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Optimization of Power Losses in Transmission Lines Using Metaheuristic Methods

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***Abstract-** Flexible AC Transmission System (FACTS) are being approached to improve the performance of transmission and interconnection networks. Numerous studies have been made recently on these systems concerning the increase of the speed of control of the parameters of the lines (voltage, impedance and phase shift). Shunt and series offsets using power electronics systems are FACTS concepts and allow the networks to be more flexible. This paper presents an overview of power loss optimization along with the use of metaheuristic methods used to minimize the power loss.*

***Keywords-** FACTS, Metaheuristic, Methods, STATCOM, TCSCM, etc.*

I –INTRODUCTION

The consumption of electrical energy is gradually increasing and this trend will continue in the future. In addition, we live in the era of electronics and computing and all electronic loads are very sensitive to fluctuations in its diet. A loss of power of duration of a cycle is sufficient to generate enormous losses. It can even cause the interruption of the different production processes. If this period is longer, some consumers will be forced to introduce their own energy sources and there are many examples. Just think of hospitals.

We became dependent on electrical energy; consumers are becoming more demanding and at the same time they are more vulnerable. They want more electric power and better quality. To ensure quality, standards are imposed and well defined. The most important are related to voltage and frequency [1]

Production plants are often far away from places of consumption. The load varies according to the season and the day part and with it the tension also varies. Long lines, lightly charged, have an overvoltage problem, but if they are overloaded the voltage tends to drop below the acceptable limit. So you have to control the voltage and stabilize it. On the other hand, the charging behavior does not facilitate this task. Most loads tend to introduce the phase shift between voltage and current, and this phase shift prevents the transport of the active power that is essential for its operation [2].

This energy is transported on conductors such as overhead lines and underground cables. For the electrical energy to be usable, the transmission and distribution network must meet the following requirements:

- Provide the customer with the power he needs.
- Provide a stable voltage whose variations do not exceed 10% of the nominal voltage,
- Provide a stable frequency whose variations do not exceed 0.5%,

- Provide energy at an acceptable price,
- Maintain safety standards,
- Please protect the environment.

The alternating current has several disadvantages of the "total power". One of them is the need for a reactive power that must be provided with the active power, so the optimization of the active power alone is not sufficient. Although it contributes to the energy consumed or transmitted, reactive power is an inherent part of all components of the system: generation, transmission, distribution, and possibly charges. Poor reactive power management increases losses; hence an increase in production costs.

So the problem of reactive energy compensation of electrical systems is to be presented as one of the main concerns of the companies producing and distributing electrical energy.

The management of a network of production, distribution or storage of energy has become an economic as well as technical issue, having to respect climatic and economic constraints. It therefore appears necessary to optimize this management in order to maximize the operating profit of the network while respecting the constraints imposed the power distribution allows:

- The balance between production and demand for electrical energy; so as not to exceed the limit values of the thermal stability, in order to avoid deterioration of certain elements of the network or the risks of hazards on the lines (cuts, short circuits, loaded lines, etc.).
- Maintenance of bus bar voltages between the tolerated limits $V_{Min} < V < V_{Max}$, to avoid excess power losses in the lines, transformers.
- The control of the reactive power, i.e. the maintenance of the reactive power between two limits $Q_{Min} < Q < Q_{Max}$, to avoid excess of the costs of using the reactive power.
- The interconnection between the power stations and the networks, which aims to increase the safety of the power supply to users, i.e. if one of the power stations fails, a new load distribution is provided by the other interconnections. Interconnection also improves the quality of power supplied in terms of voltage, frequency and also to establish a wide reserve capacity and make the network more flexible.
- Avoiding defects on the networks, i.e. the risks of overloading lines, transformers, and the risks of short circuit.
- Network planning to meet user demands in the future.

In view of all these requirements, the industrial and scientific worlds were faced with recent problems called "optimization of electrical networks" to ensure continuity of service with reduced production, transport and distribution costs, while remaining within the limits of various climatic, economic constraints, etc.

The fast development of the population and also the production are primary factors for electrical energy consumption which is then again ceaselessly expanding. Subsequently the storage of electrical energy is a tedious task, so it needs an enduring steadiness between production and consumption for that it is at first sight important to build the quantity of power stations, and of the different structures such as transmission lines, transformers, etc. This prompts an expansion in cost and a debasement of the natural environment [3]. When the network is disturbed (Short circuit, loss of a load or a group, opening of a line, etc.), the difference between the mechanical and electrical powers leads to an acceleration or deceleration which may lead to the loss of synchronism of one or more generation groups. The rotor angles oscillate until the adjustment systems protection in order to restore the march in synchronism and lead the network to a state of stable operation.

