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A Review on Application of Intelligent Techniques in Power System Losses

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Abstract*— Power system consists of a network of interconnected devices and equipment. During the operation of the network, losses are bound to occur no matter how accurate the design and modeling of the system. Four parameters affect effective power transfer efficiency of lines (whether short, medium or long) and controls power losses. These include resistance, inductance, capacitance and conductance. These parameters vary with line length. Though transformer applications in transmission networks reduce I^2R losses, however some other losses such as cooper (eddy current), core and hysteresis losses are introduced due to its inherent element in its design and modeling. Corona discharges also increase both the lines active power and energy losses due to self-excitation discharge around a large curved electrode. This paper did a comprehensive review on power system losses including various conventional as well as modern and the intelligent techniques approach in managing power system losses. Suggestions on ways of reducing these losses and as implemented in IEEE three(3), six(6),fourteen(14), thirty(30) and one hundred and eighteen (118) test bus systems and other typical transmission and distribution networks were also investigated and reported in this work.

***Index Terms*—Artificial Intelligent, Differential evolution, Losses, IEE Test buses.**

I. INTRODUCTION

A power system network is usually described as a large interconnected dynamic system. Like most other systems, no matter how carefully designed the system is, losses exist and must be modeled properly before an accurate representation of the system response can be calculated. During the flow of current in transmission lines, the characteristics of the line exhibited are explained in terms of magnetic and electric field interactions wherein the resulting phenomena from the field interactions are represented by circuit elements or parameters. Four parameters directly affect the ability of a transmission line to transfer power efficiently. These parameters can be combined to form an equivalent circuit representation of the transmission line which can be used to determine some of the transmission losses. The shunt conductance is that parameter of a transmission line that is usually associated with the dielectric losses of the line. Losses which occur due to the leakage current at the cable insulation and the insulators between overhead lines can be accounted for by the conductance between the lines or of the line to ground conductance. Line conductance is usually affected by many unpredictable factors one of which is atmospheric pressure and is not uniformly distributed along the line.

In overhead lines, leakage current is usually negligible. The primary source of loss incurred in a transmission system is in the resistance of the conductors. As the current flowing in the lines attempts to overcome the ohmic resistance of the line, power is dissipated in the form of heat. This power loss is directly proportional to the square of the rms current propagating through the line. Consequently, losses due to the line resistance can be significantly lowered by raising the transmission voltage level.

A. Line Models

Due to the required distances between conductors, the loops formed between outgoing and return conductors are of a considerable area. The changing flux in these loops will generate opposing voltages in the conductors which may be of considerable importance. There is a convenience to be gained in modeling the poly phase transmission system by a single-phase representation and to calculate parameters as per mile quantities. A transmission line with length less than 50 miles is classified as short transmission line. When electricity is transmitted along a short transmission line, the difference in conditions at the sending and receiving end is due to the series impedance of the line. This series impedance is that of a series connection between a resistive and an inductive element. This is shown in figure 1.0.

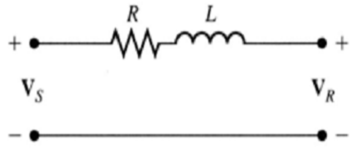

Fig 1. Short Transmission line model [1]

In Figure 1, since there are no shunt components,

$$I_s = I_R \tag{1}$$

$$V_R = V_s - I_R * (R + j\omega L) \tag{2}$$

Where V_s and V_R are the sending end and receiving end line to neutral voltages respectively while $I_s$and I_R are the sending end and receiving end currents respectively.

The induced voltage in the line is directly proportional to the current and will depend on the physical dimensions of the conductor. The value of this induced voltage per mile for a single conductor is given by;

$$E_i = 0.00466 * f * I * \mathrm{Log}_{10}\left(1.285^{\frac{d}{r}}\right) [1] \tag{3}$$

Where;$d =$ distance between conductors .;
$r =$ radius of the conductors$I =$ amplitude of the rms current;
$f =$ frequency in Hertz

Lines of length between 50 and 150 miles are classified as medium length transmission lines. A shunt capacitance is added to the short line model to create the model for the medium length lines. This extra element is needed due to the

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fact that an increase in line length increases the capacitance of the line and the effect of this capacitance on the system becomes significant. The line capacitance between two parallel cylindrical conductors expressed in microfarads per mile is given as;

$$C = \frac{0.0194}{Log_{10}\left(a+\sqrt{a^2-1}\right)} \text{ [1]} \qquad (4)$$

Where a is the distance between the conductors divided by the diameter of the conductor [1]. Typically, the shunt admittance is divided equally and place at either end of the line. This representation is as shown in figure2.0 and it is known as the nominal π equivalent circuit. By modelling the line in this manner, the receiving end voltages and currents can be obtained using the line's ABCD parameters from two port networks shown in figure 3.0

