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Influence of Optimal Network Reconfiguration of Electric Power Distribution Feeders on Power Loss Minimization: A Comprehensive Review

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Abstract: The aim of reconfiguring the electric power distribution network under normal operating conditions is to reduce the total active power losses of the network or to balance the load of the system's feeders which is an important part of distribution network operation to improve system reliability and stability. However, the three objectives of the distribution engineers is power losses minimization, maintenance of good voltage profile and minimum feeders' current levels. For the past forty two (42) years, researchers have proposed various methodologies that include pure heuristic and artificial intelligent-based methods. This paper examines a comprehensive bibliographical study and general backgrounds of researches and developments in the areas of network reconfiguration and optimization using artificial intelligent-based techniques inover sixty (60) published articles that were reviewed. The benefit of this comprehensive survey is to provide reference point for educational advancement on the recently published articles in the areas of network reconfiguration and to stimulate further research interest.

Keywords: *Artificial intelligent-based optimization algorithms,Distribution network, Load balancing, Network reconfiguration, Power loss.*

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I. Introduction

Frequent power interruptions in the Nigerian electric power distribution network have become a recurrent decimal and this is tag as one of the biggest obstacles to be tackled in the distribution section of the electric power system. The reasons for the frequent power interruptions are not far fetch from unscheduled and scheduled outages. The scheduled outages are the outages that are planned by the utility companies for routine and preventive maintenance purposes while the unscheduled outages are the outages that occurred due to fault(s) on the system such as lightning, earth failure, overload, damage of equipment, etc. Besides, the scheduled outages due to routine and preventive maintenance, the utility companies also carried out scheduled outages called load shedding due to inadequate power generation or poor system generation. When the system is overloaded or when there is poor generation, the utility carry out energy management (load shedding) in the system. This overload causes increase in power losses in the network. The Nigerian utility companies carried out energy management (load shedding) due to various reasons and limitations in the network namely:

a. Poor System Generation
b. Equipment Limitations:
- Line Limitation
- Circuit Breaker Limitation
- Transformer Limitation

c. Management Load Shedding

This is done to manage the supply-demand and also to minimize system overload. Indeed, numerous researches have been done with the aims of reducing power losses in the distribution system while maintaining its quality and reliability of the system itself [1]. Optimal network reconfiguration is one of the best ways of reducing power losses, maximizing load balancing, enhancement of voltage profileand increase in reliability of the power distribution network. Network reconfiguration is not new, it was first used by Merlin and Back in 1975, where they make use of Branch and Bound method to carried-out network reconfiguration. Since that time network reconfiguration has expanded relevantly in the areas of reducing power losses, load balancing etc. Hence, this paper presents a holistic review of the work done on optimal network reconfiguration and artificial intelligent-based optimization techniques applied in power loss reduction in the distribution system.

II. Literature Survey

Merlin and Back (1975) proposed an inter-mixed non-linear optimization model that is solved through the discrete branch and bound method. In this method, the system constraints were neglected for the purpose of the algorithm and the strength of the algorithm was that an optimal solution was obtained which was independent of the initial switch status. Merlin and Back approximated the behaviour of the distribution system by performing a DC power flow operation [2].Bernardon, Pfitscher, Canha, Abaide, Garcia, Montagner, Comassetto and Remes (n.d) proposed a heuristic algorithm for the solution of distribution network reconfiguration problem using an efficient fuzzy multi-criteria decision-making method. The algorithm implements the classical backward/forward sweep method for obtaining load flow values on the distribution network. The algorithm is based on the branch-exchange strategy. Using this strategy, the applied procedures correspond to open one switch and to close another one with the aim of producing new and promising configuration without violating the network constraints. The results showed that the multi-criteria analysis removes the less promising configurations with the aim of reducing the search space of the optimization problem to reach its best configuration [3]. It is also noticed that Rudnick, Harnisch and Sanhueza (1997) suggested a heuristic solution algorithm based on the method of branch exchange that allows drastically reduction of computation time involved in the formulation of objective function by Baran and Wu in 1989, when using the simplified power summation method. The algorithm was coded using the Turbon Pascal programming and the effectiveness of the simplified power summation techniques was investigated by comparing the uses of the interactive version of the power summation method (exact method) and the use of the simplified version (approximate method). Both methods were tested for different load factors and the results shown that both methods used for reconfiguration work satisfactorily, revealing the convenience of using the approximate method to perform reconfiguration studies in distribution networks under normal operating conditions, as the method requires a smaller computational effort compared to the exact method. But both methods converge to a local optimum, that is to say, convergence to a global optimum is not guaranteed for these methods [4]. Auguliaro, Dusonchet and Sanseverino (1998) suggested an algorithm to solve the reconfiguration problem using the combination of genetic algorithm (GA) and tabu-search. The suggested method minimizes the cost function while keeping constraints of the system such as the line power capacity, voltage drop at load point. The genetic-tabu algorithm is a tabu search combined with GA to reinforce convergence characteristics in a global solution space for effective and efficient optimization system [5]