However, the demand for electricity varies constantly over the course of a schedules, weather conditions, other criteria are also taken into account such as holiday periods, holidays, weekends, holidays and events that (strikes, sporting events, etc.). For this purpose the design of the electrical system has been made in such a way that an entire inseparable chain is integrated beginning with: production, transport and distribution to consumers. One cannot store large quantities of energy in electrical form, it is the problem is forced to produce the same quantity of electricity that must be consumed; we also know that the production groups have certain technical limitations which must not be exceeded which leads us to another problem too complicated one can translate it mathematically a non-linear problem [4].

Therefore, the economic distribution of electric power produced by power stations at particular marginal cost; has become the object of research and studies over the years. This process has been under study since 1928 due to its great importance in electric power; the numerous publications on this subject are clear proof. Several methods and algorithms have been adopted to solve this issue achieving better results. Early research has neglected losses in lines subsequently several improvements of the original proposal have been

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developed by introducing the losses as well as the operating limits of the production groups.

The optimization of the reactive energy compensation is to be understood as the choice of the powers of the capacitor banks, their locations and even the time during which they will remain in line if it is an adaptive compensation. Of course, these choices must be made so that there is the least power loss in line and an improvement in the voltage profile while having a positive economic return. The choices of the objective function are dictated by the concern to take into account both the electrical and economic aspects of the problem.

1. CHARACTERIZATION OF POWER LOSSES AND POWER IN DISTRIBUTION SYSTEMS

The energy and power losses are due to the conditions of the facilities. In general, two types of losses stand out:

- Ohmic Losses or Copper Losses: They are caused by the circulation of electric current through the circuits. Its magnitude then depends on the characteristics of the networks and the burden to which they are required. They are also called load losses.
- Vacuum losses: These are caused by the circulation of magnetization currents in the iron cores of transformers and other equipment in the network. Also included in this category are losses from stray currents in line insulators and by corona effect. The latter are manifested primarily in transmission networks. In distribution they are insignificant. Unlike load losses, vacuum losses appear whenever the circuits are energized, regardless of the level of load or power flow circulation through them.

The characterization and identification of the different types of losses in distribution networks is not easy. It is very difficult to be able to do it through measurements, and in general it is not a task that companies usually do. The Electric Power Research Institute (EPRI) of the United States carried out a very thorough research program during the years 2008 to 2011, where a large number of feeders of different companies and of varied physical and operational characteristics were analyzed, for the purposes to discriminate the different types of losses and their relative weight in the total losses.

II - LITERATURE REVIEW

In recent decades, a number of methods have been developed to resolve the issue of power flow in distribution networks. Since it is not possible to give all the work carried out in this direction, it will be sufficient to describe some of them only.

Hussain et al. (2014) presented an effective approach to overcome the issue of optimal placement of FACTS device. This approach instantaneously minimize the voltage deviation at load buses and the real power loss in transmission lines and, by optimal location and tuning parameters of FACTS. This paper considered DSTATCOM as the FACTS device and the voltage magnitude is kept 1 p.u. to find the size of DSTATCOM [5].

Taher et al. (2012) presented an immune algorithm (IA) based technique for the optimal placement of DSTATCOM FACTS device in power system. The primary objective of this paper is to reduce the installation cost of the DSTATCOM utilizing the production cost function in active and reactive scenario [6].

Duong et al. (2014) presented a technique utilizing the minimum cut approach for the optimal location of FACTS device to increase the security of power system. This paper considered TCSC as the FACTS device. Additionally, this paper uses Kirchhoff's current law for the complexity reduction of placement equations. In this approach the search scope is restricted therefore the device placement is optimized due to reduction of branches which require in investigation [7].

Bhattacharyya et al. (2014) presented an artificial intelligence based method to optimize the location and parameter settings of FACTS devices to increase the security of power system. Initially the minimization of line overload and bus voltage is executed. Furthermore, a comparative analysis of differential evolution (DE), genetic algorithm, and fuzzy logic based methods is used for the optimal location of FACTS devices. A comparative analysis is also presented among the particle swarm optimization, genetic algorithm, and differential evolution out of which the DE method outperforms other methods. A novel method is used for the detection of weak node using fuzzy membership function [8].

Esmaili et al. (2014) presented a congestion management based optimization of cost generation, active power transmission loss of FACTS devices in a multi-objective power system. This paper considered TCPS and TCSC as the FACTS devices and the proposed design is simulated on the IEEE-30 and IEEE-57 bus systems [9]. This prompts an efficient and vigorous working point where enough levels of voltage and transient security are incorporated [9].

