Optimal Location of FACTS Devices in Power Systems era: Models, Methods

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Abstract : Flexible Alternating Current Transmission Systems (FACTS) devices have been proposed as an effective solution for controlling power flow and regulating bus voltages in electrical power systems, resulting low system losses, and improved stability. Placement of these devices in suitable location can lead to control in line flow and maintain bus voltages in desired level. The FACTS devices placement problem is commonly solved using heuristic optimization techniques which are diverse and have been the subject of ongoing enhancements. This paper presents a survey of the literature from the last decade that has focused on the various techniques applied to determine optimal location of FACTS devices.

Several models and methods have been suggested for the optimal location and parameter setting of FACTS devices. This paper presents an overview of the state of the art models and methods applied to the power system problems, analyzing and classifying current trends in this field.

I. Introduction

The need for more efficient and fast responding electrical systems has given rise to a new technology in transmission, base on solid-state devices. These are called Flexible AC Transmission Systems commonly abbreviated as FACTS, which enhance stability [12-13],[62] and increase line loadings closer to thermal limits... Precisely FACTS devices allow the control of all parameters that determine active and reactive power transmission to include node voltages magnitudes and angles [16], [41] and line reactance [7].

The various sensitivity based methods[24],[48] have been proposed in literatures includes jocobian [47] based sensitivity method, Eigen-value analysis based methods , nodal analysis techniques [9],index methods [35] residue-based methods ,some of other methods are pole placement techniques, frequency response techniques, root locus techniques, projective control method, non-linear feed control method, Lambda iteration method, Eigen-Sensitivity Theory of Augmented Matrix.

The various optimization based methods have been proposed in literatures that Dynamic optimization programming algorithms[15],Mixed integer-optimization programming techniques[23],Hybrid optimization programming algorithms [2],[35], and Non-linear optimization programming techniques[9],[55] ,some of other methods are linear optimization programming techniques[17], immune based optimization algorithms,Mixed-Integer Linear Programming (MILP) .

The various artificial intelligence (AI) based methods proposed in literature includes genetic algorithms(GA),[12],[20],[22],[30],[31],[51][54],[56],[59]. Evolutionary [29],[39-42],[58],Tabu search algorithms, [28],[35],[55]. Simulated annealing (SA) based approach [32],[35], Particle swarmoptimization (PSO) techniques[1],[3-5],[36-38],Ant colony optimization (ACO) algorithms, Fuzzy logic based approach [11], Artificial neural network (ANN) based algorithms,Bacterial Swarming Algorithm (BSA) [43],Harmony search algorithm [45],Bees algorithm[46].

This paper introduces a review on optimal location and parameter settings of FACTS devices in power systems era: Models, methods. Moreover, this work analyzes and classifies current trends. This review aims to serve as a guide to power system engineers and researchers on the available models and methods on optimal location and parameter settings of FACTS devices in the modern power systems era.

The paper is organized as follows. Section 2 focuses on FACTS classification under multiple criteria: the application, technology to the power system . Section 3 discusses the Classification of Facts Controllers Allocation Techniques Section 4 outlines and classifies the published methods. Section 5 concludes.

II. Flexible AC Transmission Systems

FACTS device can be defined as: “A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability”. FACTS can be classified under multiple criteria: the application, technology, type of connection to the power system, installation cost per MVA, dynamic response of the FACTS and some other consideration.The most studied cases from the viewpoint of application are:

- Voltage Control: SVC, UPFC, STATCOM, TCSC and TCPST/PST.
- Assets Optimization: SVC, UPFC, STATCOM, TCSC, TCPST/PST and SSSC
- Line Overload Limiting: UPFC, TCSC and TCPST/PST.
- Avoid congestion and re-dispatch: UPFC, TCSC and SVC.
- Voltage stability and collapse: STATCOM, UPFC, TCSC and SVC.
- Angle stability: UPFC, TCSC, SVC and SSSC.
- N-1 Contingency criteria fulfillment: UPFC, TCSC, SVC and STATCOM.
- Transmission cost minimization: UPFC, TCSC, SVC, TCPST/PST, SSSC and STATCOM.

