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MULTI-FACTS DEVICES INSTALLATION FOR LOSS MINIMIZATION AND TECHNO-ECONOMIC IMPACT ASSESSMENT BASED ON COMPUTATIONAL INTELLIGENCE TECHNIQUE

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MULTI-FACTS DEVICES INSTALLATION FOR LOSS MINIMIZATION AND TECHNO-ECONOMIC IMPACT ASSESSMENT USING EPSO APPROACH

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ABSTRACT

This thesis presents a new meta-heuristic approach technique for optimal location and sizing of multi-unit Flexible Alternating Currents System (FACTS) device installation using single- and multi-objective problems. It also considers techno-economic impact in the system. In this research, the first objective is to develop heuristic technique Single-Objective Particle Swarm Optimization (SOPSO) for optimal location and sizing of single-unit FACTS device installation with loss minimization, voltage monitoring and taking into account the cost of installation in the system. The verification was conducted through comparative studies with Single-Objective Evolutionary Programming (SOEP) and Single-Objective Artificial Immune System (SOAIS) techniques. The effect of weight coefficient, c_1 and c_2 and the effect of population size of loss minimization are also investigated. The second objective is to determine the location and sizing of multi-unit and multi-type FACTS device installation using SOPSO and SOEP. Consequently, the third objective of this research is to develop a new meta-heuristic technique termed as Evolutionary Particle Swarm Optimization (EPSO) for optimal placement and sizing of multi-unit FACTS device with single-objective problem. Comparative studies with respect to traditional PSO and classical EP techniques indicated that EPSO has its merit in terms of loss minimization. In addition, the cluster formation of FACTS device installation is also derived from the obtained results. The cluster formation of FACTS device installation was derived by looking at how many times (frequency) the load buses are selected for FACTS device installation identified by EPSO, PSO and EP techniques. The fourth objective in this research is to develop a new optimization technique termed as sigma-Multi-Objective EPSO (σ-MOEPSO) technique for optimal location and sizing of FACTS devices installation for multi-objective problem to minimize the transmission loss and cost of installation in power system. Finally, the fifth objective is to assess the techno-economic impact of FACTS device installation in power system. This assessment is performed by using a hybrid Evolutionary Particle Swarm Optimization - Net Present Value (EPSO-NPV) for assessing the impact of FACTS devices installation in duration up to 20 years. Comparative study has been done with Evolutionary Programming - Net Present Value (EP-NPV) technique. It was found that the proposed technique has been able to produce better performance as compared to other techniques and could be beneficial to power system planner in order to perform FACTS devices installation scheme for the minimization of loss and cost in their systems.

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Abbreviations	
AC	Alternating Current
ACO	Ant Colony Optimization
AIS	Artificial Immune System
EP	Evolutionary Programming
EP-NPV	Evolutionary Programming –Net Present Value
EPRI	Electric Power Research Institute
EPSO	Evolutionary Particle Swarm Optimization
EPSO –NPV	Evolutionary Particle Swarm Optimization - Net Present Value
ES	Evolutionary Strategy
FACTS	Flexible Alternating Currents Transmission System
GA	Genetic Algorithm
GP	Genetic Programming
GTO	Gate Turn-Off
HVDC	High Voltage DC
LDC	Load Duration Curve
LP	Linear Programming
MF	Multi-Unit FACTS Device
MOEP	Multi-Objective Evolutionary Programming
MOO	Multi-Objective Optimization
MOPSO	Multi-Objective Particle Swarm Optimization
MTF	Multi-Type FACTS Device
NL	Non-linear Programming
NPV	Net Present Value
PSO	Particle Swarm Optimization
QP	Quadratic Programming
QP	Quadratic Programming
RTS	Reliability Test System
SA	Simulated Annealing
SOPSO	Single-Objective Particle Swarm Optimization
SSSC	Series Static Synchronous Compensator
STATCOM	Shunt Static Synchronous Compensator
SVC	Static Var Compensator
TCPS	Thyristor Controlled Phase Shifting Transformers
TCR	Thyristors Controller Reactor
TCSC	Thyristors Controlled Series Compensator
TS	Tabu Search
TS/SA	Hybrid Tabu Search and Simulated Annealing
TSR	Thyristors Switched Reactor
TTC	Total Transfer Capability

UPFC	Unified Power Flow Controller
σ-MOEP	Sigma-Multi-Objective Evolutionary Programming
σ-MOEPSO	Sigma-Multi-Objective Evolutionary Particle Swarm Optimization
σ-MOPSO	Sigma-Multi-Objective Particle Swarm Optimization

LIST OF SYMBOLS

Symbols	
A	operating range of the FACTS device
$a_{01}...a_{010}$	the locations of multi-unit SVC
$b_{01}...b_{010}$	the sizing of SVC
c_1 and c_2	weight coefficient
CF_0	an initial investment
C_{FACTS}	the investment cost
CF_t	the net cash flow at time t
C_i	the cost of active and reactive power before FACTS device installation
C_{inv}	the initial investment cost
f	the objective function
f_1 and f_2	the fitness values for objective 1 and objective 2
$g(x)$	inequality constraints
G_{best}	best overall position found by the particles up to the current iteration.
$h(x)$	equality constraints
IC	cost of installation of FACTS device in [US$]
$iter$	current iteration number
$iter_{\max}$	maximum iteration number
j	0, 1, 2
k	Constant
m	the number of objective constraints
M_T	the maintenance cost required each year during in lifetime T of the installed FACTS device
n	the population sizing
N (0,1)	a random variable with Gaussian distribution
N_B	the total number of buses
OC	operating condition
p_a	the archive member
P_{best}	best position of particle i th up to the current iteration
$P_{D\mathrm{b}}$	the real power generation at bus b
P_{Ga}	the real power generation at bus a
p_p	the best local guide for any particle
$P_{G,a}^{min}, P_{G,a}^{max}$	upper and lower limits of power generator by generator a
Q_1	reactive power flow through the branch before SVC installation
Q_2	reactive power flow through the branch after SVC installation
Q_{Db}	the reactive power generation at bus b
Q_{Ga}	the reactive power generation at bus a