Devi et al. (2014) presented an enhancement technique of power quality using the optimal location of Distributed-SSSC for reduction of generation cost and transmission losses in the power system. This approach instantaneously minimize the voltage deviation at load buses and the real power loss in transmission lines and, by optimal location and tuning parameters of FACTS [10].

Hooshmand et al. (2015) presented a cost free technique to get rid of congestion. Out of the different cost free techniques, utilization of FACTS devices strategy is deliberated. This paper presented a technique of optimal location of TCSC device with cost function minimization and penalty cost of emission. To accomplish this, the optimal power flow issue is resolved using the reduction of fuel cost of generators with the bacterial foraging (BF) algorithm [11].

Kumar et al. (2015) presented an Artificial Bees Colony (ABC) algorithm based technique of power quality enhancement using the optimal location and sizing of UPFC for reduction of generation cost and transmission losses in the power system. This approach instantaneously minimize the voltage deviation at load buses and the real power loss in transmission lines and, by optimal location and tuning parameters of FACTS [12]

A.R. Jordehi (2015) reviewed the PSO based techniques for the optimal location of FACTS devices. This paper also details about the generalized parameter selection for PSO algorithm for discrete variable handling, constraint handling and multi-objective handling scenarios [13].

Naganathan et al. (2016) presented an effective method to overcome the issue of optimal placement of FACTS device. BAT and PSO algorithms are used to find the optimal location for UPFC and STATCOM. This approach instantaneously minimize the voltage deviation at load buses and the real power loss in transmission lines and, by optimal location and tuning parameters of FACTS. Simulation results shows 18%-60% reduction of power loss [14].

A.R. Jordehi (2016) presented a new technique to resolve the issue of FACTS device allocation using ICA due to its strong abilities to decrease the voltage deviation and overloads. This paper considered TCPS and TCSC as the FACTS devices. A comparative analysis is also presented by which it can be observed that the proposed ICA based approach outperforms other approaches (ABC, GSA, EP, BSO, NLP, PS, ARO and BSA) [15].

Ziaee et al. (2017) presented an approach for the optimal location of line switches and TCSC device utilizing the stochastic mathematical algorithm. Simulations are implemented on IEEE 118 bus test system. It was found that the energy cost is reduced with the operation for combination of switches and TCSCs as compared to the individual usage of either TCSC or switch [16].

Ziaee et al. (2017) presented a decomposition algorithm based approach for sizing and placement of FACTS controller. This paper used TCSC as the FACTS device. Simulations are implemented on IEEE 118 bus test system with certain parameters such as; nonlinear cost, AC characteristic and load uncertainty [17].

Rao et al. (2017) presented a research paper utilizing the Newton Raphson power flow method for the optimal location of FACTS devices. They used STATCOM as the FACTS device. This paper contains two different algorithms for minimized search space in order to decrease the standard deviation and the nodal cost of the objective function. To accomplish this, an N-R power flow model is utilized for STATCOM, which utilizes the power losses of converter [18].

I. POWER LOSS OPTIMIZATION AND METAHEURISTIC METHODS

A. Introduction

Optimization is a branch of mathematics, seeking to analyze and solve analytically or numerically the problems of determining the best element of a set in the sense of a given quantitative criterion. This word comes from the Latin optimum which means the best.

The problems of optimization in electrical engineering present several difficulties related to the needs of the user (search for a global solution, reliability and precision of the solution, diversity of problems treated, reasonable calculation time, etc.) "Optimization (nonlinearity, derivatives difficult to access, etc.) and at the time of important computations. The solution of such difficulties has been the subject of numerous studies using various optimization methods. Deterministic methods rely on the calculation of a direction of research generally related to the derivation of the results with respect to the design parameters of the device. They are really only usable in the restricted case where the solution sought is considered to be close to a known solution, the starting point of this research. To overcome this difficulty, the researchers have chosen to be interested in the development of stochastic methods and to study their application to the design problems encountered in electrotechnology.

Stochastic optimization methods rely on probabilistic and random transition mechanisms. This trademark shows that few progressive executions of these strategies

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can prompt diverse outcomes for a similar introductory arrangement of an optimization issue [19].

In this chapter, we focus on the definition and the principle and the algorithm of the most metaheuristic optimization methods in the field of electro-technology and more particularly the method known as the firefly algorithm in English, where all our optimization work will be carried out based on this metaheuristic optimization algorithm.