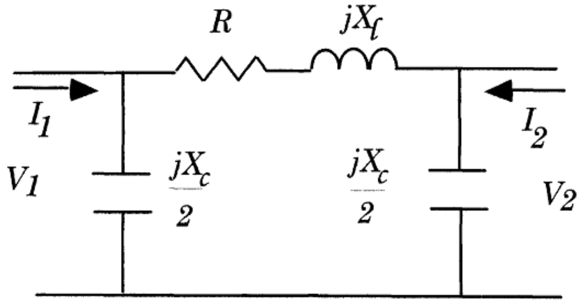

Fig. 2. Medium Length Transmission Line Models [1]

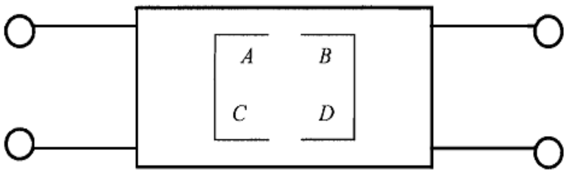

Fig.3. Two Port Networks and ABCD Parameters [1]

As transmission lines increase in length, the effect of the capacitance becomes more predominant. There is a sizable component of the total current which leads the voltage by $90°$, and the voltages induced by this current lag the phase current by $90°$ and produces the charging current. This reduces the necessary size of the sending voltage. The effect is most noticeable when the lines are subjected to very light loads. The long line model is similar to that of the medium line. The difference is that the long line is represented by distributed parameters instead of lumped parameters.

B. Corona Loss

An incomplete self-excited discharge concentrated around an electrode with a large curvature is called corona. For overhead lines, when the operating electric field intensity on the conductor surface of high-voltage power transmission lines exceeds the air breakdown strength, corona discharge takes place. Corona discharge increases the active power and electric energy losses of the lines, so the calculation result of corona losses of high-voltage power lines serves as one of the important bases to verify whether the conductor selection is economical and reasonable. This verification adopts not only the limit on the absolute value (kw/km) of annual average corona power loss per unit length, but also the comparison between the corona losses and resistance heat losses of the lines. In general corona losses should be smaller than 10% of resistance heat losses.

C. Transformer Losses

Transformer losses include main transformer losses and distribution transformer losses. Main transformer losses consist of two winding transformer losses and three winding transformer losses. In practice, the most effective way to reduce losses incurred in transmission network is through the use of transformers. If full load current is used to serve an area with modest load demands, the transmission losses would be extremely high. To prevent this from happening, the line voltage is stepped up by a large ratio, N while the line current is simultaneously stepped down by a factor 1/N. This makes it possible for the transmission line to carry large amount of power while greatly reducing the system losses. The process of varying the voltages and currents is done using transformers. Transformers do have losses of their own and the mechanism through which transformers exhibit these losses are through hysteresis,I^2R, and eddy current losses. While I^2R (copper) losses take place in the windings, hysteresis and eddy current losses take place in the core material.

Copper loss is expressed as;

$$P_{cu\ loss} = I_{rms}^2 R \qquad (5)$$

The core loss encountered in a transformer is expressed in terms of hysteresis and eddy currents [8]. These two have a net loss that can be approximated as varying linearly with frequency f and having a nonlinear dependence on the flux intensity B, of the core material [2].

$$P_{core\ loss} \propto f * B^{[1.6-2.0]} \qquad (6)$$

Hysteresis loss results from the unrecoverable energy expended to rotate the polarization of the core's magnetic material. The energy loss per unit cycle is expressed as the area enclosed by the hysteresis loop [8].

$$E = \oint d\,W_m = \oint H.dB \qquad (7)$$

The total hysteresis loss is the product of the area, core volume, and frequency. Eddy current loss is simply expressed as copper losses due to the currents induced in the magnetic material. Transformers consist of two or more windings that are coupled by a shared magnetic circuit or core which provides a path of low reluctance for common flux linkage. In order for the magnetic coupling of the windings to take place, the magnetic field must be created by one winding and linked by the other. The main component of the core which accomplishes the link is the magnetizing inductance which is modelled by a large inductor [3]. Unfortunately, all of the flux produced in one winding does not completely link the other winding and has a return path through the air. This effect of imperfect coupling is usually modelled as a small series inductor known as the leakage inductance. With a deep understanding of the interaction of magnetic and electric fields, equivalent circuit models can be designed to describe the phenomenon which takes place within a transmission line. An analysis of these models can quantify some of these losses within a transmission line which consist of 3 to 5 percent of the load. Depending on the level of accuracy desired and the length of the line, models of varying complexity may be used to describe the system. The use of transformers in the transmission system greatly reduces the I^2R losses but the transformer does bring some additional elements into the loss equation.