III. Classification of FACTS Controllers Allocation Techniques

Three broad categories of allocation techniques for determining, best suited location of FACT controllers are sensitivity based methods, optimization based method, and artificial intelligence based techniques

A. Sensitivity Based Methods

In [24], A sensitivity based method is employed for optimal location of Flexible AC Transmission system (FACTS) device like Thyristor Controlled Series Capacitor (TCSC) by performing Optimal Power Flow (OPF) . Sensitivity based method has been addressed for Optimal location and control of shunt FACTS for transmission of renewable energy in large power systems [48].

B. Optimization Based Techniques

This section reviews the optimal placement of FACTS controllers based on various optimization techniques such as a linear and quadratic programming, non-linear optimization programming, integer and mixed integer optimization programming, and dynamic optimization programming.

Non-Linear Optimization Programming (NLP)

When the objective function and the constraints are nonlinear, it forms non-linear programming (NLP).the UPFC model includes electrical equivalent circuits, a local control scheme, and a centralized control scheme Control actions are evaluated through a nonlinear optimization process in [9]. Reference [18] suggests, modeling of the Generalized Unified Power Flow Controller (GUPFC) in a Nonlinear Interior Point OPF.

Integer and Mixed -Integer Optimization Programming (IP & MIP) Techniques

A mixed integer optimization programming algorithm has been proposed for optimal placement of Thyristor Controlled Phase Shifter Transformers (TCPSTs) in large scale power system for active flow and generation limits, and phase shifter constraints in [23].

Dynamic Programming (DP) Techniques

Differential Evolution (DE) method has been addressed to solve optimal power flow in power system incorporating a powerful and versatile Flexible AC Transmission Systems (FACTS) device such as Unified Power Flow Controller (UPFC) to minimize the total generation fuel cost and keep the power flows within their security limits [14].

C. Artificial Intelligence (AI) Based Techniques

This section reviews the optimal placement of FACTS controllers based on various Artificial Intelligence based techniques such as a Genetic Algorithm (GA), Artificial Neural Network (ANN), Tabu Search Optimization (TSO), Ant Colony Optimization (ACO) algorithm, Simulated Annealing (SA) approach, Particle Swarm Optimization (PSO) algorithm and Fuzzy Logic based approach.

Genetic Algorithm (GA)

GA and PSO is applied for Optimal Location and Parameters Setting of UPFC to Enhancing Power System Security under Single Contingencies[1].A Hybrid GA Approach for OPF with Consideration of FACTS Devices is proposed in [2] **.**GA is used for Optimal Allocation of FACTS Devices by using multi-Objective Optimal Power Flow in [20].GA is employed for the max-rnin range of power flow control on any transmission line or any set of transmission lines [22], A genetic algorithm has been addressed for optimal location of phase shifters and selection of optimal number to maximize system capabilities in [30], A multi-objective genetic algorithm approach to optimal allocation of multi-type FACTS devices for power system security is proposed in [31], GA is used to Locating unified power flow controller for enhancing power system loadability in [51].A genetic algorithm has been addressed for optimal location of phase shifters in the French network to reduce the flows in heavily loaded lines, resulting in an increased loadability of the network and a reduced cost of production [54].

Evolution Strategies (EP)

In [29] [58], evolutionary programming is employed for Optimal allocation of FACTS devices to enhance total transfer capability. Reference [39] suggests optimal placement of FACTS controllers in power systems via evolution strategies. Reference [40], a hybrid-meta heuristic method based on evolutionary computing in conjunction with sequential quadratic programming has been proposed for optimal location and placement of FACTS Device such as UPFC in power system. In [41-42], Application of a multi-objective evolutionary algorithm for optimal location and parameters of FACTS devices considering the real power loss in trans- mission lines and voltage deviation buses.