B. Design Methodology

Optimization is often reduced to the mathematical resolution techniques to which are later attributed the failures encountered. As with most of the problems to be solved, optimization must be the subject of a systematic approach consisting of four phases summarized in Figure 1. The phases can be sequenced sequentially, but iterations and returns are often indispensable.

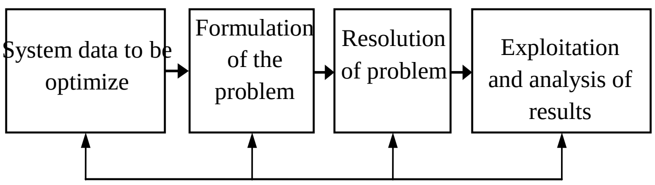

Fig 1- Steps to solve an optimization problem

1. Formulation of the Optimization Problem

The formulation of the optimization problem is fundamental in the design process because it determines the success of the next steps. It is not easy to approach because the choice of design variables is never unique and the current calculation means can manage only a limited number of them.

The design problem, described by the specifications, must be formulated into an equivalent mathematical problem. This is the most delicate step in the design process because, again, the formulation of a problem is never unique, in particular the definition of the functions characterizing the performance of the system.

It consists in precisely defining [19]:

- The objective function.
- Design parameters.
- Any constraints related to the manufacture or use of the device expressed in the specifications.
- Constraints added by the designer.

Objective Function: The objective function is one of the responses of the object that defines the objective to be attained and can be of two kinds: a cost to be minimized (cost of manufacture, consumption, operating cost, duration of development) or performance to maximize (profit, result, and transmission factor). Its choice determines the definition of the optimization problem and includes the means which allow it to be calculated, that is to say the modeling adopted for the object.

In the case of a single objective, the choice of this function is obvious. For example, if the goal is to find the characteristics of a performance-producing device whose values are specified, the objective function may take as an expression the discrepancy between performance and specifications. However, optimization problems often have to satisfy multiple objectives, some of which are competing.

Design Parameters: Parameters or design variables are controlled factors that influence performance. They can be of various natures: geometric dimensions, properties of materials, structural choices, etc. They may be quantitative or qualitative, continuous or discrete. The choice and the number of the parameters also determine the definition of the optimization problem. It may be interesting to vary a large number of factors in order to increase the search space, but the optimization process will then take longer.

Constraints can be added by the designer to have, for example, a suitable geometrical shape, to ensure the validity of the modeling retained and its proper functioning, etc.

C. Optimization Methods

1. Continuous Optimization

Continuous optimization is done by two methods, the first linear and the second nonlinear.

- Linear optimization in integers studies linear optimization problems in which a particular or all variables are controlled to get integer values.
- Nonlinear optimization delivers the normal case in which the objective or constraints (or both) contain non-linear, possibly non-convex, parts.

2. Combinatorial Optimization

Combinatorial optimization consists in finding the best solution between a finite number of choices. In other words, to minimize a function, with or without constraints, on a finite set of possibilities. When the number of possible combinations becomes exponential with respect to the size of the problem, the computation time becomes rapidly critical.

A generalized problem of optimization is solved if it consists in finding a solution $s \in X$ optimizing the value of the cost function f.

Formally, we thus seek $s^* \in X$ such that $f(s^*) \leq f(s)$ for all s∈</s>

Such a solution s^* is called an optimal solution, or a global optimum.

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D. **Heuristics and Metaheuristics**

A heuristic method (from the Greek verb heuriskein, which means "to find") helps guide the process in its search for optimal solutions [20].

In 2006, Metaheuristics (metaheuristics.org) defined metaheuristics as "A set of thoughts utilized to describe heuristic approaches that can be used to a wide variety of problems. We can see metaheuristic as an algorithmic "toolbox", usable to solve various problems of optimization, and requiring little modification so that it can adapt to a particular problem ".

Metaheuristics are a set of optimization algorithms aimed at solving difficult optimization problems. They are often inspired by natural systems, whether they are taken in physics (simulated annealing), evolutionary biology (in the case of genetic algorithms) or in ethology (case of ant colonization algorithms, jumps frogs, fireflies, or particle swarm optimization).

The principle of metaheuristics is to minimize or maximize an objective function. Their advantage is to find a global minimum for a minimization problem and not to remain stuck on a local minimum [21].