Schmidt, Ida, Kagan, and Guaraldo (2005) proposed a method of reconfiguring distribution networks considering loss minimization as the primary objective to be achieved. Their method enforces the radiality of the final solution and the core of their approach is a best first search for establishing the state of all switches (open/close) combined with the standard Newton method with second derivatives for computing branch currents. The approach does not guarantee that optimal solution will be found, but it does provide high-quality sub-optimal solutions and, above all, it results has shown very good performance when applied to the realistic distribution network [6]. Prasad, Sivanagaraju, and Sreenivasulu, (2008) proposed a novel approach to solve the radial distribution system reconfiguration problem for load balancing and active power loss reduction using a genetic algorithm (GA). The vector-based load flow method for solving radial distribution systems using the sparsity technique was suggested. The algorithm used, most of the infeasible solution are eliminated which in-turn leads to minimum search space. The results showed that the method can identify the effective branch exchange for an improvement in load balancing; optimal or near optimal configuration for load balancing to improve the voltage profile of the network with the global optimum reached with less number of bits and iterations. A study was also done by Wu and Tsai (2008) using a binary coding particle swarm optimization to identify the switching operation plan for feeder reconfiguration. The suggested method considers the advantages and disadvantages of the existing particle swarm optimization method and redefined the operators of PSO algorithm to fit the application field of distribution systems reconfiguration using the proposed shift operators' method. The results indicate that the planned method provides better and more reliable solutions than typical BPSO method for minimizing lines losses and load balancing problem [7]. Concurrently, Yuqin and Jia (2008) planned a new method that improves the unfeasible reconfigurations produce in a search process that makes the whole ant colony system algorithm inefficient. The suggested method uses integer-coded technique that incorporates the graph theory. The new searching method can aid the ant colony system algorithm to quickly get an available structure of the distribution network which guarantees the feasibility of the results on time. The method was programmed on MATLABsoftware and the test results revealed that, it makes the whole ant colony system algorithm fast, efficient and superior performance [8].Rao and Narasimham (2009) proposed a new heuristic search method for determining the minimum loss configuration of a radial distribution system. In this method, a simple heuristic rules are formed to select the optimal switches that give the minimum power loss without searching all the candidate switches in the network. The techniques in this rule is to compute the voltage difference across all open tie switches and the one with voltage above a specified voltage value and also having the highest voltage value closes first but the tie switches with voltage difference below the specified value are discarded. The algorithm reduces the combinatorial explosive switching problem into a realizable one and reduces the switching combinations to a fewer number thereby reducing the computational effort. The method was programmed in MATLAB environment and the results shown that the algorithm gives the optimum solution with a few numbers of load flow runs at 26 times and the CPU time need is very less of 0.42 sec [9]. While, Dolatdar, Soleymani and Mozafari (2009)suggested two methods in determining the optimal configuration of a radial distribution system for loss reduction. In their work, the first method carried-out the implementation of the new heuristic search method of simple heuristic rules of optimal switch selection proposed by Rao and Narasimham in 2009 with modification in the load flow programme. While the second method suggested a simple optimum loss calculation by determining optimal trees using the graph theory and the defined genetic algorithm methods. For them to demonstrate the validity of these methods, a computer simulation with PSAT and MATLAB programmes were carried out on 33 – bus test system. The results shown that the first method results showed that the first method results are better than Rao and Narasimham results and the second method which make use of graph theory and GA optimization shown that the results are better than the first method and also other methods such as Kashem et al; method [10].Quin and Wang (2009) proposed a heuristic method of optimal network reconfiguration of distribution network based on particle clonal genetic algorithm (PCGA). The work gives a loop sequence code method, which can preclude infeasible solution in the process of configuration. The uniqueness of PCGA is the combination of particle swarm optimization (PSO) with clonal genetic algorithm (CGA) which can develop respective merits, and compensate opponent defects, and then make the process of searching optimal solution efficient. PCGA is built to avoid the premature convergence of PSO and the blindness of CGA. The results of PCGA when compared, it shown a better result than CGA and CGSA and PCGA can cut the calculation time and promote the search efficiency obviously [11].

Chouhan, Wan, Lai, Feliachi and Choudhry (2009) suggested a multi-agent based reconfiguration of a smart distribution system when fault occur. The multi-agent had two categories of agents in the suggested multi-agent system (MAS) architecture, which is Local Agent (LAG) and Global Agent (GAG). The reconfiguration algorithm is embedded inside the GAG, such that whenever it receives fault location itstarts reconfiguring the network to reroute power to critical loads. The main objective of reconfiguration is to always supply the critical load without exceeding the line capacity while maintaining the voltage limits. The approach of the multi-agent is to incorporate graph theory algorithm to reconfigure the system. The multi-agent system makes use of both centralized method and the method was developed in MATLAB and MATPOWER environment; the results obtained shown a very promising and superior ability of the multi-agent systems in the field of fault detection and reconfiguration [12]. Bruno, Lamonaca, Scala and Steechi (n.d) suggested an algorithm that is based on simulated annealing (SA) for developing optimal network reconfiguration (ONR) for the application of advanced distribution management system (ADMS) in real-time framework. The ONR algorithm developed is based on simulated annealing meta-heuristic method which is implemented in MATLAB code. The algorithm looks for new configuration and communicates necessary topological changes to the Open Distribution System Simulator (OpenDss). The results shown that the methodology is able to ensure the selection of an optimal configuration minimizing system losses and respecting all technical and operative constraints [13]. Bernardo, Garcia, Ferreira and Canha (2009) suggested a heuristic algorithm for the solution of distribution network reconfiguration problem using an efficient fuzzy multi-criteria decision making method and a method for constructing typical load curve. The heuristic search algorithm was based on the branch-exchange strategy and the decision making technique for the approach was based on Bellman – Zadeh method in 1970. The algorithm was implemented in a proof – of – concept tool and the results showed promising, since significant improvement in the power loss reduction and number of interrupted customer per year was reached [14]. Chakrabarti, Ledwich and Ghosh (2009) proposed a distribution system reconfiguration method for maximizing the reliability of the system. The aim was a driven reliability distribution network using the probabilistic models of the network. The enhanced binary particle swarm optimization (BPSO) algorithm was used to determine the optimal configuration of the switches statuses and the Monte Carlo Simulation technique is used to compute the reliability of the network to evaluate the loss of load expectation (LOLE) and the loss of energy expectation (LOEE) at the load points. The modified IEEE 13 bus system was tested and the result shown that the load was normalized for the first day of each month in a year [15]. Rama, Rao and Sivangaraju (2010) proposed a plant growth simulation algorithm (PGSA) to reconfigure distribution network for power loss reduction and to keep load balancing. The algorithm (PGSA) implements a guiding search direction that changes dynamically as the change of the objective function and it does not require any external parameters. The validity and the effectiveness of the method shown that using the PGSA algorithm, the feeder reconfiguration problem can be solved efficiently for loss reduction as well as improving the load balancing index when the results were compared to genetic algorithm (GA) [16]. Sirisumrannukul (2010) presented a reliability worth enhancement using simulated annealing (SA) in optimal network reconfiguration of distribution system. The objective is to minimize the total customer interruption cost (ECOST) with the constraints that all load points have to be electrically supplied and radially connected. The method was simulated using the 6 – bus Roy Billiton Test System (RBTS) and the 69 bus system. The results shown that the total customer interruption cost was reduced (i.e., the system reliability worth is enhanced) and the system reliability indices were also improved [17].

