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# A Review on the Determination of Optimal Location and Size of FACTS Devices

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**Abstract: S**in the optimal location, appropriate DG unit sizes needs to position in order to present maximum economical environmental, as well as for the technical advantages. Due to the potential solution for some problems such as scarcity of transmission capacities and maximizing the consumption of power, the DG sources have received good attention. The optimal sizing and positioning of DG are essential to enhance the stability and reliability. In spite of presenting several studies on research for the appropriate positioning of DG, the methodical principle for this problems are still an uncertain issue. In fact, the main issue is the complexity of this procedure. In this paper, several research works in the field of best positioning and sizing of FACTS is examined. Here, classification of several approaches is also discussed, which is exploited to resolve the issue of best location as well as sizing, is explained with the various kinds of objectives utilized. The several constraints considered in this research work are losses of power, improvement of stability of voltage and deviation of voltage, reduction of optimal installation cost, minimization of cost of energy, improvement of bus voltage, etc.

**Keywords**—Optimal Location; Sizing; FACTS; Metaheuristic; Powerless; Voltage Deviation

| Acronym | Description |
|---|---|
| DG | Distributed Generation |
| ICA | Imperialistic Competitive Algorithm |
| BSOA | Brainstorm Optimisation Algorithm |
| CABC | Chaotic Artificial Bee Colony |
| TLBO | Teaching Learning Based Optimization |
| MOPI | Multi-Objective Performance Index |
| PFDE | Pareto Frontier Differential Evolution |
| PSO | Particle Swarm Optimization Algorithm |
| HMSFL | Hybrid Modified Shuffled Frog Leaping |
| GSA | Gravitational Search Algorithm |
| FACTS | Flexible Alternating Current Transmission System |
| VSI | Voltage Stability Index |
| GA | Genetic Algorithm |
| SVC | Static VAR compensator |
| RDS | Radial Distribution System |
| ABC | Artificial Bee Colony |
| TCSC | Thyristor Controlled Series Capacitor |
| ACO | Ant Colony Optimization |
| STATCOM | Static Synchronous Compensator |

## I. INTRODUCTION

In order to indicate the small-scale electricity generation, the phrase DG is often exploited [16]. Nowadays, DG is very trendy due to the utility of electrical energy enhancements with the demand [18]. The DG system minimizes the emissions of the greenhouse gases, enhances the security of energy, and maximizes the power reliability and quality [17]. Mostly the distribution system minimizes because of the DG sizing and placement. In RDS, the minimization of power losses is attained with improved voltage regulation and improvement of stability of voltage. However, the primary reason of the DG is to perform as a basis of active electric as well as nonreactive power.

For assigning the DG units, there are diverse problems, and therefore several optimization approaches are developed that is alienated into best size and positioning problem optimizations. Here, the heuristic, analytical as well as deterministic-approaches are exploited for enhanced optimization. More approaches such as

Tabu search method [19], GA [8], PSO [10], ACO [20], and ABC [6] have been developed in several researches. In recent times, the amalgamations of methods are exhibited in several works. The confronts faced in assigning the DG units such as the reduced security, optimal position, and sizing, voltage instability, fluctuations in the circuit level, difficulty, penetration level. Hence, these confront should be given significance, as well as numerous research works, are presented about the procedure of discovering the best solution in FACTS devices [21].

In 1988, Hingorani introduced the idea of flexible AC transmission system [22]. The conventional ideas and practices of the power system are changed in the deregulation of the electricity market. By installing FACTS devices [27] [28], the enhanced exploitation of the conventional power system is to maximize capacities, which becomes vital [23]. In the world, the power grid of the electric is one of the largest man-made machines. This machine comprises of transmission lines, synchronous generators, transformers active/reactive components, switches and relays, and controllers.