The metaheuristic methods are thus solutions-based methods: at each iteration, they manipulate a set of solutions in parallel [22] and apply the same search pattern several times during the optimization. These methods are also considered as global optimization methods: they aim at determining the overall optimum of the objective function of the problem, avoiding "trapping" in one of its local optima, or by accepting a degradation of the objective function along their progression according to the information collected during the exploration, or by using a population of points as a research method, the idea being always to "escape" from a local minimum, have a better chance of finding the optimal. Guided local search is an example of metaheuristic which modifies the objective function [19].

They thus overcome the disadvantage of classical methods and heuristic methods by driving research towards the global optimum. Moreover, like heuristics, metaheuristics generally do not offer a guarantee of optimality, although it has been possible to demonstrate the convergence of some of them. Non-deterministic, it often incorporates a stochastic principle to overcome the combinatorial explosion. It sometimes uses the accumulated experience during the search for the optimum to better guide the rest of the research process. They thus make it possible to explore and exploit the research space more effectively.

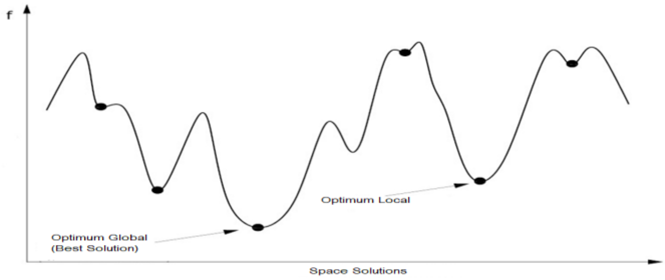

Fig 2-Local minimum and global minimum

In Figure 3, metaheuristics (MH) try to find the optimum global (OG) of a difficult optimization problem (f(x)) (with discontinuities (DC), for example) without being trapped by local optima (LO) [23].

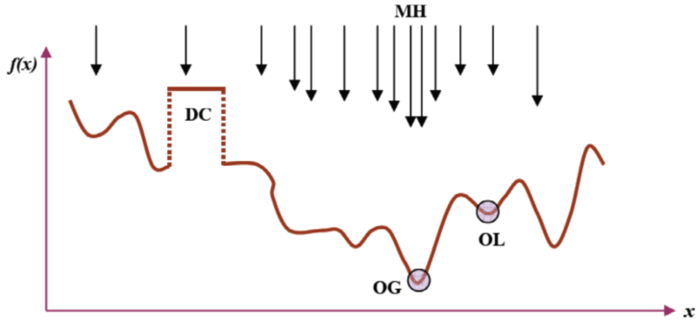

Fig 3- Simplified representation of a metaheuristic approach [23]

1. Concept of Neighborhood

Several metaheuristics use the notion of neighborhood. Recall that the optimization problem consists in finding a solution x* which minimizes an objective function f on the space of the solutions S. The different local search algorithms are distinguished essentially by the way of constructing or generating the neighborhood and also by the solution way of choosing a solution in the neighborhood of the current solution x. The neighborhood of a solution is a subset of solutions that can be achieved by a series of given transformations. We can thus define the neighborhood as follows [21]:

$$N(x) = y \in S : dist\ (x, y) \leq \varepsilon \quad (1)$$

2. Framework of Metaheuristics

The entry of metaheuristics marks a compromise of the two areas: they apply to a wide range of discrete problems, and they can likewise adjust to continuous problems. Likewise, these techniques share the accompanying qualities [21]:

- They are, at least in part, stochastic: this approach makes it possible to face the combinatorial explosion of possibilities.
- Often discrete origin (with the notable exception of PSO), they have the advantage, decisive in the continuous case, of being direct,

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that is to say that they do not resort to the calculation, often problematic, gradients of the objective function.

- They are inspired by analogies: with physics (simulated annealing), with biology (genetic algorithms) or with ethology (colonies of ants, frogs jumping, artificial bee colony, fireflies)
- They share the same disadvantages: the difficulties of adjusting the parameters of the method, and the high calculation time.

III –CONCLUSION

When batteries of capacitors are placed, the reactive components of the branch currents are reduced due to the prompt supply of reactive power and the active components of these currents also decrease due to the improvement of the voltage where not only a reduction of the active power losses but also a reduction of the reactive power losses. If the introduction of this power component did not have a great effect on reducing the cost is due to the fact that we took a small value as the price of mVAr produced. The method presented in most of the papers classified among the heuristic methods is carried out in two steps which are the result of a tenfold increase in the problem of the locations of the sizes. It has been shown that in the case of some authors, the stress on the voltage has been violated and therefore in the last and would not have to lead to a solution. The optimum sizes of the batteries should be determined in such a way that they make the economic cost or return function maximum.

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