$Q_{comp,a}^{min}, Q_{comp,a}^{max}$	upper and lower limits of reactive power source *a*
r	the discount rate
$rand_1$ and $rand_2$	random number between 0 and 1
$S_i^{\ k}$	current position of particle *i* at iteration k.
S_i^{k-1}	spot of agent *i* in k-th iteration
S_v	the saving incurred over the year
t	population size
T	the total time period of the project (in years)
t_i	the hours for operation during the year
V_a^{min}, V_a^{max}	upper and lower limits of voltage magnitude at bus *a*
v_i^{k+1}	velocity of particle *i* at iterations.
v_i^{k-1}	velocity of agent *i* in k-th iteration
w	weight function.
$w_{\max}$	maximum weight equal to 0.9
$w_{\min}$	minimum weight equal to 0.4
w_{i3}	the fourth strategic parameter (weight) associated with particle *i*
w_{ij}^{*}	weight updated by the evolutionary programming
X	a decision vector
x	a control variables of multi-unit FACTS device
$x_1 \ldots x_8$	the location of multi-unit FACTS device
$x_{11} \ldots x_{1n}$	the location of MTF
$x_{21} \ldots x_{2m}$	the sizing of MTF
$x_9 \ldots x_{16}$	the sizing of multi-unit FACTS device
X_{TCSC}	the controllable reactance
Y_{ab}	magnitude of bus admittance element *a,b*
θ_{ab}	the of bus angle of bus admittance element *a,b*
σ	the firing angle of thyristor
T	the learning parameter

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND

The continuous increase in electric energy demand has led to an augmented stress of the transmission lines and higher risks for faulted lines. The power flow over the transmission lines is mainly limited by some characteristics such as the thermal limits, the stability limits and the voltage limits. When the power flows on transmission lines, it causes loss of electrical power which introduces heats on power lines causing the copper to expand and the line to sag. At a higher temperature, the sag becomes permanent and eventually the copper melts and the line breaks [1]. During this process, the small increase in the line resistance does not protect it from damage. This can lead to transmissions line failures which in turn initiate voltage instability conditions. These limitations have led to emergency for additional transmission line installation in order to increase the generation capacity. However, to develop a new system it is difficult for economical, environmental, and political issues [2, 3]. One of options that can be employed is to install the flexible alternating current transmission system (FACTS) devices.

FACTS device represents a modern technological development in the electrical power system [4]. FACTS devices are revolutionizing the power transmission network, increasing the efficiency and stability of the power system [5]. In comparison with other corrective control strategies i.e. load shedding and generation rescheduling; the utilization of FACTS device is a more economic solution, since it has lower operational cost and no extra cost will involve for the charge in generation and load [6, 7].

This chapter presents a new meta-heuristic approach to optimal location and sizing of FACTS devices using computational intelligence technique: namely Evolutionary Particle Swam Optimization (EPSO) with single- and multi-objective problem considerations. The optimization algorithm is developed based on the hybridization between Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) for better performance. Also, the formed cluster has been developed based on the frequency of particular buses or lines are chosen for FACTS devices installation. Later, the techno-economic impacts are assessed using hybrid EPSO-NPV to view the long-term effects of the installation of FACTS devices.

1.2 PROBLEM STATEMENT

The reactive power planning has gained more attention in the past two decades [8]. The reactive power control is usually carried out by means of adjusting electromechanical devices such as the switched inductors, the capacitor bank, and phase-shifting transformers. Therefore, these devices act in relatively slow manner, cannot be switched frequently and cannot be used efficiently in some situations [7]. However, the FACTS devices can control the phase angle, the voltage magnitude at chosen buses or lines impedances of a transmission system through some adjustments in parameters [9]. Therefore, it is attractive to installing the FACTS devices in a power transmission system to control the power flow for achieving a more efficient use of transmission line [10]. Due to the high cost of FACTS devices it is important to place them optimally in a power network. Nevertheless, the optimal FACTS devices allocation problem is to identify the optimal location and sizing of new installed FACTS devices in order to optimize a set of objectives functions with a range of operating constraints. Some of the objectives are the loss reduction, ATC enhancement, congestion management, and economic approach to minimize the overall system cost function. It is noted that each of the objectives improves the power system operation. However, the improvement in single-objective does not guarantee improvement to other objectives. Generally, the single-objective is non-commensurable, and often represents conflicting objectives.

Allocation of the FACTS devices through single- or multi-objectives without considering the economic objectives is not the practical one. Therefore, both technical and economic objectives should be considered in formulating the FACTS devices installation problem.

Traditionally, voltage stability can be improved by the installation of FACTS devices at buses or lines of the network. The increase of reactive power loading subjected to load bus can cause the voltage decay in power system. This led to the possibility of voltage instability condition. However, it is become non economical because the cost for FACTS devices is expensive. Utilities company need to design and implement the correct way to minimize the cost applied in their system, efficiently. Thus, the problem statements can be summarized into the following points:

i. The FACTS device very expensive it is important to allocate them optimally in power system network.
ii. The single-objective optimization problem is non-commensurable and often represents conflicting objectives.
iii. The placement of FACTS device through single or multi-objective without considering the economic objective is not a practical.

1.3 OBJECTIVES OF THE RESEARCH

The objectives of this research are as follows:

i. To develop a Particle Swarm Optimization (PSO), Evolutionary Programming (EP) and Artificial Immune System (AIS) techniques for optimal location and sizing of single FACTS device with single objective to minimize the transmission loss, or minimize the cost of installation which also considers voltage profile improvement for the system under loading condition.
ii. To develop a Particle Swarm Optimization (PSO), Evolutionary Programming (EP) and Artificial Immune System (AIS) optimization engines for optimal location and sizing of multi-unit and multi-type FACTS device with single objective to minimize the transmission loss, or minimize the cost of installation considering the voltage profile improvement for the system under loading condition.
iii. To develop Evolutionary Particle Swarm Optimization (EPSO) technique of single-objective to identify the placement and sizing of multi-unit FACTS device in power system network.

iv. To develop a sigma-Multi-Objective Evolutionary Particle Swarm Optimization (σ -MOEPSO), sigma-Multi-Objective Particle Swarm Optimization (σ-MOPSO), and sigma-Multi-Objective Evolutionary Programming (σ-MOEP) techniques for optimal location and sizing of multi-unit FACTS device to minimize the transmission loss and cost of installation with monitoring the voltage profile for the system under loading condition.
v. To develop hybrid EPSO-Net Present Value (NPV) for economic impact based on the investment in FACTS devices.