Tabu Search Algorithm (TS)

A TS algorithm has been addressed for determining Optimal Allocation of FACTS in Power Systems for optimal placement of FACTS controllers in [28] . Reference [55], a hybrid-meta heuristic method based on tabu search in conjunction with Nonlinear Programming Methods has been proposed for optimal location of FACTS Device in power system.

d. Simulated Annealing (SA) Algorithms

Reference [32], a hybrid-meta heuristic method based on SA in conjunction with PSO has been proposed to loss minimization. Hybrid TS/SA approach has been proposed for optimal placement of multi-type FACTS devices in [35].

Particle Swarm Optimization (PSO) Algorithms

In [3], a Particle Swarm Optimization (PSO) algorithm has been addressed for the solution of the Optimal Power Flow (OPF) using controllable FACTS controllers to enhance power system security. In [4],a Particle Swarm Optimization (PSO) technique has been addressed for optimal location of FACTS controllers such as TCSC, SVC, and UPFC considering system loadability and cost of installation. FACTS Allocation Based on Expected Security Cost by Means of Hybrid PSO is proposed in [5].Application of PSO technique has been addressed for optimal location of FACTS devices considering cost of installation and system loadability in [36].

Particle swarm optimization is used for optimal placement of unified power flow controllers in electrical systems with line outages in [37]. Reference [38] suggests optimal placement of multiple STATCOM for voltage stability, loadabilty.

Fuzzy Logic (FL) Algorithms

With increasing loading of existing power transmission systems, the problem of voltage stability and voltage collapse, has also become a major concern in power system planning and operation. Such problems are solved in literatures. References [16], A fuzzy logic based approach has been addressed for optimal placement and sizing of FACTS controllers in power systems.

Harmony Search (HS) Algorithm

The HS algorithm has been applied to determine the optimal location of FACTS devices such as UPFC, TCSC, and SVC in a power system to improve power system security [61].Another method for placement of multi-type FACTS devices such as SVC, Thyristor Controlled Phase Angle Regulators (TCPARs), and UPFC using HS algorithm was presented [62].

TABLE 1

TAXONOMY OF THE REVIEWED MODELS

References	No of Devices	Type	Method	Design variables	Objective	Objective function
1	single	UPFC	GA+PSO	Location+parameter setting	single	Power systems security
2	two	TCSC+TCPS	Hybrid GA	Location	single	minimum cost
3	single	UPFC	PSO	Location	single	cost
4	multiple	SVC+TCSC+UPFC	PSO	Location	multiple	loadability+cost
5	single	TCSC	pso	Location+parameter setting	single	Cost
6	single	TCPS	power thyristor technology	Parameter setting	single	AC Power transmission
7	multiple	Phase shifter+SVC	optimization	location+size	multiple	power flow and voltage control
8	multiple	SVC+TCSC	current injection	Location	single	Power system security
9	single	UPFC	non linear model	Parameter setting	multiple	Static and dynamic security
10	single	phase shifter	integrated OPF	Parameter setting	single	Power system security
11	multiple	TCSC+TCPS+OLTC+UPFC	Fuzzy based method	Parameter setting	multiple	power flow solutions
12	multiple	STATCOM+SSSC+SVC	transient stability model	Parameter setting	multiple	voltage and angle stability
13	multiple	SVC+UPFC	OPF based ATC enhancement model	Location	single	Transfer capability enhancement
14	single	UPFC	DE	Location+parameter setting	multiple	Cost+Security
15	single	TCSC	TCSC power flow model	Parameter setting	single	Power flow
16	multiple	UPFC+TCSC+SVC	FACTS Devices model in NR	Location	multiple	Voltage profile and loss
17	single	UPFC	LP based OPF	Location + parameter setting	multiple	to relieve over loads and voltage profile
18	single	GUPFC	Non linear nterior point method	Location	multiple	voltage control ,active and reactive power flows
19	multiple	TCSC+UPFC	Linearized (DC) Network model	Location	single	POwer flow control
20	single	UPFC	GA	Location	multiple	loadability+cost
21	multiple	TCSC+UPFC	Optimization based method	Parameter setting	single	maximize transfer capability
22	multiple	TCSC+UPFC	GA	Parameter setting	single	POwer flow control
23	single	TCPST	Mixed Integer Linear Programming	Location + parameter setting	single	Maximize loadability
24	single	TCSC	sensitivity analysis	Location	single	minimizing total system cost
25	multiple	SVC, TCSC, TCVR, TCPST&UPFC.	GUI Based GA	Location + parameter setting	single	Maximize Power systemloadability
26	multiple	TCPAR+UPFC	SCOPF	Location	single	Global optimal solution
27	single	UPFC	FACTS Operation algorithm	Parameter setting	single	Power system security
28	single	UPFC	parallel tabu search based method	Parameter setting	single	maximize transfer capability
29	multiple	TCPAR+TCSC+SVC+UPFC	EP	Location	single	enhance total transfer capability