II. LITERATURE REVIEW

In 2019, [2] did a study on minimization of losses in power systems by reactive power dispatch using particle swarm optimization. In the study, it was asserted that the reduction of active power losses during the transmission of electric power was imperative for the economic and reliable operation of the power system and brought to the fore that the active power losses in transmission lines were dependent on resistance, leakage losses, and voltages. It also posited that since voltages were closely coupled to reactive power, active power losses could be minimized by the optimal control of generator voltages, synchronous capacitor voltages, transformer taps position, reactive power of shunt compensators etc. From this viewpoint, achieving optimal reduction of active (real) losses during power transmission was very imperative. In the study, reduction of active power losses through the optimal dispatch of reactive power and optimal control of voltages using particle swarm optimization (PSO) was proposed. Simulation of the study was implemented using MATLAB while MATPOWER was used to solve the load-flow. The process was validated using a 14-bus IEEE test power system whereby a loss reduction of 8.3% was achieved. During the study, it was confirmed that PSO could solve with great efficiency problems in which the objective function was complex. It was suggested that the proposed technique could be applied to problems such as reducing losses in national grid networks. PSO could also be used to solve problems such as reactive power planning as well as transmission network expansion planning.

In 2018, [3] did a study on network reconfiguration using modified particle swarm optimization algorithm. The study exhibited a successful strategy to ideally reconfigure a power distribution system which involved locating the ideal blend of switches which resulted in minimal power network losses in a distribution radial arrangement. Modified particle swarm optimization (MPSO) was used in the study. To determine the appropriateness of the suggested strategy, MPSO was compared with genetic algorithm (GA), ant colony optimization (ACO) and selective particle swarm optimization (SPSO) in reconfiguring a power distribution system under base loading conditions on an IEEE 30-bus radial network. It was shown that MPSO out performed GA, ACO, and SPSO in terms of significance of output and profile of voltage. In 2017, [5] did a study on multi-objective optimal reactive power dispatch for distribution systems. The study presented multi-objective differential evolution (MODE) algorithm for multi-objective optimal reactive power dispatch (RPD) for the minimization of real power loss, total voltage deviation, and total capacity of reactive power sources in a distribution system. They said in distribution systems integrated with distributed generation (DG), optimal reactive power dispatch could be achieved by controlling reactive power of the DG, FACTS devices, and other sources of reactive power.

The effectiveness of the proposed MODE algorithm was demonstrated for RPD in the standard IEEE 33-bus radial distribution system having distributed generators and reactive power sources. In 2017, [6] did a study on the optimal network reconfiguration in distribution systems for loss reduction and voltage profile improvement using hybrid algorithm of PSO and ACO. In the study, it was said that considering the time varying nature of loads in conventional distribution systems, network reconfiguration was a combinatorial complex optimization problem. In the study, a hybrid configuration of particle swarm optimization (PSO) method with ant colony optimization (ACO) algorithm called hybrid PSO-ACO algorithm was presented for optimal network reconfiguration in a distribution network in the presence of distributed generation (DG) resources. The objective of the study was minimizing power losses and improving the voltage profile. MATLAB-based simulation was conducted on a 33-bus IEEE test feeder to verify the effectiveness of the proposed technique. The results obtained demonstrated the accuracy and efficiency of PSO-ACO algorithm. In 2016, [6] did a study on distribution power loss minimization using particle swarm optimization and genetic algorithms. They said with growing renewable energy integration, the main structure of power systems was changing from large centralized generating plants connected to bulk transmission networks into decentralized systems with small generating systems connected directly to the distribution network near load buses in what is known as distributed generation (DG). The focus of the study was the application of particle swarm optimization (PSO) and genetic algorithm (GA) for the location of distributed generator placement and also for the minimization of power loss in the distribution network taking into account the integration of distributed renewable energy sources minimization of the active losses subject to several constraints was undertaken in the study. Also, enhancement of voltage stability by improving the voltage profile was also undertaken. In 2016, [7] did a study on reconfiguration of distribution system and application of ant colony optimization technique (ACOT) for loss minimization. The study presented network reconfiguration of a distribution system which was carried out by making changes in its topological structure with the help of switches. The switches were opened and closed such that the final network could be a radial network. The objective of the feeder reconfiguration considering distributed generation was to obtain the best arrangement of branches which represented an optimal distribution network with least power loss and enhanced power supply reliability.

