [46] Deb et.al have solve service restoration problem using NSGA-II in this method no sharing parameters are required. Huang e.al in [47] had used this method to achieve service restoration in distribution system. In[48] Y. Kumar et.al has proposed NSGA-II for priority customers and also

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presence of remotely controlled, as well as manually controlled switches, have also been considered. Again in this method global optimization of problem is not guaranteed.

c) Particle swarm optimization: PSO was invented by Kennedy and Eberhart in 1995.It is relatively recent heuristic search method whose mechanisms are inspired by collaborative behavior of biological populations.PSO is similar to GA in context that both are population based search methods.It is inherently continuous and must be modified to handle discrete design variables .It can serve as a strong tool for solving highly non-linear and non differentiable, mixed integer optimization problem.. Weighting factors are also used .This method is comparatively the best in terms of convergence and global optimum solution. In[49]Kennedy et.al has discussed discrete binary version of the particle swarm optimization. In[50-52]PSO is being discussed as a generalized tool in power engineering. A. Arya et.al. in [53] an algorithm was proposed based on multi objective Particle Swarm Optimization for network reconfiguration problem. Two main objectives, minimization of switch operation and maximization of load were taken in account.

d)Ant colony optimization**:** Ants have the exceptional ability to find the shortest path from the nest to the food source; this fact is also used to find the optimal solution. This method uses a population to collectively solve the optimization problem under consideration. This technique gives better quality of results compared to other techniques. Though, it may take a considerable amount of time to give desired results. In [54] the proposed algorithm is based on a hyper-cube framework (HC-ACO) searches for an optimal switching sequence, and the solution provides an effective service restoration strategy that improves system reliability. It has a disadvantage that the switches should operate around the area isolated by a fault for better operation. In [55] an improved ant colony optimization is discussed, the use of stochastic spanning tree to search path limits the search path in the feasible region and improve the global search efficiency.

In[56] Xie.et.al proposed a novel model of multi-mobile agent vulnerability detection and restoration (MAVDRS) which the restoration mechanism adopts ACO is proposed, results shows that the model can ensure intranet security, has a lower delay and has a higher network band width utilization. In[57] Ling et.al proposed a new distributed model for power system restoration by combining multi-agent technology with ACO this work consist of bus intelligent agents and a single intelligent agent, they both interact to give optimal solution. Simulation shows that method is robust for the changes of electric network topology.

e) Differential evolutionary technique**:** Differential evolution (DE) is a method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Such methods are commonly known as meta-heuristics as they make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. DE can therefore also be used on optimization problems that are not even continuous, are noisy, change over time [58-59].Huang et.al [60] proposed, an enhance differential evolutionary algorithm(EDE)method which combines variable scaling DE and ant colony algorithm is employed to solve the multi-objective optimization problem. Results show that the proposed method was superior to that of the existing methods in terms of convergence time .

f) Artificial neural network.: Neural networks are simplified models of the biological neuron system, is a massively parallel distributed system made up of highly interconnected neural computing elements that have the ability to learn and thereby acquire knowledge and make it available for use .NN are simplified imitations of the central nervous system and motivated by the kind of computing performed by the human brain . In[61]Hsu et.al proposed two approaches using AI, that is ANN approach and pattern recognition method. The effectiveness of the proposed approaches is demonstrated by service restoration of an underground distribution system of fortunately, neural network training and database updating are usually carried out offline, therefore time is not a crucial factor at the training stage. After the ANN has been trained and the training patterns have been stored in the pattern recognition method, it requires only a very short period to obtain the desired restoration plan.

In[62] Aurtro discusses limitations encountered in some currently used restoration techniques and a proposed improvement based on artificial neural networks (ANNs).Multilayered perceptron (MLP) was used and trained with a supervised learning algorithm called back-propagation. A MLP consists of several layers of processing units that compute a nonlinear function. however, the existence of more than one layer makes the weight adjustment process for problem solution difficult.

g) Fuzzy logic: This theory exhibits immense potential for effective solving of the uncertainty in the problem. Uncertainty may arise due to partial information about the problem, or due to

information which is not fully reliable. In this method, different parameters of the distribution system
such as out of service load number of switching operation, bus voltage, line current, loading of transformer etc. are taken as fuzzy variables.

In[63] Kuo et.al discussed an approach based on fuzzy set theory is developed to estimate the loads in a distribution system and to devise a proper service restoration plan following a fault. To estimate the loads on branching points without real-time meters, typical hourly load patterns for several types of days are established for commercial, industrial, and residential customers.

In[64] Huang et.al proposes the use of a fuzzy cause-effect (FCE) network to achieve the multi-objective service restoration of distribution systems, the weighted sum strategy is employed to convert these objectives into a single objective function by giving relative weighting values. The weighting factor of each objective is assessed via the analytical hierarchy process (AHP) approach.

In[65] a fuzzy set based fault location algorithm is presented. It uses fault related data from fault sensors as well as study results from short circuit analysis and handles the uncertainty in these data with fuzzy set formulation.

In[66] Kaewmanee et.al presents a fuzzy decision algorithm in which the system operator is able to use linguistic expression, to identify proper switching orders with the information of feeder loads and feeder lengths.

V. OTHER TECHNIQUES

Kleinberg et.al in [67] proposes a method to improve service restoration through load curtailment. Load curtailment programs including direct load control and demand response allow system operators to directly and/or indirectly reduce a portion of total customer demand. It is shown that the addition of load curtailment allows for one or more of the following, a reduction of the total number of switch operations required, an increase to the number of customers served, and/or an increase to the total amount of load restored. These improvements are demonstrated through simulation results from a 416-bus multiphase distribution system.