30	single	TCPAR	GA	Optimal number +location	single	maximizing system capabilities
31	multiple	FACTS Devices	GA	OPtimal allocation	single	Power system security
32	multiple	FACTS Devices	SA/PSO Techniques	optimal placement	single	Active power loss minimization
33	single	TCSC	OPF	Location	multiple	static security and reduce losses
34	multiple	FACTS Devices	Location index	Location	single	steady state stability
35	multiple	multi type FACTS Devices	hybrid TS/SA Approach	placement of FACTS devices	single	cost
36	multiple	FACTS Devices	pso	optimal placement	single	cost of installation and loadability
37	single	UPFC	pso	optimal placement	single	Power system security
38	multiple	STATCOM	PSO	placement of STATCOM+Size	single	Voltage stability Margin,losses,loadability
39	multiple	FACTS Devices	Evaluationary strategies	Location	multiple	loadability,security
40	single	UPFC	EP AND sqp	placement and control	single	Power flow
41	multiple	FACTS Devices	Evolutionary programming	location +parameter setting	multy	active power loss minimization& voltage deviation
42	multiple	UPFC devices	evolutionary optimization techniques	Location + parameter setting	single	Transfer capability enhancement
43	multiple	FACTS Devices	bacterial swarming algorithm	location+parameter control	multiple	minimize real power losses,to improve voltage profile
44	multiple	FACTS Devices	group search optimizer (GSOMP)	location +control parameters	multiple	reactive power dispatch
45	multiple	FACTS Devices	Harmony search algorithm	Location	single	to improve power system security
46	multiple	TCPST+TCSC+SVC	Bees algorithm	Location + parameter setting	single	ATC enhancement
47	multiple	FACTS Devices	singular analysis of jacobiam matrix	Location	single	POWER SYstem stability
48	multiple	shunt FACTS Devices	sensitivity analysis	Location + parameter setting	multiple	voltage control ,power systems security
49	multiple	TCPAR+TCSC	power flow control technique	location +parameter setting	multiple	Congestion management
50	single	FACTS Devices	power flow control technique	Location	single	loadability,losses stability
51	single	UPFC	GA	Location	single	loadability
52	multiple	shunt FACTS Devices	line model	Location	multiple	voltage,power flow
53	multiple	SVC TCSC STATCOM	extended voltage phasor approach	Location	single	Transient stability
54	multiple	series FACTS Devices	GA	Location	single	Loadability,Cost
55	single	FACTS Device	tabu search+ nonlinear programming	Location	single	opf
56	multiple	shunt FACTS Devices	GA	Location	single	Optimal power flow
57	single	UPFC	controlling of UPFC	Location	single	power transmission control
58	single	UPFC	EP+SQP	placement and control	single	power flow control
59	multiple	fACTS Device	GA	Location	single	Congestion management
60	single	UPFC	augmented lagrangian multiplier	Location		steady state perfomance,increases loadability
61	multiple	UPFC, TCSC, and SVC	Harmony search algorithm	placement	single	Power system security
62	multiple	SVC ,TCPAR UPFC	Harmony search algorithm	placement	single	cost

IV.CONCLUSION

This paper presents a bibliographical survey of the published work on the application of different heuristic optimization techniques to solve the problem of optimal placement and sizing of FACTS devices in power systems. Various heuristic optimization techniques that have been used to address the problem are summarized and classified. The paper also provides a general literature survey and a list of published references as essential guidelines for the research on optimal placement and sizing of FACTS devices.

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