The study was demonstrated using a test system of 33 buses. The simulation code was done in MATLAB for analysis. In 2015, [8] did a study on cost effective distributed generation placement using differential evolution for loss reduction in networked systems. They said the available practice of deploying distributed generation was in distribution systems which could be extended to transmission systems in order to obtain better performance such as maximum real power loss reduction, better voltage profile and so on. The performance improvement of the system was dependent not only on DG itself but also on proper rating and location of same. They said such placement was to be done from an economic point of view. The study proposed a new strategy of DG placement using fuzzy and differential evolution algorithm for optimizing an objective function which produces maximum cost savings, yet better loss reduction in transmission systems. The proposed methodology is verified on the IEEE 14-bus test system with encouraging results obtained.

In 2015, [9] did a study on the effect of constriction factor on minimization of transmission power loss using particle swarm optimization. In the study, transmission loss function was the problem objective while the specified bus voltage was the system constraint in formulating the problem. Newton-Raphson (NR) method and particle swarm optimization (PSO) technique was used to carry out the load-flow study and this was done on the IEEE-14 and IEEE-30 test bus system. On the basis of result for voltage and phase angle at each bus, PSO gave a more accurate result than the NR method. This was also the case for minimum transmission power loss calculation for line flows and losses. The effect of constriction factor on the rate of convergence was also investigated and the result plotted on a graph for both test systems. In 2015, [10] did a study on optimal reactive power flow control for minimization of active power losses using particle swarm optimization. In the study, they said the optimal reactive power flow (ORPF) was the principal focus of most electric energy companies and was considered the main aspect for proper operation of the power system. They said the solution to the ORPF problem aimed at optimizing a selected objective function such as minimization of losses through the optimal adjustment of power system control variables while at the same time satisfying various equality and inequality constraints. It is against this background that the principal focus of the study was the determination of the optimum operating conditions of the controlled variables within the constraints of controlled variables and minimization of transmission losses at normal operating conditions of the system. It was ascertained that the constraints for the objective function were the upper and lower values of voltages at load buses, the lower and upper values of generator reactive power, the normal operating values of transformer tap settings, and generator terminal voltages. Particle swarm optimization method was used to obtain the optimum operating conditions of the controlled variables and minimization of transmission losses. The 6-bus Ward-Hale and 30-bus IEEE system was used in the study.

In 2014, [11] did a study on impact of modified differential evolution strategy on reactive power dispatch problem. In the study they said the reactive power dispatch (RPD) problem was a nonlinear, mixed integer optimization problem in which real power losses and voltage deviations for a fixed economic dispatch could be minimized. The study proposed differential evolution (DE) to be used in finding a solution to problems of this type. They said classical DE sometimes suffered from the problems of slow convergence. In the study, a new modified DE was employed to settle RPD control variables. They said RPD optimized power system losses by controlling reactive power control variables such as generator voltages, transformer tap settings, and other sources of reactive power such as capacitor banks. Thus, improved voltage profile, system security, power transfer capability, and efficient system operation could be achieved. Simulation results based on the proposed method were compared with other evolutionary techniques reported in the literature. The results obtained proved the potential of the proposed approach and underscored its effectiveness and robustness in solving RPD problems. The IEEE 118-bus test system was used in the study. In 2014, [12] did a study on the economic load dispatch of thermal power plants using evolutionary techniques including transmission losses.

In the study, they said with increasing load demand and with large interconnections of various networks, it was essential to operate generating stations optimally within their constraints. The cost of generation was mainly consumed by the running cost of generation. Also, the major economic factor affecting power system planning, operation, and control was the cost of generating real power. The main focus of the study was the minimization of the cost of real power generation by optimal allocation of generating units to load demand subject to equality and inequality constraints. They said optimum generation scheduling played an important role in optimal operation of power systems. To obtain economic scheduling, lambda iterative approach using differential evolution programming was proposed. Economic dispatch was focused at the operating fuel cost while satisfying load demand and operational constraints. The study was carried out with the inclusion of transmission losses. The proposed method was tested with two sample systems by considering various load demands. The numerical results showed the performance and applicability of the proposed method. In 2013, [13] did a study on power system stability by reducing power losses using optimization techniques. In the study they said the optimization of reactive power had a considerable influence on secure and economic operation of power system. They said even though there was no production cost associated with reactive power, this imaginary power had a significant influence on transmission losses. In order to improve the voltage profile and minimize power losses, active and reactive power had to be controlled. From the foregoing, the study did a comparison between two optimization techniques such as particle swarm optimization (PSO) and modified particle swarm optimization (MPSO) and their application to minimizing power losses such as active and reactive power (objective functions) in order to reduce the voltage drop thereby improving the stability of the given power system. The study was done using the IEEE 3-bus and IEEE 6-bus power system and the superior techniques were presented. In 2013, [14] did a study on power system reactive power system optimization based on global differential evolution algorithm. They said reactive power optimization played an important role in the optimal operation of power systems and has a great influence on the security and economics of power systems. They said reactive power optimization was a large-scale, highly constrained, nonlinear optimization problem, whose task was the minimization of the transmission power loss while maintaining the load bus voltages within designated limits.