Algazar, Mehanna and Alkzaz (2011) suggested optimal reconfiguration of radial distribution system using forward/backward updates method. The method makes use of the voltage across the tie switches by determining their terminal voltage whether is less than a specified value by +5% from the rated value and then, has to transferred from a lower voltage side of tie switch to higher voltage side after checking the power of the transformer and all feeders to avoid overloading. The power losses were calculated before and after the switch changes and the results shown significant power loss reduction and system stability [18]. Pournaras, Yao, Ambrosio and Warnier (n.d) illustrates the application scenarios of organizational control reconfiguration for the robustness of a smart power Grid. The scenarios require some degree of coordination; the coordination and computational intelligence of control elements requires capabilities for dynamic binding reconfigurations of the generation, transmission and distribution. The new type of control application suggested provides reconfiguration services for dynamic binding reconfigurations that are required for this application of internet of things which can be modeled as a control application using the application-level self-organization services in internet-scale control systems (ALSOS-ICS) model. ALSOS-ICS allows a higher interoperation and modularity between control applications and a higher flexibility, integration and applicability of dynamic binding reconfigurations in the domains of the Internet-scale cyber-physical control systems [19]. Hemmatpour, Mohammadia and Rashidinejad (2011) presented a novel approach for optimum reconfiguration and optimal location of DGs in distribution networks based on a hierarchical two-stage optimization problem to improve power system voltage stability margin and reduce active power losses. They developed toolbox to assess the power system voltage stability margin based on Lagrangian method and the proposed method used harmony search algorithm (HSA) to solve the mentioned optimization problem which was implemented in IEEE 33 and 69 test bus systems. The results shown merits in both reconfiguration problems and DGs planning with efficient searchability and robustness' in result as compared with particle swarm optimization (PSO) techniques [20]. Ananthapadmanbha, Prakash, Pujar, Gangadhara and Gangadhara (2011) proposed a new method for system reconfiguration and fault restoration of a distribution network. The approach is a single and multi-fault cases system which includes the method of compensation. An iterative method is used to determine the optimal compensation solution which the network configuration and fault restoration of a distribution network. The approach is a single and multi-fault cases system which include method of compensation and iterative method that were used to determine an optimal compensation solution which also enables the variation of the solution when the network configuration changes. The new level-wise approach was programmed in MATLAB 7.6 for implementation. The new approach shown decrease in network losses enormously with lesser switching changes while maintaining the voltage profile and line loading within limits with optimal results obtained for given conditions. But the approach didn't put fault detection and location into consideration and also, the process was 70% manual [21]. Arya, Kumar and Dubey (2011) proposed a novel selection regime for the choosing of global best (gbest) and personal best (pbest) for swarm members in multi-objective particle swarm optimization (MOPSO) without using external archives. The novel method changes the logical status of a switch which was normally open while it considers the minimization of the number of switched on lines. The results of the novel algorithm (MOPSO) shown a monumental improvement and have advanced features that are different from other conventional optimization methods when compared with the conventional genetic algorithm (GA) and the normal particle swarm optimization method [22]. Chen, Zhang and Zheng (2011) developed a distribution network reconfiguration method based on simulated annealing immune (SAI) algorithm. The method make use of Boltzmann simulated annealing operator to select new solutions in order to avoid local optimum characteristic of heuristic methods. The advantages of the SAI algorithm are that the evolution is finished in infeasible solutions, and the discrimination and disposing of infeasible solution is avoided. The result shows quick convergence speed when compared to Fuzzy genetic algorithm applied by Li and Xueyun [23]. Shakeer and Babu (2012) planned an adapted ant colony optimization (AACO) for distribution network reconfiguration using the graph theory. The method used new codification to represent feasible radial topologies of the distribution system based on meta-heuristic search techniques. In the AACO, some rules are framed to generate only feasible radial topologies and the AACO transforms any infeasible individual, whenever generated into feasible one under the guidance of the rules framed to optimize the conventional ACO. A heuristic spark ignites the search engine of the method to enhance the pace of the conventional ACO. The suggested method incorporates the advantages of heuristics to increase the pace of the search techniques without losing diversity. The simulation results showed that the suggested method provides a promising tool for reconfiguration problem in the distribution network but the results were not compared to others advanced meta-heuristic methods [24]. Chakravorty (2012)proposed an improved