1.4 SCOPE OF WORK

First of all, this study involves the development of a new heuristic approach for optimal location and sizing of FACTS devices using computational intelligence technique: namely Particle Swam Optimization (PSO) technique for single objective function to minimize the transmission loss with considering the cost of installation and the voltage profile. For the purpose of validation, the proposed technique are tested on two test systems namely IEEE 30-Bus Reliability Test Systems (RTS). For this study, static var compensator (SVC) and thyristors controlled series compensator (TCSC) are chosen as the compensation device. The experimental results are compared with those obtained from Evolutionary Programming (EP) and Artificial Immune System (AIS) technique in the attempt to highlight its merit. On the other hand, the effect of weight coefficient and the effect of population size on loss minimization was also are investigated.

Consequently, the development of a new approach for optimization is Particle Swarms Optimization (PSO) technique for optimal location and sizing of multi-unit and multi-type of FACTS device installation. With the same previous objective function to minimize the transmission loss, which considers improvement of voltage profile and cost of installation in power system, tests were performed on the IEEE 30-Bus and IEEE 118-Bus RTS to realize the effectiveness of the proposed technique. Verification was conducted through comparative studies with Evolutionary Programming (EP).

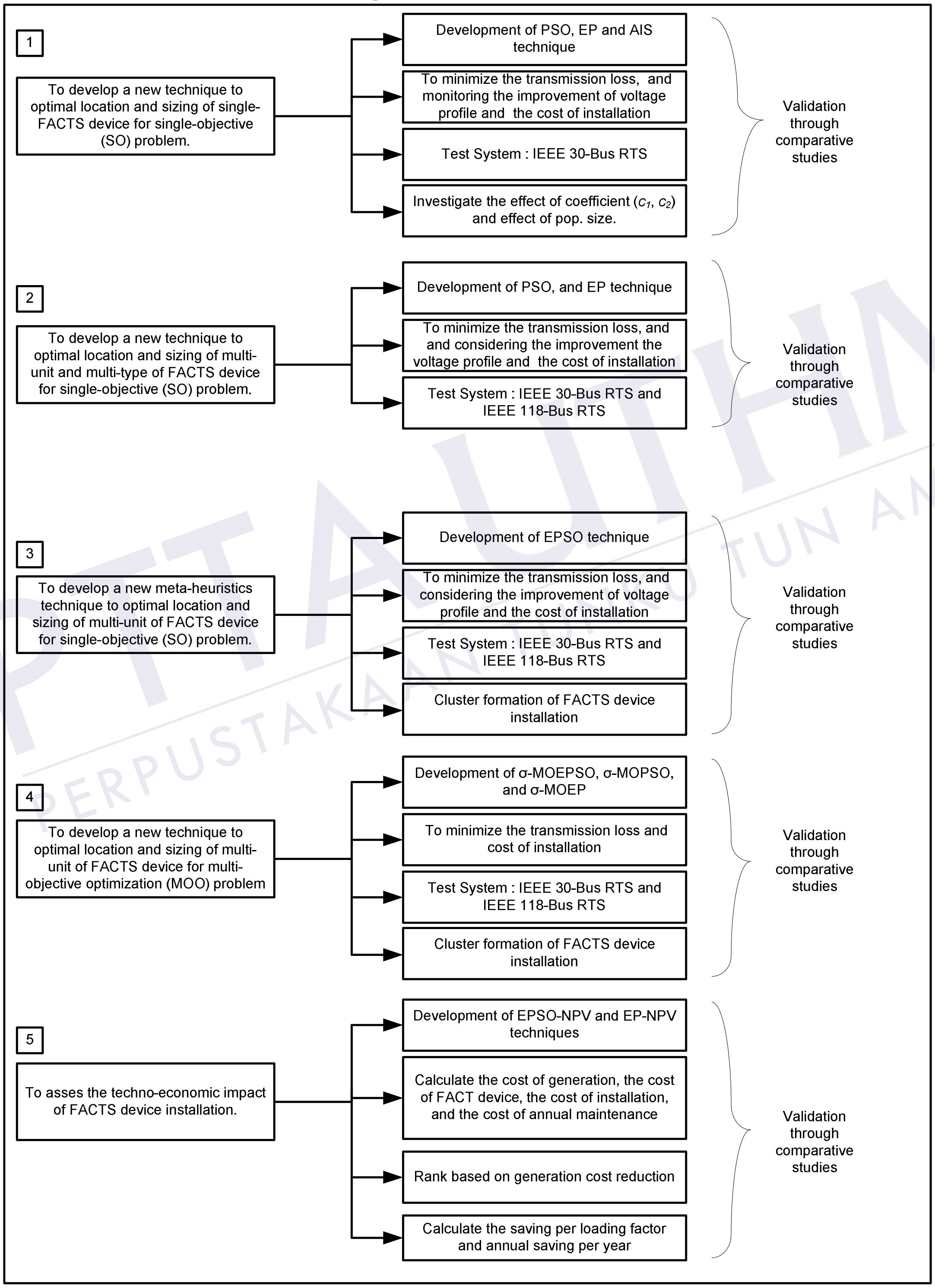
The development of meta-heuristics approach for optimal location and sizing of FACTS devices using computational intelligence technique: namely Evolutionary Particle Swam Optimization (EPSO) techniques are consequently conducted. They are meant for single objective problem to minimize the transmission loss considering the cost of installation and the voltage profile. The proposed technique is developed based on the combination between Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) to improve the weakness experienced in the conventional PSO [11, 12]. For the purpose of validation, the implementation of the proposed technique are tested on IEEE 30-Bus, and 118-Bus RTS. For this research, only SVC is chosen as the compensation device. Comparative studies with respect to traditional PSO and EP techniques indicated that EPSO has its merit in terms of loss minimization. In addition, cluster of FACTS device installation are derived from the obtained results.

The development of a new meta-heuristics optimization technique termed as sigma-Multi-Objective EPSO (σ-MOEPSO) technique for optimal location and sizing of FACTS devices in multi-objective problem to minimize the transmission loss and cost of installation in power system.

As a final task, the assessment of techno-economic impact of FACTS device installation in power system has been performed. This assessment is conducted by using a hybrid form between Evolutionary Particle Swarm Optimization (EPSO) and Net Present Value (NPV) tools namely: EPSO-NPV for assessing the impact of the installation of FACTS devices for the duration of up to 20 years. This assessment involves the cost of FACTS devices, the cost of installation, the generation costs and the annual maintenance cost.