This could be achieved by changing transformer taps, adjusting generator terminal voltage, and connecting shunt capacitors. The study proposed global differential evolution (GDE) algorithm with a view to improving convergence speed and avoiding local optima. The study said experimental results showed that the GDE algorithm was effective in solving reactive power optimization problems and its optimization results better than other algorithms. In 2012, [15] did a study on a new attempt to optimize optimal power flow (OPF)-based transmission losses using genetic algorithm. The study presented a new method in finding the optimal solution of power flow transmission losses. They said the basic solution of the OPF was obtained when the objective function (production cost) was minimized satisfying a set of system operating constraints. For reactive power optimization, the OPF problem was formulated as minimization of system active power losses and improvement in voltage stability of the system. In the study, the solution of the optimal power flow was obtained for the IEEE 30-bus system using genetic algorithm (GA). The objective was minimization of transmission losses. The result obtained using GA were compared with those obtained using particle swarm optimization. In 2012, [16] did a study on the optimal location of unified power flow controller by differential evolution algorithm considering transmission loss reduction. The study presented a differential evolution algorithm for finding the optimal location and best parameter setting of a unified power flow controller (UPFC) for the minimization of active and reactive power losses in the power system. By re dispatching the power flows in power systems, the minimization of power losses could be obtained through the optimal allocation of UPFC. Simulation results were obtained for the IEEE 14-bus and 30-bus system. The proposed method was compared with particle swarm optimization. They concluded by saying that installing UPFC in the optimal location determined by differential evolution could significantly minimize the active and reactive power loss in the network.

In 2011, [17] did a study on an application of genetic algorithm (GA) and least squares support vector machine (LS-SVM) for tracing the transmission loss in deregulated power system. The study proposed a new technique for tracing the transmission loss in deregulated power system through the application of GA and LS-SVM. The idea was to use GA as an optimizer for determining the optimal values of hyper-parameters of LS-SVM and then through the adoption of a supervised learning approach, training of the LS-SVM model was carried out. Proportional sharing method (PSM) was used to trace the loss at each transmission line which is then used as a teacher in the proposed hybrid technique called GA-SVM method. Based on load profile as input, and PSM output for transmission loss allocation, the GA-SVM model was expected to learn which generators were responsible for transmission losses. The IEEE 14-bus model was used to validate the effectiveness of the proposed method.

In 2010, [18] did a study on genetic algorithm (GA) based transmission loss optimization under deregulated environment. In the study it was found out that transmission losses were roughly 3-5 percent of total power generation. This meant that loss allocation could significantly affect the competitive position of GENCOs in the power market. Moreso most of the participants in the electricity market hardly ever reflected transmission losses in their spot pricing due to the complicated aspects of loss allocation. It was further posited that transparent method for allocating transmission losses between interrelated parties in an equitable and fair manner was required. It was against this background that a systematic method for reactive loss optimization using GA and load flow analysis for deregulated transmission systems was proposed. They highlighted the fact that due to the nonlinear nature of power flow, tracing loss and power flow in a meshed network offered complications. In the study, loss optimization using equivalent power flow model was treated as a fitness function where conventional power balance equation was considered as a constraint. Furthermore, accuracy of the method was improved using ac load flow by changing the tap position of the existing transformer in the system. The proposed methodology was used to depict the information related to the optimization status of total system loss with or without the installation of external devices to minimize the investment cost in a deregulated market. The IEEE 30 bus system was used validate the effectiveness of the method. In 2009, [19] did a study on transmission loss and load flow allocations via genetic algorithm technique. In the study it was that said transmission loss and load flow allocations were important issues to be considered in a deregulated electricity market. Due to the nonlinear nature of electric power flow, tracing the loss and power flow in a meshed electricity network was a complicated endeavour. Due to the complexity of the electrical power network, determining the contribution of a particular generator to a particular line loss and/or load loss was not a straightforward affair. The study then discussed load flow and loss allocation using genetic algorithm (GA) technique. They highlighted the fact that GA was an optimization method that applied natural phenomena such as genetic inheritance and Darwinian strife for survival to solve optimization problems such as transmission loss and load flow allocation. In the study, Ward-Hale 6-bus test system was used to demonstrate the effectiveness of the technique and validated using the IEEE 30-bus system. Comparisons with other techniques were also given. In 2009, [20] did a study on differential evolution particle swarm optimization algorithm for reduction of network loss and voltage instability.

