##### Table of symbols

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| Symbol | Meaning |
| *vik* | The velocity of bat *i* at iteration *k*. |
| *xik* | The position of bat *i* at iteration *k*. |
| λi | The frequency of bat *i*. |
| *β* | Random number of a uniform distribution in the range [0,1]. |
| (*xik*)*best* | The best position of bat *i* at iteration *k*. |
| *Lik* | The loudness of bats at iteration *k*. |
| *rik* | The pulse emission rate of bats at iteration *k.* |
| *ri0* | The initial value of the pulse emission rate. |
| *ε* | Random number in the range [-1,1]. |
| *Lavgk* | The average loudness emitted from all bats at iteration *k.* |
| *VL* | The voltage magnitude at each load bus. |
| *VLmin* and *VLmax* | The minimum and maximum limits of load bus voltage, respectively. |
| *pfoverall* | The overall power factor at substation. |
| *pf min* | The minimum limit of overall power factor at substation. |
| *NC* | The optimal number of capacitors placement. |
| *NCmax* | The maximum number of possible locations of capacitors. |
| *NDG* | The optimal number of distributed generations (DGs). |
| *NDGmax* | The maximum number of possible locations of DGs. |
| *PDGj* and *QDGj* | The active and reactive power injections by DGs at bus *j*. |
| *PDGTotal* | The total active power injection by DGs. |
| *QDGTotal* | The total reactive power injection by DGs. |
| *PLTotal* | The total active power load in kW. |
| *QLTotal* | The total reactive power load in kvar. |
| *QCj* | the reactive power injection at location *j*. |
| *QCjmin* and *QCjmax* | The minimum and maximum limits of reactive power injection at location *j*, respectively. |
| *PLossTotal* | The total power loss. |
| *QCTotal* | The total capacitor banks reactive power. |
| *PLossi* | The power loss in line *i*. |
| *Peff /q* and *Qeff /q* | The total effective active and reactive power loads beyond the node *q*, respectively. |
| *Vp* | The voltage magnitude at nodes *p*. |
| *δp* | The voltage angle at nodes *p*. |
| *Rk* and *Xk* | The resistance and reactance of branch *k*, respectively. |
| *Si* | The specified power injection at node *i*. |

Chapter 1

# Introduction

## General

The distribution system is at the heart of the emerging smart electrical system and the role of distribution system operators is on the verge of a real revolution. Operators are in fact the ones who will have to master technical complexity, limit the sudden rise in costs and ensure the quality of service expected by customers. The distribution grid, which ensures continuity of supply, is a vital infrastructure for our economies to function effectively. This has been true for a long time and is increasingly becoming the case. The distribution network is one of the most complex industrial facilities currently in use [1].

In fact, until now electricity was very predictable, going from large power plants to large electricity transmission grids, then to the distribution grids to supply customers. The direction of the flow was predictable. With the development of distributed generation (DG), a significant proportion of generation is connected to the distribution grid. Furthermore, the means of DG are mainly wind and solar power stations, whose generation varies depending on the wind and sun. It is therefore possible, for example, to have a generation greater than the local consumption in the middle of the afternoon in a housing development where there are many solar panels, at a time when people are at work or school and when the panels produce at their maximum rate. Therefore, the electricity temporarily flows that will return a higher voltage to the grids. At night, the flow returns to its usual direction. There are therefore varying directions of flow [1].

The term “optimization” refers to a choice that must be made from several possible solutions, while respecting a finite number of constraints. A human desire for perfection finds its expression in the optimization theory, which teaches how to describe and fulfil an optimum. The optimization tries to improve system performances in the direction of the optimal point or points. The optimization can be defined as a part of the applied or numerical mathematics or a method for system design by computer in accordance with either one stress theoretical aspect (existence of the optimum solution conditions) or the practical aspect (procedures for obtaining the optimum solution) [2].

The analytical solution [3] used to solve an optimization problem depends on the form of the criterion and constraint functions. The simplest situation to be considered is the unconstrained optimization problem. In such a problem, no constraints are imposed on the decision variable, and different calculus can be used to analyze them. Another relatively simple form of the general optimization problem is the case in which all the constraints of the problem can be expressed as equality relationships. However, conventional optimization techniques have been developed that can efficiently solve several classes of problems with these inequality restrictions.

Many difficulties such as multi-modality, dimensionality and differentiability are associated with the optimization of large-scale problems. Traditional techniques such as steepest decent, linear programming (LP) and dynamic programming (DP) generally fail to solve non-deterministic polynomial-time hard (NP-hard) problems such large-scale problems especially with nonlinear objective functions. Most of the traditional techniques require gradient information and hence it is not possible to solve non-differentiable functions with the help of such traditional techniques. Moreover, such techniques often fail to solve optimization problems that have many local optima. To overcome these problems, there is a need to develop more powerful optimization techniques and research is going on to find effective optimization techniques since last three decades. One of the population-based optimization techniques developed during last three decades is the Archimedes Optimization Algorithm (AOA).