FIGURE 1.1 illustrates the overall research framework on the proposed technique for optimal location and sizing of FACTS device installation.

FIGURE 1.1
Overall Research Framework on the Proposed Technique for Optimal Location and Sizing of FACTS Device Installation



1.5 ORGANIZATION OF THESIS

This thesis has been written in eight chapters.

Chapter One introduces the background of the topic and motivation of this study. Subsequently, the problems related to the topic are explained briefly. Based on the problem statement, the objectives of the study are outlined. Lastly, the organization of the thesis is presented for giving and overview of the whole chapters.

Chapter Two presents the literature review on the related studies of this research. Initially, the optimal location and sizing of FACTS device using artificial intelligence (AI) technique are reported and criticized before focusing on the application of Particle Swarms Optimization (PSO), and Evolutionary Particle Swarm Optimization (EPSO), Evolutionary Programming (EP) and Artificial Immune System (AIS) in optimization problem. Lastly, the previous related work the techno-economic impact issues affecting the technical and economic using Evolutionary Particle Swarm Optimization –Net Present Value (EPSO–NPV) are also previewed.

Chapter Three presents the optimization techniques for optimal location and sizing of FACTS device using Single-Objective Particle Swarm Optimization (SOPSO) algorithm for minimization of transmission loss and the voltage profile improvement. In this study, Static Var Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) are chosen as the compensation devices. Subsequently, to know whether the proposed technique is reliable and efficient, the results are compared with Evolutionary Programming (EP) and Artificial Immune System (AIS). The effect of weight coefficient and population size on loss minimization is also investigated.

Next, in Chapter Four, the developed optimization algorithm using Single-Objective Particle Swarm Optimization (SOPSO) for optimal location and sizing of multi-unit and multi-FACTS device installation are described. This objective function for this section is to minimize the transmission loss, improve the voltage profile and monitoring the cost of installation.

Chapter Five discusses a new approach of meta-heuristic to determine the optimal location and sizing of Multi-unit FACTS device termed as Evolutionary Particle Swarm Optimization (EPSO). Experiments were performed on the IEEE 30-Bus RTS and IEEE 118-Bus RTS to realize the efficiency of the proposed technique. In addition, comparative studies are conducted by comparing the results with Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) techniques. Finally, the clusters of SVC installation when loading variation at weak buses are developed.

Chapter Six focuses on the multi-objective optimization (MOO) problems to minimize the transmission loss and minimize the cost of installation. To carry out these multi-criteria optimization process Sigma-Multi-objective Evolutionary Particle Swarm Optimization (σ-MOEPSO) technique has been developed. Comparative studies are conducted by comparing the results with sigma-Multi-objective Particle Swarm Optimization (σ-MOPSO) and sigma-Multi-objective Evolutionary Programming (σ-MOEP) techniques. The clusters are formed based on the frequency of buses being selected for SVC installation in power system.

Chapter Seven implements the techno-economic impact using Evolutionary Particle Swarm Optimization – Net Present Value (EPSO-NPV) technique. This is aimed to review the FACTS device installation in power system from in view of technical and economic aspects in the long terms.

Chapter Eight presents the overall conclusion of the study. This is followed by several potential future works and recommendations.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents literature review on the related past research work with the study. It begins with the review of Flexible Alternating Currents Transmission System (FACTS) devices for solving the problems in the power system. Consequently it further discusses the work on optimal location and sizing FACTS devices using Artificial Intelligence (AI) techniques. Based on the latest research, the utilization of AI in optimal location and sizing of FACTS devices using PSO is a technique that has advantages over other techniques. Therefore the subsequent studies will focus on the use of PSO and EPSO techniques in this research. Furthermore, EP and AIS techniques are also studied for comparison with the above techniques. This chapter also discusses the recent studies of single-objective and multi-objective optimization in power system problem. Lastly, based on the objective of this research the previous related work the techno-economic issues affecting the technical and economic well studied briefly. This is to get a rough idea that the used of FACTS devices have a positive effect over the long term. Finally, the gap is discovered in the previous work are described which significantly motivates this research.

2.2 DEFINITIONS OF FACTS DEVICE

IEEE PES Task Force of the FACTS Working Group defined terms and definitions for FACTS and FACTS Controllers [5, 13]. Further explanation of these definitions is given in [14].For others terms and definitions, reader can refer to the IEEE dictionary [15].

- *Flexibility of Electric Power Transmission*: The ability to accommodate changes in the electric transmission system or operating conditions while maintaining sufficient steady-state and transient margins.
- *Flexible Alternating Current Transmission Systems (FACTS)*: Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability.
- *FACTS Controller*: A power-electronic based system and other static equipment that provide control of one or more AC transmission system parameters.
- *Static Var Compensator (SVC)*: A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage). Additionally, the CIGRE and IEEE defines a Static Var Compensator (SVC) is a shunt connected static generator and/or absorber of reactive power whose output is varied so as to maintain or control specific parameters of an electrical power system.
- *Thyristor Controller Reactor (TCR)***:** A shunt-connected, a thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristors valve.
- *Thyristor Switched Reactor (TSR):* A shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a stepwise manner by full- or zero-conduction operation of the thyristors valve.
- *Thyristor Controlled Series Compensator (TCSC)*: A capacitor of the thyristor reactance compensator which consists of a series capacitor bank shunted by a thyristors–controlled reactor in order to provide a smoothly variable capacitive reactance.