The highlighted the fact that to solve the reactive power dispatch (RPD) problem, several techniques had been proposed such as gradient method, nonlinear programming, quadratic programming, linear programming, and interior point method. They said even though these techniques had been successfully used to solve the RPD problem, some difficulties were still associated with these techniques. One of these difficulties was the multi-modal nature of the problem to be handled. Also due to the non-derivative, nonlinear, and non-convex nature of the problem, majority of the techniques usually converged to a local optimum. It was against the foregoing background that the study introduced a differential evolution particle swarm optimization method for dealing with optimal reactive power dispatch focused at power loss reduction and voltage stability improvement. They said the optimal RPD of power systems sought to allocate reactive power control variables so that the objective function composed of power losses is minimized and the prescribed voltage limits are satisfied. The proposed method determined the optimum settings of reactive power control variables such as generator excitation, tap changing transformers, and shunt compensation that reduces power losses while maintaining the voltage stability. IEEE 30-bus system was used in the study. Numerical results showed that the proposed method was superior to other methods reported in the literature. In 2009, [21] did a study on minimization of voltage deviations, power losses, and control actions in a transmission power system. In the study they said the philosophy behind minimizing economic losses and maximizing the quality of delivered power had greatly influenced the strategies for the operation of power transmission network in recent times. They said security and economic consideration dictated that it was important to develop better control algorithms for operating the power system particularly close to loading limits. They said the control of voltage levels was one of those algorithms that had been developed and required further improvement in order to guarantee a secure and profitable use of the network. In essence they said that control of voltage levels was accomplished through the control of production, absorption, and flow of reactive power at all levels of the system.

The highlighted the devices used for this purpose which included series and shunt capacitors, shunt reactors, synchronous generators, tap changing transformer etc. They said the goal of a voltage control algorithm was to guarantee that voltage levels at all buses were within acceptable limits and also ensure reduction in the I^2R and I^2X losses. From foregoing, a multi-objective genetic algorithm based on NSGA ii was implemented to find an optimal condition of minimum voltage deviation, minimum power losses, and minimum number of control actions of a transmission network system. Generators and transformers with off-nominal tap ratio were the devices to be controlled. Different probabilities of mutation factors were compared where it was proved that a more important mutation factor could improve the velocity of convergence without getting into a random search. The algorithm was compared with other published results and a successful performance of the implemented algorithm was proved. The IEEE 30-bus system was used in the study. In 2008, [22] did a study on optimum reactive power dispatch using differential evolution (DE) for improvement of voltage stability. In the study, a differential evolution (DE)-based approach for solving optimal reactive power dispatch for voltage stability enhancement was presented. The monitoring methodology for voltage stability was based on the L-index of load buses. The objective was to minimize the sum of squares of the L-indices subject to limits on generator real and reactive power outputs, bus voltages, transformer taps, and shunt power control devices such as static var compensators (SVCs). The proposed algorithm was applied to the IEEE 30-bus system to find the optimal settings of reactive power control variables. The optimal reactive power dispatch results obtained using DE were compared for the cases with and without flexible AC transmission systems (FACTS) devices such as the static synchronous series compensator (SSSC).In 2008, [23] did a study on swarm intelligence and evolutionary approaches for reactive power and voltage control.

The study presented a comparison of swarm intelligence and evolutionary techniques based on approaches for minimization of system losses and improvement of voltage profile in a power network. They said efficient distribution of reactive power in an electric network could be achieved by adjusting the excitation of generators, the on-load tap changer positions on transformers, and proper switching of discrete portions of inductors and capacitors. This being a mixed integer non-linear optimization problem, Meta heuristic techniques could be used for obtaining a solution. To this end, four algorithms were used namely differential evolution (DE), particle swarm optimization (PSO), a hybrid combination of DE and a mutated PSO (MPSO). The effectiveness of these algorithms was evaluated based on their solution quality and convergence characteristics. Simulation studies on the Nigeria power system showed that PSO based solution was more effective than DE approach in reducing real power losses while keeping the voltage profile within acceptable limits. The results further showed that MPSO allowed for a further reduction of the real power losses while maintaining a satisfactory voltage profile.In 2007, [24] did a study on differential evolution approach for reactive power optimization of Nigerian grid system. In the study, they highlighted the fact that one of the principal tasks of a system operator was to ensure that parameters of a power system network such as voltage and line loads were kept within predefined limits so as to ensure high quality of service to the consumers and power system stability. It was ascertained that changes in the network topology and/or loading conditions often caused corresponding variations in voltage profiles of the system and that these problems could be addressed through rearrangement of reactive power sources with associated decreases in transmission losses. The focus of the reactive power dispatch has two aims; Improvement of system voltage profile and the minimization of system losses at all times. It was further investigated that reactive power flow could be controlled by suitably adjusting the following facilities; tap changing under load transformers, generating units reactive power capability, variation, switching of inductors, switching of unloaded/unused lines, and switching of flexible ac transmission systems (FACTS). Clearly, the reactive power and voltage control is a constrained, mixed integer, nonlinear problem of considerable complexity. It was against this background that differential evolution (DE) was applied to solve this type of problem. They said DE appeared to ally qualities of established computational intelligence with a more striking computational performance, thus suggesting the possibility of on-line applications in the control centre.