evolutionary programming technique for radial distribution power loss minimum reconfiguration. The enhanced performance of evolutionary programming: a Fuzzy controlled evolutionary programming (FCEP) was suggested. The method reduces combinatorial explosive switching problem into a realizable one and reduces the switching combination to a few number. The mutation Fuzzy logic controller developed help to speed up the evolutionary process by adaptively adjusting the mutation rate. The equality and inequality constraints were used to guarantee the optimal solutions search by the FCEP which are feasible and the results showed 66.20% power loss reduction when compared to the initial configuration [25]. Wang, Li, Liang, Zhong, and Wang (2012)presented a distribution network reconfiguration method of an ant colony and tabu search hybrid algorithm. The Hybrid method improves the search rate of the algorithm greatly and avoids local optimum during the search process. Through the implementation of the hybrid algorithm with the IEEE 69 bus test system and comparing the results with that of Genjun, Lei and Guoging in 2001; Shaogun, Zifa and Yixin in 2004; the result showed a good feasible and also the superiority of the ant colony and tabu search hybrid algorithm in distribution network reconfiguration [26]. Xiaodan, Huanfei, Zhao, and Hongjie (2011) presented a reconfiguration model suitable for distribution network reconfiguration with micro-grids operation. The model was decomposed into two sub-problems: capacity sub-problem and a reconfiguration sub-problem. While the former was used to determine the optimal capacity of each island, and the latter is used to find the optimal reconfiguration with less power loss. The multi-objective problems were solved using the improved branch exchange method by Gvanlar et al. in 1988 and Baran& Wu in 1989 and the method was validated using the IEEE 33 – node system and the PG8E 69 – node system. The results showed that power loss reduction and voltage profile improvement changes nonlinearly with maximum extra power (SMG) in the two distribution network investigated [27]. Also, Abdelaziz, Osama, Elkhodary, and EI – Saadany (2012) proposed two heuristic optimization techniques to find the most appropriate topology of the distribution system with and without distributed generation (DGs) units that minimize the total system power loss. The ant colony optimization which was implemented in the hypercube framework (HC – ACO) and harmony search (HS) algorithms suggested were implemented with 32 and 69 – bus test systems. The two test systems with a different number of nodes were studied to demonstrate the effectiveness of the proposed methods and the convergence characteristics of both algorithms were also compared and the benefit of implementing the ACO in the HC framework. Adding DGs to the reconfiguration process further reduces the power losses in the system. Their results showed promising; the low computation effort and short simulation time make them suitable for real-time implementation [28]. Rashtchi and Pashai (2012) proposed ant colony search algorithm (ACSA) to solve the optimal reconfiguration in radial distribution systems with and without distribution resource (DG) for power loss reduction that determines the optimal location and size of DG according to problem constraints. The ACSA algorithm was implemented in MATLAB programme for a typical distribution system of 13-bus and 33 IEEE bus systems and the rules in the system make the ACSA become an extremely powerful method for optimization problems. The results showed that the DGs have the improvement effects on loss reduction and it increases system power quality. Also, the computational results of the 33 IEEE bus system showed that the ACSA method is better than the GA method [29]. But recently, Li, Wu, Chen, Shi, Xiong and Wang (2012) proposed a new power loss estimation model considering the transient power loss due to network reconfiguration. The heuristic greedy algorithm approach was used to achieve the line power loss (TPL) in the radial distribution network. Their method follows the Distflow solution approach proposed by Baran and Wu taking into consideration to modify the model of the network reconfiguration and the power loss model combining the distribution LPL and TPL to form a new model. The suggested algorithm was implemented in MATLAB environment and the IEEE 33-bus system was used in the simulation of the model to demonstrate the effectiveness and, the simulation results showed that the suggested model gives a better result in reconfiguration than Disitflow approach does in the unconventional model [30]. Cho, Shin, Park, and Kim (2012) presented a novel DG reliability cost that expresses the interruption damage of the DGs due to feeder faults when islanding operation is prohibited. The reliability cost which is a composite cost (CCOST) consists of the expected customer interruption cost (ECOST) and the DG reliability cost (DGRC). The CCOST was used as an objective function in the network reconfiguration using a GA optimization tool. The reconfiguration algorithm was implemented in MATLAB environment and the network reconfiguration with the suggested objective function was applied to a modified 33 bus test system. The results of the reconfiguration showed that in a distribution system with a light load interruption cost, the DGRC has much influence on the CCOST as the ECOST does. However, owing to a lower DGRC than ECOST, the DGRC has little influence on the CCOST in the test system with a heavy load interruption cost but the optimization tool was not compared to evaluate the accuracy and efficiency [31].