2.3 FLEXIBLE ALTERNATING CURRENTS TRANSMISSIONS (FACTS) DEVICES

FACTS devices is a concept proposed by N.G. Hingorani [16]; a well-known term for higher controllability in power system by means of power electronics devices. The

Electric Power Research Institute (EPRI) was supporting the development of high power electronics for such applications as High Voltage DC (HVDC) Transmission and reactive compensation of ac line, and in the late 1980s formalized the concept of FACTS [17]. The FACTS initiative was originally launched, with two main objectives: (1) to increase the power transfer capability of transmission system and (2) to keep power flow over designed routes. The benefits of FACTS devices are; to increase the system transmission capacity, power flow, control flexibility and rapidity [18], to improve the transmission system management, increased dynamic, transient grid stability and enabling environment [19]. FACTS devices provide strategic benefits for improving transmission system management through better utilization of existing transmission assets, increased transmission system reliability and availability, increased dynamic and transient grid and enabling environmental benefits [20]. On the other hand, from [21] it was reported that FACTS devices can provide control of one or more AC transmission system parameter such as voltage magnitudes, phase angle of bus voltages, line impedance to enhance controllability and increase power transfer capability. The basic applications of FACTS devices are increased of transmission capacity, voltage control, power flow control, reactive power compensation and stability improvement. A. Deihimi *et. al* [22] reported that the ability of FACTS devices to control those parameters likes series impedance, shunt admittance, bus voltage, voltage drop, and phase angle that govern the operation of transmission system, provides the possibility of improving system performance such as system security, system loadability and total generation fuel. The first generation of FACTS controller employed thyristors as the power electronic switching elements and combination with the reactive components. Static Var Compensators are widely employed for shunt compensation of the transmission system, the large industrial loads and remotely-located loads of moderate size. The series compensation by means of thyristors-controlled series capacitors (TSCS) and thyristors-controlled phase shifting transformers (TCPS) can provide power flow control to minimize the system congestion problems [23]. The second generation of FACTS controllers uses the Gate Turn-Off (GTO) or similar power semiconductor in voltage-source inverted configurations. The shunt compensation is provided by the static synchronous compensator (STATCOM), the series compensation by static synchronous compensator (SSSC) and the combined series-shunt compensation by the unified power flow controller (UPFC) [24]. The main types of FACTS devices include the following [5]:

- Static Var Compensator (SVC)
- Static Synchronous Series Compensator (SSSC)
- Static Synchronous Compensator (STATCOM)
- Thyristor Controlled Series Compensator (TCSC)
- Thyristor-Switched Series Capacitor (TSSC)
- Thyristor-Controlled Series Reactor (TCSR)
- Thyristor-Switcher Series Reactor (TSSR)
- Unified Power Flow Controller (UPFC)
- Thyristor-Controlled Phase Shifting Transformer (TCPST)

2.4 OPTIMIZATION TECHNIQUE APPLICATION IN POWER SYSTEM

One of the problems experienced in power system is the large amount of data set and system complexity. Even if an exact algorithm may be developed and applied to find an exact optimal solution of the problem, its resolution time or space complexity may not be acceptable in a simulation scenario. However, many problems can be solved using an approximate solution if the dimension and the complexity of the problem do not encourage the use of exact resolution techniques. Heuristic algorithms work with approximated solutions and the objective is to find the optimum among all possible solutions. This solution presented a compromise between quality and speed, being the solution admissible within a reasonable simulation time. Heuristic algorithms can be categorized into two categories namely: Greedy algorithms and Search algorithms [25]. Greedy algorithms build the solution in a progressive way, obtaining a sequence of locally optimal choice. They have a good computing efficiency but they do not guarantee the global minimum. On the other hand, the search algorithm is an exhaustive search which tries all possible solutions from a predetermined set and picks the best one. Heuristics methods are useful with non-convex problems, non-smooth and non-differentiable. With other devices installed in power system it may increase the difficulty to treat this optimization problem with conventional optimizations methods. The problem to be solved is multi-objective optimization which requires the simultaneous maximization of the stability margin, improving the voltage profile and the minimization of the installation cost of additional reactive power sources. The conventional optimization methods are based on successive linearization and the use of first and second derivations of the objective function and its constraint equations as the search directions [26]. These methods are good enough for the optimization problems of deterministic quadratics objective function with only one minimum point. However, the equations of the problems in power system are complex and nonlinear which have caused the solution being trapped at local minimum and possibility of causing divergence of results. Therefore, the new evolutionary optimization techniques are very appealing since they do not need any kind of differentiation or linearization.

There have been a number of methods available in recent years for optimization in transmission and distributions system, namely the conventional or artificial intelligence (AI) based technique. The conventional optimization methods that have been developed are such as Tabu search (TS), Gradient, and Linear programming (LP), Non-linear programming (NL), Quadratic programming (QP), and Interior point methods. However, the conventional methods have experienced a difficulty due to insecure convergence, sensitive to initial search point, and algorithm complexity [27]. Hence, the artificial intelligence methods such as Hybrid Tabu Search and Simulated Annealing (TS/SA), Genetic Algorithm (GA), Evolutionary Programming (EP), Evolutionary Strategy (ES), Genetic Programming (GP), Bee Algorithms, Fuzzy Decision Making, Artificial Immune System (AIS) and Particle Swarm Optimization (PSO) are developed to overcome the problems confronted by these conventional methods[20, 27-33].

In the practical system, optimal locations of FACTS devices depend on comprehensive analysis of steady-state stability, small signal stability, voltage stability, and other factors considered such as cost and installation conditions. From the literature, the optimal location and setting of FACTS devices have retained the interest of worldwide researchers in power system, with different methods and criteria are used in this field. G. I. Rashed *et al* [25] used the GA and PSO techniques for finding out the optimal number, the optimal locations, and the optimal parameter settings of multiple TCSC to achieve maximum system loadability in the system with minimum installation cost of these device without any violations in the thermal or voltage limits. From the results, it is shown that TCSC device has improved the line flows even to their thermal limits and most of the time, TCSC are capacitive to reduce the reactance of the lines where they are located. The PSO technique has been reported to be is faster than the GA technique in the beginning of optimization. However, the increase of generation study, shown that the performance of GA is better than the PSO. Also, from the perspective of time, it found that the PSO technique is much faster that the GA.

P. Bhasaputra *et. al* [26] used a hybrid tabu search and simulated annealing (TS/SA) approach to minimize the generator fuel cost in OPF control with FACTS devices. With multi-type FACTS devices installed, the reduction in total generator of fuel cost is more than the individual installed FACTS devices. The hybrid TS/SA approach is effectively and successfully implemented the total generator fuel cost saving and fast computing time. R. Mohamad Idris *et. al* [27] used Bee Algorithm (BA) to determine the optimal locations of FACTS devices to maximize the available transfer capability (ATC) of power system. The three types of FACTS that have been used in this research are SVC, TCSC and TCPST. From the outp uts it is shown that BA could effectively locate the devices and reach the optimum solutions faster than GA with a higher value of ATC. BA does not require external parameters such as cross over rate and mutation rate. BA gives better result in terms of speed of optimizations and accuracy of the results. BA needs the large number of trials.