At the end of the study, DE achieved a considerable reduction of real power losses while simultaneously keeping the voltage profile within acceptable limits. In 2007, [25] did a study on implementation of new evolutionary techniques for transmission loss reduction. In the study, they described the optimal power flow as a static, nonlinear program which had the goal of scheduling the controls of a power system in such a manner that certain objective functions like real power loss was optimized with certain constraints enforced on the solution. The perspectives that had been used in solving the OPF problem were studying the effects of load increase or decrease on voltage stability or power flow solvability, generation rescheduling to minimize the cost of power generation, and controls such as taps, shunts, and other modern VAR sources adjustment to minimize real power losses in the system. They highlighted the fact that the main disadvantage with the classical approach to OPF solution laid in the fact OPF was highly sensitive to starting points as a result of non-monotonic solution surface. They said this type of problem could be solved using evolutionary techniques. It is from this view point that a comparison between bacteria foraging algorithm (BFA), conventional genetic algorithm (CGA), and differential genetic algorithm (DGA) with regard to transmission loss minimization considering the New-England 39-bus power system as a test case was made. With all the standard equality and inequality taken into consideration, solutions which minimized losses by changing the tap settings of various transformers were obtained. They said from previous literature, there were certain buses in the system where reactive power injection from capacitor banks could improve the voltage profile and reduce transmission losses. In the study, BFA with some modification so as to fasten the convergence of the optimization problem was employed. Comparison between the three methods suggested the superiority of the BFA. In 2007, [26] did a study on Ant Colony Optimization based technique for voltage control and loss minimization using transformer tap setting.

In the study they said in power systems, transmission losses were a major factor to consider when it was necessary to transmit electric power over long distances or in the case of relatively low load over a vast area. They said active power losses accounted for 20% to 30% of total generational losses. Losses included line and cable losses, transformer losses, and machine losses. It was against this background that they said continuous demand in power transmission networks caused by reactive had been highlighted as the main factor in voltage depreciation and increase in total transmission loss. The study presented a new approach using ant colony optimization technique to determine the optimal values of transformer tap setting for voltage control and loss minimization in power systems. The focus of the study was to search for a solution made up of the best possible combinations of transformer tap setting that would improve the voltage and reduce power losses in the power system. The study was conducted using the IEEE 30-bus system and the results revealed that the proposed technique had the possibility of achieving optimal solutions in addressing the problem. In 2007, [27] did a study on the comparative application of differential evolution and particle swarm techniques to reactive power and voltage control. The study presented a comparative application of two Meta heuristic approaches namely differential evolution (DE) and particle swarm optimization (PSO) to the solution of the reactive power and voltage control problem. They said effective distribution of reactive power in an electric network led to the minimization of the system losses and improvement of the system voltage profile. This, they said could be achieved by varying the excitation of generators, tap-changing positions of on-load tap changing transformers, as well as by switching discrete portions of inductors or capacitors. They said this was a mixed integer, nonlinear optimization problem which could be solved using Meta heuristic techniques. The feasibility, effectiveness, and generic nature of DE and PSO investigated were demonstrated on the Nigerian Grid System and the New England Power System. Comparisons were made between the two approaches in terms of solution quality and convergence characteristics.

The simulation results indicate that both approaches were able to remove the voltage limit violations even though in some instances, PSO procured a slightly higher power loss reduction as compared with DE. In 2005, [28] did a study on distribution network reconfiguration for loss reduction using ant colony system algorithm. In the study, they said network reconfiguration in distribution systems was a very important way to save energy. Although due to its nature it was inherently a difficult optimization problem. In the study, distribution system reconfiguration for loss reduction was being applied in which the behaviour of real ants was developed into a series of steps which found the most efficient network reconfiguration. Ants of an artificial colony were able to search for successively shorter feasible routes by using information accumulated in the form of a pheromone trail deposited on the edges of their travelling paths. In the study, a conventional distribution system load flow algorithm was used to check the constraints. Power flow constraints, voltage deviation, and the power transferred through the lines were to be met. A 14-bus system with three feeders, 19 branches, and 11 load centres was used as a case study. The results obtained gave an optimal network. In 1999, [29] did a study on optimal phase arrangement of distribution transformers connected to a primary feeder for system unbalance improvement and loss reduction using a genetic algorithm. The study presented an effective approach in optimizing the phase arrangement of distribution transformers connected to a primary feeder and system unbalance improvement and loss reduction. This being a multi-objective optimization problem for a radial-type distribution feeder, a genetic algorithm (GA) based approach was proposed to find a solution. They said the major objective for this problem were balancing the phase loads of a specific feeder, improving the phase voltage imbalance and voltage drop, reducing the neutral current of the main transformer feeding the feeder, and minimizing the system power losses. Also considered were the type and connection of distribution transformer banks as well as their connected loads. The corresponding load patterns for every load type were also taken into account. On the basis of the proposed GA-based approach, an application program was developed to perform the optimal phase arrangement problem. Numerical results of an actual distribution feeder with 28 load tap-off points validated the proposed approach. The confirmation was done using computer simulations. In 1999, [30] did a study on a genetic algorithm (GA) based approach for improvement in voltage profile and real power loss minimization.