Archimedes Optimization Algorithm (AOA) [7] is based on Archimedes’ principle which states that “Any object, totally or partially immersed in a fluid or liquid, is buoyed up by a force equal to the weight of the fluid displaced by the object.”. AOA emulates the behaviour of many objects, which have different densities and volumes, immersed in the same fluid and each one tries to reach equilibrium state.

Capacitor banks are commonly used in a distribution system to provide reactive power locally, resulting in reduced maximum kVA demand, improved voltage profile, reduced line/feeder losses and decreased payments for the energy. Capacitor banks are installed close to the load, on the poles, or at the substations. Maximum benefit can be obtained by installing the shunt capacitor banks at the load. This is not always practical due to the size of the load, distribution of the load and voltage level. In distribution and certain industrial loads, the reactive power requirement to meet the required power factor is constant. In such applications, fixed capacitor banks are used. Sometimes such fixed capacitor banks can be switched along with the load. If the load is constant for the 24-hour period, the capacitor banks can be on without the need for switching on and off. In high voltage and feeder applications, the reactive power support is required during peak load conditions. Therefore, the capacitor banks are switched on during the peak load and switched off during off-peak load. The switching schemes keep the reactive power levels more or less constant, maintain the desired power factor, reduce overvoltage during light load conditions, and reduce losses at the transformers and feeders [8].

The distribution feeder is nonlinear because most loads are assumed to be constant complex power loads. The approach of the linear system can be modified to take into account the nonlinear characteristics of the distribution feeder. In this approach, the backward/forward sweep (BFS) algorithm is one of the most common ways used for load flow in distribution system. The BFS algorithm involves mainly an iterative three basic steps based on Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL). The three steps are named as the nodal current calculation, the backward sweep and the forward sweep and they are repeated until the convergence is achieved. In the nodal current calculation, all the current injections at different buses are determined. The backward sweep is primarily a current or a power-flow summation with possible voltage updates. The forward sweep is primarily a voltage drop calculation with possible current or power-flow updates. This algorithm is based on the fact that, the current at the end of the sub-lateral is zero whereas the voltage at the source node is specified. Therefore, by the application of the three steps in iterative scheme, a radial distribution feeder can be solved.

Distributed generation (DG), also called on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy, or distributed energy generates electricity from many small energy sources. A DG is the use of small-scale power generation technologies located close to the load being served. DG stakeholders include energy companies, equipment suppliers, regulators, energy users, and financial and supporting companies. For some customers, DG can lower costs, enhance efficiency, improve reliability, reduce emissions, or expand their energy options. DG may add redundancy that increases grid security even while powering emergency lighting or other critical systems [9].

The optimal placement of DGs and capacitor banks [10-18] is considered as a single objective optimization problem in distribution systems to determine the optimal locations and sizes of DGs and capacitors in different combination cases of them to achieve performance enhancement of distribution systems. The objective function is power loss reduction. In order to solve these objectives, the optimization algorithm should be used under security and operational equality and inequality constraints.

## Project Contributions

The main contributions of the project can be summarized as follows:

1. An efficient optimization algorithm, called AOA is used to find the optimal locations and sizes of DGs and capacitors according to single objective function to enhancement the performance of distribution systems.
2. An efficient BFS algorithm is used for the load flow calculations in distribution systems.
3. A comparison between the proposed procedure using the AOA and other optimization techniques such as DP, fuzzy, GA and PSO to find the optimal combination of DGs and capacitors is presented.

## Scope of the Project

The project contains seven Chapters followed by two appendices for test systems data and the BFS algorithm. These contents can be summarized as follows:

***CHAPTER 1*** presents a brief introduction of the distribution system problems with introducing proposed solutions for some optimization problems and the optimization techniques. Hence, it summarizes the objectives and contributions of the project.

***CHAPTER 2*** presents a survey on the methods used to enhancement the performance of distribution networks such as DGs capacitor banks.

***CHAPTER 3*** presents the problem formulation of the optimal placement of DGs and capacitors in radial distribution systems by introducing the objective function and system constraints.

***CHAPTER 4*** presents the AOA to determine the optimal locations and sizes of DGs and capacitors with minimizing the objective of power loss or TVD and improving the voltage profile in distribution systems.

***CHAPTER 5*** presents the different test systems which are used to apply the proposed procedure. Moreover, the results and comments are presented.

***CHAPTER 6***  presents the conclusions of this project.