P.K.Towari *et. al* [19] proposed GA technique for finding the optimal choice and location of FACTs controllers and also in minimizing the overall system cost, which comprises of generation cost and investment cost of FACTS devices. W.Ongsakul e*t. al* [28] presented EP to identify the location of four FACTS devices for maximizing the total transfer capability (TTC) of power system. From the results it is shown that optimally placed OPF with FACTS devices by EP could enhance the TTC value far more that without FACTS devices. M. M. E. Metwally *et. al* [29] proposed EP technique to determine the optimal location of FACTS devices in power system with objective to minimize the overall cost function includes the investment cost of SVC and the generation costs of power plants. The results shown that this method can be used to minimize the total cost function, including generations cost of power plants and investments costs. S. Chansareewittaya *et. al* [32] used GA and PSO to determine the locations of multi-type FACTS devices to enhance power transfer capability of power system. However, PSO have more advantages than that GA. PSO gives higher benefits to cost ratio and faster convergence than EP. According to characteristics of FACTS device, various criteria have been considered in placement problem. Most of reported objective functions in literature are: network loadability [34, 35], the ability to control the power flows [36], loss reduction [37], voltage profile improvement [31], static voltage stability enhancement [38-40], power plants fuel cost reduction [26] and minimization the overall system cost function [41], and total generation fuel cost [42] or maximized the return of investment as in [43]. Therefore, due to the various benefits of FACTS device is explained previously, these device was applied in this study to solve the power system problems.

Particle Swarm Optimization (PSO) algorithm is developed by Kennedy and Eberhart in 1995 [44, 45] based on the social behaviors of animal swarms (e.g. bird blocks and fish schools) [11] and its deals with problems in which a best solution can be represented as a point or surface in the n-dimensional space. PSO represents a system that is initialized with a population of random solutions [46]. The PSO provides a populations-based search procedure in which individuals called particle and changes their positions. The main advantage of swarm intelligence techniques is that they are impressively resistant to the local optimal problem. Also, PSO is employed mostly because it is simple in concept, it is easy to implement, it is efficient and it is a flexible mechanism to enhance global and local exploration abilities. The PSO is more effective than traditional algorithms in most cases [47]. Application of this technique can be found in [45, 48-55] . From [56], the main merits of PSO are simplicity in concept implementation, computationally efficient, and robustness to control parameters. Abido *et. al* [33] introduced PSO to solve the OPF problem because this is a highly non-linear and multimodal optimization problem. In this study the applications of PSO were formulated for multi-objective functions which are to minimize fuel cost, to improve the voltage profile and to improve stability of voltage in power system. The result shows that improvement of optimal point of 11.25% for minimizations of fuel cost. The most important problems faced by power systems are voltage stability, due to increased loading on the system and the difficulty to increase the transmission capacity to cope with this increased demand. A. A. El-Did *et. al* [57] proposed solution algorithms for preventive control problem through finding the optimum location, type and size of static shunt compensation devices by using PSO to increase the stability margin in the system. The comparison with GA shows that PSO is capable of dealing with integer variables as well as continuous variables. The main advantage of this algorithm is the easy formulation of the problem while adding any type of constraints required. The PSO has got the capability of dealing with this type of optimization problems which are highly complicated. Therefore, this solution can be used in other type of optimizations problems existing in the field of power systems planning and operations.

M. Saravanan *et. al* [18, 58] proposed PSO technique for finding the optimal locations of single and multi-type FACTS devices with minimum cost of installation and to improve system loadability. In IEEE test system, UPFC gives the maximum system loadability but the cost of installations is higher when compared with all other cases. On the other hand, TSCS has minimum cost installation with better improvement in system loadability. SVC gives lowest cost of installation but with minimum improvement in system loadability. R. Benabid *et. al* [59] proposed PSO for optimal locating and setting of multi-type FACTS devices in order to maximize static voltage stability margin, to reduce real power losses, and load voltage deviation. S. Mollazei *et. al* [60] used a multi-objective PSO algorithm to finding the optimal location of TCSC and its parameters in order to increase the total transfer capability, to reduce the total transmission losses and to minimize voltage deviation.

H. Hashemzadeh *et al* [12] proposed PSO method for locating series FACTS devices in deregulated electricity markets in order to reduce and manage congestion. The objective functions for this research are to minimize the total congestion cost and total generation cost. The results are presented that TCSC is a good choice for reduction in transmission congestion costs and control of power flow in the lines. S. Auchariyamet *et. al* [56] proposed optimization technique based on PSO is developed to determine the optimal locations of SVC and TCSC and their parameter values. This study has three objective functions namely minimization of the installation cost of SVC or TCSC, minimization of energy loss cost, and minimization of the total cost (e.g. sum of the installation cost and energy loss cost). Results of the study show that SVC and TCSC are good choice to serve as Var sources for reactive power compensation because it can reduce system real power loss and improve the bus voltages. However, SVC and TCSC may not be appropriate as they are not cost-effective at least in the short term. Later, H. Yoshida *et al* [61] employed PSO for reactive power and Voltage/VAR Control (VVC) with consideration voltage security assessment. The work is meant to find out an on–line VVC strategy for example AVR operating values of generators, the number of reactive power compensation equipment and the tap positions of transformer. Jong-Bae Park *et. al* [21] proposed a Modified Particle Swarm Optimization (MPSO) to economic dispatch with non-smooth cost function. The equality constraint is resolved by minimizing the degree of freedom by one at random. The results from the proposed technique are compared with GA, TS, EP, MHNN, AHNN and NM methods. Cui-Ru Wang *et al*. [62] proposed an MPSO technique to solve economic dispatch problem. In this technique, part icle not only studies from itself and the best one but also from other individuals. By this technique, the opportunity to determine the global minimum is increased and the influence of the initial position of the particles is decreased. The particle adjusts its velocity according to two extremes: the best position of its own and the other is not always the best one of the group, but selected randomly from the group. PSO has been successfully applied to various power system optimization problems such as reactive power and voltage control [61],unit commitment [46], optimal power flow [63], reactive power dispatch [64] and economic dispatch [21].