In the study, the problem was defined as minimizing real power losses by controlling generator terminal voltages, transformer tap positions, and reactors and capacitors as switchable reactive power sources. Penalty functions were used in the problem formulation which included constraints such as voltage limits and generator reactive power limits. They said one disadvantage of the conventional GA was that it could be time intensive. Because of this micro GA was proposed as a more time efficient alternative. The feasibility and effectiveness of both approaches applied to the problem of reactive power control and voltage profile correction was verified on a 110/25/10 KV municipal power system, represented on an operator training simulator in all physical and operational details. In 1999, [31] did a study on on-line combined use of neural networks and genetic algorithms to the solution of transformer iron loss reduction problem. In the study a new approach using neural networks and genetic algorithms to solve the transformer iron loss reduction problem was proposed. They said neural networks were used to predict iron losses of wound core distribution transformers at the early stages of transformer construction. Also, genetic algorithms combined with neural networks were used to improve the grouping process of the individual cores by reducing the iron losses of assembled transformers. Results from the application of the proposed technique on a transformer industry demonstrate the feasibility and practicability of the proposed research. In 1993, [32] did a study on distribution systems copper and iron loss minimization using genetic algorithm (GA). In the study, GA was used to minimize distribution system losses including power transformer iron loss. They said transformer iron loss was approximately proportional to the square of a transformer’s primary voltage. Therefore, the minimization of the sum of transformer iron loss and line resistive loss by adjusting line voltages and line currents appropriately could be carried out. The problem was formulated as a complex, combinatorial optimization problem whose solution was obtained using GA. Several numerical examples were used to validate the proposed method.

III. WAYS OF OPTIMIZING POWER SYSTEM LOSSES

Power losses can be optimized using intelligent techniques for overall improvement in network strength and effective economic operations in terms of reliability and availability through either the conventional or intelligent techniques. These losses could either be active or reactive and could be optimized by controlling voltages of the generator, series and shunt synchronous capacitors, transformers tap changing, optimal dispatch and control of voltage as well as active and reactive power conventionally or through any of the Artificial Intelligent Techniques(AIT) as reviewed in the literature of this paper. These approach when applied to power system network could reduce losses to as low as 5%.The benefits of AIT is that no matter how complex the mathematical modeling of the system is, it can be handled very easily and gives very accurate results with better efficiencies. It is because it is an optimization process it will involve setting up and objective function with the system constraints. Various AIT applications to power system losses reviewed in this work include the following: PSO, DEPSO, MPSO, SPSO, ACO, ANN, GA, MGA, MODE, Hybrid PSO-ACO, DE, GDE, LS-SVM, DGA, CGA, BFA, Combined GA and ANN. With the concept of AIT, power system network can be reconfigured to either improve voltage profile, power system stability, protection, reliability, voltage transfer capacity etc. Modern devices have also been employed in optimizing power system losses. These include FACTS and custom power devices whose principle of operation is based on power electronics. FACTS devices finds vast application in transmission and distribution network while custom power devices are applied majorly in distribution network. These devices include static compensator (STATCOM), thyristors controlled series compensator (TCSC), static var compensators (svar), static synchronous series compensators (SSSC) unified power flow controller (UPFC), interline power flow controller (IPFC), dynamic static compensator (D-STATCOM) etc. it should be noted that loss effective power system network results in financial savings for the power company via reduction in technical and non-technical losses.

IV. CONCLUSION

This work reviewed power system losses in various sections of the power network using both the conventional power system devices and equipment such as synchronous capacitors/condensers, transformers tap changing settings, generator voltage control. FACTS as well as custom power devices whose principle of operations and functionality is based on power electronics which has also found vast applications for the reduction of power system losses was also considered optimization, comparative studies on various artificial intelligent techniques with respect to their applications to power system studies were also reviewed with the best optimal solution while formulating their objective functions with the necessary constraint variables.

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