For further improvement of the existing restoration algorithm one algorithm had been merged together to form a hybrid model to meet the system requirement, Combination of fuzzy with heuristic approach was used in[31]. In [68] a combination of PSO and GA is being used to solve both constrained and unconstrained optimization problem .In[69] combination of fuzzy and GA is implemented to overcome the convergence problem of GA. Chu et.al. [70] proposed a hybrid two-step approach of GA-ACO . First, the mutation operator of Generic Algorithm (GA) is used to identify all possible switch combinations that satisfy the operation conditions within a time slot.

VI. SERVICE RESTORATION IN MICROGRIDS AND DISTRIBUTED GENERATION.

Microgrids is a small-scale power supply network that is designed to provide power for a small community.It enables local power generation for local loads. It comprises of various
small power generating sources that makes it highly flexible and efficient. In [10] the effective placement and capacity of interconnected DGs are being investigated in order to come up with a better ways of restoration, .In[71-76] application of microgrids in service restoration is discussed.

VII .FUTURE SCOPE FOR RESEARCH

A) Networked system:

A future work topic is the consideration of networked system networked system adds complexity to the distribution system that the loads may be energized from several paths.several constraints that in corporate all the possible paths and the utility considerations be required in order to account for different system topologies.

B) Control strategies:

Centralized control strategies are accepted as optimal control strategies but this may not be possible for some distribution systems. Therefore , an interesting topic of study in distribution system would be development of control schemes which mix centralized and local control strategies.

C) Data management:

Data management is an urgent issue in service restoration.Load is increasing very rapidly so as the number of monitoring system and meters, hence more data is to be handled. Efficient interfaces between customers information and distribution automation functions must be created so as to produce timely results.

D) Efficiency consideration:

To make existing algorithm more effective much dynamic approach is required . For example, PSO has a very high convergence rate and few researchers have tried to modify the existing PSO to design MOPSO which is very efficient. It would be very useful (for real-time applications in power system) to have a MOPSO that could produce reasonably good approximations of the Pareto front of multi objective optimization problems. A first attempt to design such a type of MOPSO is reported in [77] but more work in that direction is certainly expected, since this topic has been recently explored with other types of multi-objective evolutionary algorithms as well .

Apart from above some other research areas can be, self adaptation of algorithm parameters ,reliability evaluation in distribution system and challenges occurred in service restoration due to in-depth restructuring of electricity market.

TABLE I. COMPARISON BETWEEN VARIOUS METHODS

Method	**Distinctions**	**Limitations**	**Employed by**
• Analytical approach • Graph trace theory	• Non-iterative in nature • Less computing time • No Convergence problem • maximizes the restored loads in distribution by using the DG availability[26]	• For complex system accuracy is affected.	Ukack et.al[23] Borges et.al[24] Thi et.al[26]
Heuristic	• less computing time. • Reliable approach.	• Requires significant amount of data for optimal solution. • Not efficient for large system. • Convergence problem. • Fault on a single feeder was considered.[14]	Hsu et.al[27,29]
Tabu search • Parallel tabu search. • Probabilistic tabu search.	• Multi objective optimization possible. • Offers near optimal solutions to many practical optimization problems. • computational time was improved in parallel and probabilistic tabu search.	• Lot of computational time in creating the solution candidates in realistic problems.[58]	Gracia et.al[34] Lee et.al[36] Mori et.al[35,37]
Simulated annealing.	• It points out to locate a good approximation to the global optimum of a given function • Probabilistic approach. • Effective for large systems.	• Convergence time is more in some cases.	Hossam et.al[39] Lin et.al[40]
Genetic algorithm • Parallel genetic algorithm • Hybridised GA. • Genetic tabu algorithm.	• Multiobjective optimization. • Effective for non linear and non -differential problems. • hybridized GA can perform on non-radial systems also. • GTA overcomes the convergence problem of GA. • In [38] loss cost and reliability both were considered.	• Global optimization is not garaunteed.[76] • Weighting factors are required.[26] • Large number of iteration for large networks. • Convergence problem is there.[26,76] • Is not a generalized method for every system.	Y Kumar et.al[41] Inagaki et.al[44] Augugliaro[45] Shin et.al[38]

Nsga –II	• No weighing factors required. • Fast and no convergence problem • Priority customers were considered.	• Global optimization is not guaranteed.	Deb et.al[46] Y.Kumar et.al[48]
Particle swarm optimization • BPSO	• Best global optimal solution of all. • No Speed and convergence problem. • In [54] constrained and unconstrained both types of problem can be solved.	• Inherently continuous so modified version BPSO is used in service restoration problem .	Keneddy.et al[49] A. Arya et.al[53] Yang et.al[68]
Ant colony optimization/ • Enhanced ACO	• Inherent parallism. • Robust. • Enhanced ACO limits the search path in the feasible region and improve the global search efficiency and decreases the time.[56]	• Time of convergence is uncertain.	Watanbe et.al[54] Lu et.al[55]

IX. CONCLUSION

This paper has represented an overview of power system restoration and summarized various restoration issues and strategies. Various optimization tools have been discussed and their relative comparison has been done. For further improvement of restoration algorithms hybrid algorithms are developed . Finally, some topics that seems to have a good scope in future research in this area have also been discussed .

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