Several methods have been applied to solve power system problem in recent years, such as Evolutionary PSO (EPSO) [65-67], improved PSO [31, 68], and adaptive PSO [28] Z.A Vale *et al* [28] present a method to placement reactive power compensation using EPSO technique to find the best operation point for minimizing power losses. EPSO [11, 12, 65-72] is an improved version of traditional PSO with additional Mutation to the strategic parameters and Selection, by Stochastic Tournament, of particles passing to the next movement iteration. In terms of particle swarms, EPSO relies on involving weights in the movement equation, instead of an explicit random factor. Therefore, EPSO is less dependent on parameter externally defined by the user. EPSO has proven to be efficient, accurate and robust, with successful applications to power system problem [11, 69, 71, 72]. G.Baskar *et. al* [68] proposed improved PSO, PSO, EP, fast-EP, and Mean Fast-EP technique to alleviate line overloading for contingency constrained economic load dispatch (CCELD) with win objectives function are minimization of fuel cost and minimization of severity index. IPSO method has stable convergence characteristics and non-oscillatory which gives minimum fuel cost. Jong-Bae Park *et. al* [73] present an efficient approach for solving economic dispatch problems with non-convex cost functions using IPSO. The proposed IPSO is applied to three different non-convex economic dispatch problems with valve –point effects, prohibited operating zones with ramp rate limits as well as transmission network losses, and multi-fuels with valve-points effects. B.K.Panigrahi *e.al* [74] approach adaptive –variable population-PSO (APSO) technique for economic load dispatch (ELD). APSO can be effectively used to solve smooth as well as non-smooth constrained ELD problems. H. Mori *et. al* [75] proposed a new hybrid meta-heuristics method that makes use of TS-EPSO techniques to solve the unit commitment (UC) problem in power system with objective to minimize operation-cost even as satisfying on the power balance, unit output and minimum up/down time of unit. Santiago P. Torres *et. al* [76] developed Unified Particle Swarm Optimization (UPSO) and EPSO to applied for static transmission expansion planning in electrical networks. The results shows that the UPSO (u=0; u is *unification factor* [77]) outperformed EPSO in terms of robustness and computing efficiency. On the other hand, in [78, 79] [80] used UPSO and EPSO in order to improve the overall PSO performance.

The Evolutionary Programming (EP) is one of the artificial intelligent method is introduction by David B. Fogel in 1960 [81] was inspired from natural selection process to find the global optimum of complex problem [67]. Evolutionary algorithms are based on computational models of fundamental evolutionary processes which involved initialization, mutation, selection and reproduction. It has been successfully applied to various scopes in power systems to solve the optimization problem related to unit commitment [82], optimal reactive power dispatch [52] and reactive power planning (RPP) [43, 83]. Musirin *et. al.* in [84] proposed EP to define the optimal placement of FACTS device for maximization the total transfer capability (TTC) of power system. EP also searches for FACTS parameters, FACTS locations, and the real power generations except the slack bus in power system, the real power loads in sink area and generation bus voltages. Fogel in [81] proposed a loss sensitivity approach for placement of Phase Shifter Series Capacitors (PSSC) and Static VAR Compensators. In this research, EP technique was used to optimize the sizing of UPFCs with objective to minimize loss in the system. Somansundaram *et. al* [85] proposed EP technique for solving security constraints optimal power flow problem. The controllable system quantities in the base case state are optimized to minimize the some defined objective function subject to the base-case operating constraints in addition to the contingency-case security constraint. Fitness function converges smoothly without any oscillations. P. Attaviriyanupap *et. al* [86] used EP technique for a new bidding strategy within a day-ahead energy and reserve markets. The optimal bidding parameters for both markets are fine by solving an optimization problem that takes unit commitment constraints such as generating limits and unit minimum up/down time constraints into account. The proposed technique is developed from the view points of a generation. Jayabarathi *et. al* [86] proposed the Classical Evolutionary Programming (EP), Fast EP and Improved FEP methods to solve the economic dispatch problems : ED of generators with prohibited operating zones (POZ), ED of generators with piecewise quadratics cost function (PQCF), combined economic-environmental dispatch (CEED) and multi-area economic dispatch (MAED). The constraints considered are the power balance, generating capacity, prohibited operating zones, area power balance, generation limits and tie-line limits constraints. Nor Rul Hasma Abdullah *et. al* [87] proposed EP for solving constrained reactive power control (CRPC) problem with considering multi-contingency (N-m); generators outages and line outages. This technique determines the amount of reactive power to be compensated to the system in enhancing the voltage stability or minimizing the real power transmission loss in the system when the system is subjected to stress and contingencies. In [88], EP technique has been proposed for solving the reactive power planning under normal state without contingencies compared to conventional optimization technique. The technique obtained the good result for global optimization especially in non-continuous and non-smooth situation. On the other hand, in [63] and [89], EP has been employed for other power system problems and shows stability, flexible and a better potential of applications of the method to power system economical operations. In [85], it is proposed that EP technique is used to solve the OPF problem under different contingency cases with objective function to minimize the quadratic fuel cost function by properly adjusting both discrete and continuous control variables. Also, similar in [90] using OPF formulation to validate EP technique in deregulated electric market. On the other hand, Improved EP technique are discussed in [91] to optimize the non-convex generator fuel cost curve. To validate the proposed technique, comparative study with different method were developed to solve the same problem. Results reveal that in favor of the Improved EP in terms of solution accuracy and execution time. Next, Lai and Ma [92] developed EP to minimize the real power losses in power networks by regulating the power flow with optimal setting of UPFC. The proposed technique was tested under various contingencies scenarios. Venkatesh *et. al* [93] used EP to solve the OPF problem while accounting for UPFC formulation with minimum of the real power losses and the best voltage profile. In [94], W. Ongsakul developed EP to maximize the total transfer capability between generation and load center areas. The technique optimally adjusts the real power outputs and voltage magnitudes at generation buses such that the total loads in the sink are maximized. References [95] proposed the hybrid EP and Sequential quadratic programming (SQP) for multi-objective formulation of security constrained OPF problem with the quadratic fuel cost and the active power losses. The hybridization reduced the computation time and outperformed the performance of each individual method. In [96] hybrid method which combined EP and classical gradient search method with the objective to minimize the quadratic fuel cost function was proposed. Also, similar objective function in [97] and [98] using parallel EP technique. Padhy in [99] applied EP technique for solving the OPF problem by calculating the wheeling rates of active power at various part of the transmission network. In [100] EP was employed to find the short run marginal cost for bilateral transactions. The cost is computed based on the OPF solution with the non-smooth fuel cost function as the objective function. Conversely, Sood *et. al* [101] used a hybrid method i.e.: EP was combined with the steepest decent method to calculate the wheeling rates of both real and reactive power based on the solution of the OPF. A similar hybrid method was presented in [43] with objective to optimize the voltage profile with three types of fuel cost functions. In [102] a hybrid technique of EP and Newton-Raphson method was proposed to optimally select the best wheeling option when a privately owned generator is introduced in an existing network.