Nagy, Ibrahim, Ahmed, Adail and Soliman (2013) presented an optimization technique based on genetic algorithm for distribution network reconfiguration that was to reduce the network losses to a minimum. The algorithm was programmed in MATLAB environment and a 16-bus system was used to demonstrate the effectiveness of the algorithm. The results of the new configuration compared to the base configuration showed high efficiency in power loss reduction but the algorithm was not compared to other algorithms [32]. Yanli, Dexiang, Nong and Xue (2013) suggested orthogonal experiment design algorithm for distribution network reconfiguration. The orthogonal algorithm is based on the principle of orthogonal table which uses the combinational mathematics theory which is based on the Latin Square and orthogonal Latin square. The algorithm was tested using IEEE typical three-feeders' system and the result of the new configuration was compared with the based configuration which showed a better power loss reduction of 9.54% and the most obvious advantages of the suggested method was its ease of operation and understanding of the model but the method was not compared to other optimization methods to evaluate its effectiveness [33].

Benavides, Machado, Costa, Ritt, Buriol, Garcia and Franca (n.d) presented greedy randomized adaptive search procedure (GRASP) meta-heuristic method for switch allocation problem with switch reconfiguration problem as a sub-problem. Their objective is to evaluate the reliability of the network by using two approaches of the upper bound and lower bound reliability system which is referred to network connectivity. They create electrical synthetic instances of the problems and applied GRASP and Tabu search (TS) algorithms for optimal switch allocations. A comparison of both meta-heuristics on the synthetic instances and other instances from the literature surveyed shown that the GRASP algorithm finds slightly better results than tabu search algorithm [34]. De-Oliveria, Ochoa, Padilha, Roberto, and Mantovani (n.d), presented a friendly graphic interface and reconfiguration functions developed and simulated, using Visual Basic Language. The visual tool was implemented using the Visual Basic Language (VBL) and the Fortran Language was used to implement the reconfiguration algorithm. The visual facilities record the network data imputed and shows the results of the based configuration and the five (5) configurations with their losses respectively on the simulator. Consequently, their simulators improve the efficiency and the dynamism of the power distribution networks training, planning and operation. The results were helpful for engineers and students for decision making and training respectively [35]. Rezaci and Vakilian (n.d) reported the implementation of power loss minimization and capacitor placement cost minimization using the modified particle swarm optimization (MPSO) algorithm. They consider capacitor placement/setting and the distribution reconfiguration as combinatorial and complex optimization problems and, they applied the direct approach to solving power flow problem in their method. The MPSO algorithm was used to solve the optimization problem by programming it in MATLAB environment. The simulation results using the MATLABsoftware were performed on two sampled distribution networks and their results shown the effectiveness of the optimization method especially the optimum switching of the capacitors into the network accompanied with network reconfiguration to minimize the losses more effectively. The results of the suggested method were compared with the existing methods in the literature surveyed, such as the Masoum et al., method and Gallego et al., method and their methods showed promising [36].

Salman, Mohamed, Shareef and Ghoshal (n.d) reported a new method for voltage sag mitigation in the distribution system by optimal network reconfiguration using an improved genetic algorithm (GA). The improvement of GA makes use of the developed encoding and decoding techniques of switching strings during optimization process to maintain the radial structure of the distribution network. The coding techniques exclude all the infeasible switching strings from the search space thereby improving the computation time and it was tested using 16 – bus distribution system. The proposed method was simulated using a practical 47-bus test distribution system and the simulations results shown that the application of the suggested method of GA with the new technique of coding systems proves to be efficient and feasible for improving the bus voltage profile during voltage sag duration but decision must be taken by the engineer to compromise minimum line losses for the system reliability [37]. Rao, Ravinda, Satish, and Narasimham (2013) reported a new approach to network reconfiguration and installation of distributed generation (DGs) units in the distribution system. An efficient meta-heuristic HSA used in the optimization process of the network reconfiguration and DG installation. Different power loss reduction scenarios were suggested using the reported method and the existing methods on 33 buses and 69 bus test systems. The simulated results establish the superiority of the new method and also, the simultaneous network reconfiguration and DG installation methods using the harmony search algorithm (HSA) perform better and were more effective in reducing power loss and improving the voltage profile compared to a genetic algorithm (GA) and the redefined genetic algorithm (RGA) [38]. Khalil, Geopinich and Elbanna (2013) proposed a selective particle swarm optimization (SPSO) tool for optimal capacitor placement problem and optimal feeder reconfiguration problem in the distribution network to evaluate individual and simultaneous implementation. The suggested algorithm was tested in 16 – bus system and the practical distribution network of the Taiwan Power Company published in the literature surveyed considering three scenarios. The reported method was compared to other methods such as SA, GA, and ACSA. The simulated results shown that the best loss reduction ratios after distribution network reconfiguration (DNR) were the same for different optimization methods used but the loss reduction ratios after capacitor placement (CP) and DNR obtained by the SPSO were the best among the methods used and also, the simulation results shown clearly that simultaneously considering both DNR and CP were more effective than using only one technique [39]. Divya and Bindu (2013)elucubrate the effectiveness of ant colony optimization (ACO) algorithm in distribution network reconfiguration. The algorithm was applied to 14 buses, 3 – feeder benchmark system from the literature surveyed as suggested by Civanlar et al. The crux of ACO algorithm is in the effectiveness and optimal tuning the control parameters to achieve a global solution. The results showed that the performance of the algorithm on reconfiguration problem is satisfactory with respect to the optimal solution, the speed of convergence and constraints realizations but they didn't compare the algorithm results to other meta-heuristic methods [40].

Peng and Low (2013) proposed an efficient algorithm for optimizing a single branch exchange step in the distribution system for optimal feeder reconfiguration (OFR) based on second-order cone programme (SOCP) relaxation of optimal power flow (OPF). Their algorithm makes use of the relaxed method suggested by Baran and Wu in 1989 with little modification which was equivalent to the full AC power flow model for a radial network and the proposed algorithm solved the OPF using the convex relaxation method. The 56 – bus Southern California Edition (SCE) was simulated as a test system in MATLAB environment using convex (CVX) optimization toolbox and the results of the algorithm shown optimal solution to OFR in radial distribution network[41]. Tomoiaga, Chindris, Sumper, Sudria – Andreu, and Villafafila – Robles (2013) proposed a genetic algorithm based on NSGA II to solve the optimization problem in a non-prohibitive execution time. The suggested algorithm generate just radial configuration using the branch exchange heuristic method to produce the initial population and by crossover operator, a multi-objective reconfiguration (MOReco) was done with comparative tests performed on some active tests system in the literature surveyed. The results demonstrated the accuracy and the promptness of the proposed algorithm [42]. Bakkiyaraj and Kumarappan (2013) presented a method for the optimal enhancement of reliability parameters of a distribution system using biogeography-based optimization (BBO) algorithm. The suggested method was a comprehensive optimal reliability enhancement model that is formulated by imposing constraints on the primary load point indices and customer oriented indices. The suggested approach was applied to both radial and meshed sample test systems and the results were compared with existing literature. It was found that BBO algorithm successfully searches the optimal solution by converging to a lower total cost while achieving the optimal reliability parameters of the system when compared with genetic algorithm (GA) and the classical polynomial time algorithm [43]. Kumar, Ramana, Kamakshaiah, and Nishanth (2013) reported the methods use in distribution network reconfiguration in various published popular journals. The report attempt to summarize literature survey carried out over the past two and half decades in various published journals with all such methods studied and to analyze the best possible method for network reconfiguration of the distribution systems. The report presented the merits and demerits of all methods in network reconfiguration of the distribution system and they were furnished for the purpose of having a better idea of the various methods [44].