Artificial Immune System (AIS) is a new method of Artificial Intelligence (AI) used for computational models and problem solving methods [103]. It is a biological immune system which is highly parallel, distributed and adaptive system [104]. The basic immune models and algorithms are Bone Marrow models, negative selection algorithm, cloned selection algorithm and immune network models. Some of applications of AIS are fault and anomaly detection, data mining, agent based system, autonomous control, optimization, robotics and security of information systems. The original AIS technique is based on three major immunological principles: hyper-mutation, receptor edition and cellular memory. These characteristics enable the assessment of multiple optimal using local and global [105, 106]. It works on the principles of pattern recognition and clone selection principle, implemented to accomplish learning and memory acquisition tasks. In [107], AIS are adaptive systems inspired by theoretical immunology and observed immune functions and applied to complex problem domains. The natural immune system is a very complex system with several mechanisms for defense against pathogenic organisms. In [108], AIS can be defined as metaphorical systems inspired from the human immune system. It is very complex system with several mechanisms to protect our bodies against the attack from foreign bodies called antigens. The purpose of the immune system is to recognize all cells within the body and categories those cells as either self or non-self. Some of computational models have been developed based on several principles of the immune system for instance immune network model, negative selection algorithm, positive selection algorithm and clone selection algorithm [103, 109]. Also, in [110] it appraises the application of AIS to solve all kinds of application such as pattern recognition, feature extraction, learning and memory. S.A. Jumaat *et. al* [111] mentions that AIS is Artificial Intelligence (AI) method used for computational models and problem solving techniques, biological immune system which is highly parallel, distributed and adaptive system [81]. K. Lashshmi *et. al* [106], used clone and selection based AIS to maximize the profit of generation company, GENCO's based on forecasted information for example power demand and prices. Profit based unit commitment problem is one of the optimization problems in restructured electricity markets. This problem determines the generating unit schedules for maximizing the profit of GENCO's subject to all prevailing constraints. B. Vanaja *et. al* [112] reported that AIS has been applied to solve the constrained Economic Load Dispatch with objective function to minimize the total generation cost. Based on the comparative study with GA, it is concluded that the developed technique is easy to implement and capable of finding feasible near global optimal solution. S. I. Suliman *et. al* [113] presented an applications of AIS using clonal selection principle for on-line prediction of voltage stability condition in power system. The fast computation, populations of antibodies are operated simultaneously and the newly discovery technique are the factors that have motivated the application of AIS for predicting the voltage stability condition. S. Ishak *et. al* [114] proposed AIS technique to determine the location and sizing of SVC in power system for improving the voltage level and minimizing the transmission loss in the system. The presented technique focused on a systematic view of the immune system and does not take into account cell-cell interactions. In [115], Titik Khawa Abdul Rahman *et. al* presents an AIS technique with clonal selection principles for solving the economic dispatch problem in power system to determine the active power to be generated by the generating units in a power generation system. R. Geetha *et.al* [93] employed AIS technique to solve the combined economic and emission dispatch (CEED) problem. This technique utilizes the clonal selection principle and evolutionary wherein cloning of antibodies is performed followed by hyper mutation. The results reveal that the technique is easy to implement, has convergence within an acceptable execution time and optimal solution for CEED problem with minimum the total operating cost and minimum emission. From the reviewed literature it is discovered that the AI approach are successfully in the power system problems. Consequently, due to the various advantages of AI techniques, EPSO technique was applied in this study to minimize the loss in the system with optimal location and sizing of FACTS device installation.

2.5 MULTI-OBJECTIVE OPTIMIZATION IN POWER SYSTEM PROBLEM

Multi-objective optimization (MOO) domain covers a lot of real optimization problems [75]: production practice, engineering design, social production, and economic development [47]. Some intelligence calculations based approach; evolutionary computation, swarm intelligence and artificial immune system have been used for solving MOO problems. In most cases, the objective function may conflict with each other. This may cause some multi-objective optimization problems not to have the unique best global solution [47]. The solution can make all objective function to be optimum at the same time. Ali Deihimi *et. al* [22] proposed fuzzy multi-objective decision making and genetic algorithm techniques for optimal allocation and type of FACTS devices. Transmission power loss, apparent power security index, voltage security index and the absorbed reactive power by transmission system are considered as the objectives. D. Radu *et. al* [116] approach a multi-objective genetic algorithm (MOGA) to optimize three parameters i.e. the location, the types and sizes of FACTS device with maximizing the security system and minimizing the investment cost of FACTS device. In [117], NSGA II (Non-dominated Sorting Genetic Algorithm) was used for determining the optimal location and sizes of TCSC with consideration of power loss reduction, investment cost minimization, security margin improvement and available transmission capacity enhancement. On the other hand, M. Belazzoug *et. al* [118] proposed Ellitist Non Dominated Sorting Genetic Algorithm for optimal location and ratings of SVC and TCSC to minimize the transmission loss in electrical network. In [119], it proposed two-stage of solution in environmental economic dispatch (EED) problem : a multi-objective differential evolution algorithm and multi-attribute-decision-making (MADM). The fuel cost, emission of atmospheric pollutants, and the real power loss are considered as objective functions. From the results it was discovered that this technique enables a fast convergence towards the true Pareto front and promotes the uniform spread of solution. Moreover, a self-adaptive mechanism in the control parameters is developed to improve the robustness of the algorithm. Ya-Chin Chang *et. al* [120] used the modal analysis [MA] technique to determine the location of SVC installation with maximum loading margin (LM) and minimum cost of installation. In [121], multi-objective particle swarm optimization technique is proposed to solve a cost-efficient congestion management method for smooth and non-smooth cost function. A realistic frequency and voltage dependent load flow model of load and generator regulation characteristics were investigated. The successful application of PSO in many single objective optimization

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