Bernardon, Pfitscher, Canha, Ramos, Sperandioand Garcia (2014) reported a new methodology for automatic reconfiguration of the distribution network in real-time using analytic hierarchy process (AHP). The algorithm developed was based on the heuristic method of branch exchange adaptation suggested by Cherkaoui, Bart and Germond in 1993 and on AHP multi-criteria decision-making method to identify the best network configuration. The algorithm obtains the load flow value by implementing the backward/forward sweep method and the simulations results of the real-time optimization process by the suggested algorithm showed the feasibility of the methodology [45]. Shamsudin, Omar, Sulaiman, Jaafar and Kadir (2014) developed an algorithm for optimization of power losses and voltage profile improvement in the distribution network. The SIGA (Selection Improved Genetic Algorithm) algorithm was successfully implemented in MATLABVr. 2013 using the IEEE – 33 bus distribution system and the validity of the proposed algorithm was performed by adjusting the parameters that influence the power losses and voltage profiles with the results of the power losses and voltage profiles shown. The results showed both conventional GA and SIGA results in power loss reduction and voltage profile improvement but somehow SIGA algorithm demonstrates higher reduction of power losses and a better improvement of voltage profile compared with the conventional GA algorithm [46]. De-Bonis, Mazza, Catalao, Chicco, Torelli and Di-Bari (2014) proposed a novel approach to address discrete optimization problem associated with optimal network reconfiguration in the distribution system. The main idea is to design artificial dynamic model that describes the optimization process by introducing the information related to the network reconfiguration with minimum distribution network losses. The Torelli control Box (TCB) solver help the model to interface with other modules representing the specific mathematical formulation of the problem to be solved and the power flow of the complete solution set was calculated using the classical backward/forward sweep (BFS) method. The results obtained shows that the TCB approach can effectively solve the optimal distribution network reconfiguration problem and the main advantage of the TCB approach was that the solution is found in a fast way avoiding the need for performing a search on the network topology [47]. Velasquez, Morillo, Barco and Cadena (2014) proposed an efficient pareto-based approach to solve multi-stage and multi-objective optimization problems (MSMOOPs) in distribution networks. The none-dominated sorting genetic algorithm II (NSGA II) was implemented in Dig silent software to solve the MSMOOPs and the simulation was done using 33-bus test feeders with DGs installed. The simulations results showed the importance of both topology and protection systems planning to enhance the reliability in radial distribution feeders and the proposed solving scheme leads to the prime-pareto optimal set concept which may become a generalized method to elucidate MSMOOPs [48]. Shivakumari, Kiran and Marulasiddappa (2014) presented a simple approach for distribution reconfiguration with distributed generators. The switching indices method were used for the network reconfiguration and the idea was that, to arrange the switching indices in the descending order and those branches having the largest index values were the candidate branches for reconfiguration. The distributed generators were considered as constant power sinks as they are represented as negative loads. The algorithm developed was applied to a standard 16 bus system and the results shown promising as about 55% loss reduction in the optimized network with DG units as compared with the initial network without DG [49].

Babaei, Asemani and Babaei (2014) reported a distribution network reconfiguration in the presence and absence of dispersed sources using ant colony optimization algorithm (ACO). The algorithm was simulated using 33 bus radial distribution system and the simulation results were compared with a genetic algorithm. The results confirmed the correctness and effectiveness of installation of distributed generation sources simultaneously with optimal reconfiguration which increased stability, further reducing losses and improving the density of the lines with ACO algorithm proving better results than GA [50]. While Tandukarand Gyawali (2014) surveyed and implemented the application of binary coding of particle swarm optimization technique for feeder reconfiguration in IEEE 33 bus test system. They make use of the Wu and Isai shift operators technique in 2008 for optimal reconfiguration of the network. Their results showed significant power loss reduction proving or authenticating the method potency in power loss minimization in distribution network reconfiguration [51]. Huang, Hara and Kita (2014) proposed a new algorithm named as intelligent flow algorithm (IFA) for reconfiguration issues which innovate the numerical searching methods in conventional artificial intelligent algorithms to generate the optimal supplying configuration based on its topological property. The IFA algorithm was programmed and simulated in MATLAB environment using the 33 and 43-bus distribution systems with different cases studied. The simulation results were compared with genetic algorithm (GA) and the IFA has shown strong effectiveness with all global optimum found and the calculation time lesser of about 5.5 sec which is applicable for online reconfiguration but IFA algorithm has the possibility of making wrong selection in the flow generation and this mistake is difficult to revise completely in a single feeder system [52]. Also, a study by Jacob and Malathi (2014) reported the application of ant colony optimization (ACO) technique to solve the optimal network reconfiguration in the distribution system. The concept of the network reconfiguration was simulated in the existing real-life electric distribution networks at different load levels with the help of MATLAB software as a computational tool for implementing ACO algorithm for reconfiguration of 33-bus test distribution system. In the simulation process, three scenarios were considered to analyze the superiority of the proposed algorithm and the superiority was proving in the positive feedback characteristics to make sure a rapid search for a global solution while the distributed computation avoid premature convergence and the constructive greedy heuristics help to find an acceptable solution as soon as possible. The simulation results were compared and the ACO algorithm outperforms HAS algorithm and gives better result in power loss reduction and voltage profile improvement etc. [53]. Tripathy (2014) proposed a new method to reconfigure an electric power distribution network under the normal operating conditions to reduce the active losses of the network reconfiguration using Lagrange multiplier method programmed in MATLAB environment with the 6-bus and 33-bus systems as a test system. The results shown reduction in active power loss and maximization of system reliability but the reactive power losses were not considered [54]. Singh and Arora (2014) reported recently, a developed approach of harmony search algorithm (HSA) for optimal reconfiguration and capacitor placement in the distribution network for optimal reduction of power losses for dynamic load in the network. The proposed method was implemented in MATLAB 7.0 using the standard IEEE 33-bus distribution system and the Newton Raphson method was employed for calculating the power losses. The simulation results for different scenarios before and after reconfiguration, placement and non-placement of the capacitor and network reconfiguration; and capacitor placement simultaneously by the proposed algorithm prove better results than other meta-heuristic algorithm such as GA and ACO with less CPU time in the simultaneous case but the global optimality may not guarantee robustness and reliability [55]. Ahmadi and Marti (n.d) presented two methods of solving optimal network reconfiguration in distribution system using linear current flow (LCF) technique. An efficient relaxation technique of the hexagon relaxation method was used in the problem formulation by mixed integer linear programming (MILP) and mixed – integer quadratically constrained programming (MIQCP) methods. The losses were calculated using the constant P-Q load models and conventional power flow with the configuration obtained using the suggested methods for various test systems and the extensive simulation results were compared with similar studies in the literature surveyed. From the comparison, the proposed methods obtained same optimal configuration that exhibits better performance in terms of computation times and voltage profile improvement with promising power loss minimization [56]. Zhan, Xiang and Chen (2014) proposed the application of weighed entropy theory in vulnerability assessment indexes of micro-grids based on complex network theory. The micro-grid on-line reconfiguration (MOLR) model was formulated with the objective of minimizing the vulnerability value. The improved cell bat algorithm (ICBA) and the control strategy were used to ensure the MOLR optimal operation and two scenarios were considered to analyze the micro-grid reconfiguration. The CERTS system in the literature surveyed was used as test system for the simulation process and the simulation results were compared to meta-heuristic methods such as GA and PSO, the ICBA algorithm reconfiguration method prove better convergence while the MOLR suggested has proving a real-time dynamic simulation based on very short-term load forecasting to guide the operators, whether to reconfigure at the next moment but many assumptions in the system may inhibit the accuracy of the final solution [57]. Sandhya and Kanth (2015) reported a new heuristic method for simultaneous network reconfiguration and optimal DGs placement in the distribution system. The harmony search algorithm was developed in MATLAB environment and simulations were carried out using the IEEE 33 bus test system at different load levels considering five (5) different scenarios or cases. The sensitive factor method was used to determine the DGs installation buses after power flow computation and the simulation results for the different scenarios shown that simultaneous network reconfiguration and optimal DGs installation method prove more effective in reducing power loss and improving the voltage profile compared to other scenarios but the algorithm was not compare to other heuristic algorithm to evaluate its effectiveness [58].

Sulaima, Nasir, Shamsudin, Sulaiman and Dahalan (2015) presented a modified evolutionary particle swarm optimization (MEPSO) algorithm for effective power loss reduction in the distribution network and it advances in the computational time. The Newton Raphson load flow techniques were employed to calculate the power loss across each maneuver switches and the ranking concept was introduced to modify the conventional EPSO with the best-ranking position chosen according to the least values of power losses which are sorted from the combination of a new and old set of positions. The MEPSO algorithm was programmed in MATLAB environment and simulations were carried out using a real 69-bus IEEE test system. The simulations were compared with the conventional particle swarm optimization (EPSO) techniques. The results showed that MEPSO algorithm achieved the highest percentage of the power loss reduction but there is the possibility of the algorithm being trapped [59].

Dursun, Karaosmanoglu and Umurkan (2016) presented a new network configuration on the chosen network section from Istanbul to reduce the system losses by evaluating the fitness of the based configuration. The optimal reconfiguration was carried out based on power flow pattern and the power flow was calculated using the Newton Raphson method. The 95-bus test system was used for simulation and the various alternative switching operations were simulated. The results showed that the methodology reduces system losses by 26.6% with the configuration but the result did not guarantee a global optimum solution and the disadvantages of consecutive switching were not addressed [60]. Recently, Lavudya (2017) presented an efficient algorithm for network reconfiguration associated with DG allocation to reduce real power losses in radial distribution networks. The reconfiguration problem was solved by the selective particle swarm optimization (SPSO) algorithm and the optimal sizing and placement of DGs were carried out using the sensitivity analysis method. The suggested method was evaluated using the IEEE 33-bus distribution system and simulations were carried out in MATLAB environment with different load cases studied. The results showed that the method proved the strong ability in power loss reduction and voltage profile improvement but the suggested algorithm was not compared to evaluate its effectiveness [61]

III. Artificial Intelligent Based Optimization Techniques

Distribution system routing, rerouting and loss minimization are dealt with effectively using Evolutionary algorithms and swarm intelligence techniques [40]. Modern heuristics or artificial intelligent-based optimization techniques try to simulate living organisms (human) behaviour. These intelligent-based tools present a better, faster and accurate solution to an optimization problem than the existing conventional (classical or traditional) optimization techniques [62]. The mimicking behaviour of living organisms by the algorithms when simulated on a computer environment is known as artificial intelligent.These artificial intelligent-based tools provide the utilities' engineers with innovative solutions for efficient analysis, optimal operation and control, and intelligent decision making [40]. Hence, some modern heuristic or artificial intelligent-based optimization techniques used recently for optimal network reconfiguration (ONR) and optimal decision making problems are briefly explained below:

3.1 Evolutionary Computation (EC)

"The term Evolutionary computation is used to describe the field of investigation that concerns all evolutionary algorithms offers practical advantages to the researcher facing difficult optimization problems. Naturally, evolution is a hypothetical population-based optimization process. Simulating this process on a computer results in stochastic optimization techniques that can often outperform classic methods of optimization when applied to difficult real-world problems [63]. The advantages of EC are multifold, including the simplicity of the approach, its robust response to changing circumstance, its flexibility and other facets" [63].

3.2 Evolution Strategies (ES)

"Evolution strategies (ES) is a name that coversa wide family of related algorithms. These algorithms follow the general biological paradigm of exploring a search space by means of processes mimicking mutation, recombination, and selection. ES employ real –coded variables, and in its original form, it relied on mutation as the search operator, and a population size of one. ES evolved to share many features with Genetic Algorithms (GAs). The major similarity between these two types of algorithms is that they both maintain populations of potential solutions and use a selection mechanism for choosing the best individuals from the population. The main differences are ES operates directly on floating-point vectors, whereas classic GAs operate on binary string; GAs rely mainly on recombination to explore the search space, whereas ES uses mutation as the dominant operator" [63].

3.3 Evolutionary Programming (EP)

"Evolutionary programming (EP) is a stochastic optimization strategy similar to a GA that places emphases on the behavioral linkage between parents and their offspring, rather than seeking to emulate specific operators as observed in nature. EP is a similar to ES, although the two approaches developed independently. Likes both ES and GAs, EP is a similar to ES, although as the two approaches developed independently. Likes both ES and GAs, EP is a useful method of optimization when other techniques as gradient descent or direct analytical discovery are not possible. Combinatorial and real-valued function optimization in which the optimization surface or fitness landscape is “rugged,” possessing many locally optimal solutions are well suited for EP” [63].

3.4 Differential Evolution (DE)

Differential evolution (DE) is a population-based optimization technique which uses the differences of randomly sampled pairs of objective vectors for its mutation process. The object vectors’ differences will pass the objective functions’ topographical information toward the optimization capability. DE is a stochastic direct search optimization method. It is generally considered as an accurate, reasonably fast and robust optimization method. The main advantages of DE are its simplicity and therefore easy use in solving optimization problems requiring a minimization process with real-valued and multimodal (multiple local optima) objective functions. DE has been attracting increasing attention for a wide variety of engineering applications” [63].

3.5 Tabu Search (TS)

“Tabu search (TS) is basically a neighborhood of current solution. As the current solution changes in each iteration, the neighborhood also changes until the best solution is obtained. On its own is not an efficient optimization technique, hence, it should be combined with other optimization techniques” [64].

3.6 Simulated Annealing (SA)

“The name simulated annealing (SA) originates from the analogy with the physical process of solids and the analogy between the physical system and simulated annealing is that the cost function and the solution (configuration) in the optimization process correspond with the energy function and the state of statistical physics respectively. In statistical mechanics, a physical process called annealing is often performed in order to relax the system to a state with minimum free energy. In the annealing process, a solid in a heat bath is heated up by increasing the temperature of the bath until the solid is melted into liquid, then the temperature is lowered slowly. SA is effective in network reconfiguration problems for large-scale distribution systems, and its search capability becomes more significant as the system size increases” [63].

3.7 Genetic Algorithm (GA)

“Genetic algorithm (GA) is a search algorithm that based on the conjecture of natural selection and genetics. The features of a genetic algorithm are different from other search techniques in several aspects. Firstly, the algorithm is a multipath that searches many peaks in parallel, hence reducing the possibility of local minimum trapping. Secondly, the GA works with a coding of parameters instead of the parameters themselves. The coding of the parameter will help the genetic operator to evolve the current state with minimum computations. Thirdly, the GA evaluates the fitness of each string to guide its search instead of the optimization function” [63]. The GA work with a population of individuals represented by bit strings and modifies the population with random search and competition [64].

3.8 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is an exciting new methodology in evolutionary computation that is somewhat similar to the genetic algorithm in that the system is initialized with a population of random solutions [63]. PSO is a population-based search algorithm, which solely depends on the behavior of the flock of birds or schooling of fish. “In PSO, a number of particles are randomly generated to form a population and are discarded, like in GA. The search behavior of a particle is therefore influenced by that of other particles within the swarm. PSO can be said to be a kind of symbiotic cooperative algorithm” [64]. PSO has been found to be extremely effective in solving a wide range of engineering problems [63].

3.9 Ant Colony Optimization (ACO)

Ant Colony Optimization (ACO) is based on foraging techniques of real ant colonies. ACO tool mimic the behavior of real ants. “Real ants are capable of finding the shortest path from food sources to the nest without using visual cues. They are also capable of adapting to changes in the environment, e.g, finding a new shortest path once the old one is no longer feasible because of a new obstacle. Studies by ethnologists reveal these, such capabilities are essentially due to what is called “Pheromone trails,” which ants use to communicate information among individuals regarding the path and to decide where to go” [63]. ACO algorithm is a tool that tries to find the shortest path from point A to point B by mimicking real ants’ situation that finds the shortest path between the food source and nest without any visual, central and active coordination mechanism.

IV. Conclusion

The paper has successfully presented a comprehensive literature survey of the work done on optimal network reconfiguration and its influence in reducing power losses in the distribution system. From the literature review, the use of artificial intelligent-based optimization techniques have widely replaced classical and pure heuristic methods in carry-out optimal reconfiguration studies in the distribution network and its influence in selecting optimal topology in the network. Besides, the survey shows that much work have not been done on network reconfiguration of the Nigerian distribution networks using artificial intelligent-based optimization tools, hence, the need for the comprehensive literature survey. The paper is based on many research articles published since last forty two (42) years ago onthe modern optimization tools and different available literature which were surveyed. The paper also serve as an eye opener to power system researchers, engineers, utility, practitioners andin addition, it provides a formidable ground for researchers in the area of network reconfiguration.

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