Generally, the FACTS controllers are exploited in order to solve several steady states in power system control issues. Nevertheless, current studies expose that FACTS controllers have exploited to improve the stability of the power system also to their most important function of power flow control [25]. By an AC transmission line, it recognized the power flow as an impedance function of line. Also, phase as well as the amplitude angle among the receiving end voltages and the sending end voltages, are recognized. In network power system, the reactive and active power flow in the lines is controlled by means of appropriate coordination of FACTS devices [24]. Moreover, FACTS devices enhance voltage profile, power transmission capacity, improving power system stability. In maximizing the transmission capacity and enhancing power system stability, the FACTS devices are recognized to be effectual. However, to use their advantages their locations, types and capacities should allocate appropriately. A number of substitute formulations for best positioning and sizing of FACTS is proposed [2] [3] [4] [5] [6] and [7].

On the basis of the size and placement of the added compensators, the advantages of reactive power compensation depend [26]. Due to economic considerations, the improvement of shunt controllers is unfeasible as well as redundant in all buses. For Var compensators, recognizing the optimal location engrosses the computation of steady-state constraints for the network. On the other hand, due to the nonlinearity of the load flow model, the issue happens to extremely multifaceted, furthermore a wide study need to carry out to resolve it. Various examinations on the exploit of these controllers have been conducted and described in the literature for voltage as well as angle stability applications. In power system, a variety of approaches are exploited in order to optimize the assignment of these devices.

## II. LITERATURE REVIEW

In 2013, Hasan Doagou-Mojarrad *et al.* [1] developed an interactive fuzzy satisfying approach that was on the basis of the HMSFL method. In the distribution network, it can resolve the issue of the Multi-objective best sizing as well as placement of DG units. In addition, objective functions of the proposed method were modeled using fuzzy sets.

In 2016, Bahram Poornazaryan *et al.* [2] presented a novel index to attain the best location and sizing of DG unit. By load variations, it can minimize losses as well as it improves the voltage stability. A novel ICA-based method was developed to resolve the optimization issue.

In 2015, A. Rezaee Jordehi [3] proposed a BSOA, which was used to discover the optimal location as well as the setting of FACTS. The SVC and TCSC were exploited for both shunt and series FACTS compensators. The experimental outcomes exhibit that the SVC and TCSC tend to minimal values of overloads, voltage deviations, as well as losses than the conventional methods.

In 2014, ThanhLong Duong *et al.* [4] proposed the minimum cut approach on the power system. In addition, it was exploited to minimize the search space and to determine the optimal set of TCSC devices the Kirchhoff's law of current was utilized. Finally, the results showed the efficiency of the method on the IEEE 6, 30 and 118 bus systems.

In 2017, Satish Kansal *et al.* [5] proposed a hybrid method for best placement of multiple DGs. For the best placement of multiple DGs, the hybridization of analytical approach, as well as the heuristic search in power distribution network, was proposed in order to minimize the loss of power. Here, based on the analytical method the DGs sizes were estimated for every bus, and the PSO was exploited to determine the locations. Under operating limitations, the objective function was reduced. Enhancements in bus voltage profile, as well as the best DGs power factor, were also noticed.

In 2015, N. Mohandas *et al.* [6] presented MOPI to decide DG units for the best location and sizing. This method was exploited to enhance the voltage stability of the radial distribution system. With exploiting weighting coefficients, different technical problems were amalgamated. A CABC method was utilized to solve under several operating constraints. Here, constant power load model, real power DG units, and other voltage-dependent load methods were contemplated. The efficiency of the proposed method was demonstrated by testing it on a 69 as well as 38-node RDS.

In 2011, Sajad Rahimzadeh and Mohammad Tavakoli Bina [7] studied the optimal positioning of series and parallel FACTS devices. Here, the STATCOM was chosen SSSC device as well as FACTS device as parallel devices. With respect to restructured environment, the optimization problem was formulated, and a novel objective function was interpreted. Hence, for power market participants its reduction can ease the congestion as well as equitable circumstances. In addition, an index on the basis of the objective function value was implemented in a specific designed method to resolve the best number of each FACTS device.

In 2012, Esmaeil Ghahremani and Innocent Kamwa [8] developed a GUI on the basis of the GA to try to discover the best locations. FACTS Placement Toolbox, which was a user-friendly framework, the user have a chance to select the network of the power system. Additionally, in that framework, the user can verify the settings of GA as well as decide the types as well as numbers of FACTS device in the network to be assigned. Finally, experimental outcomes demonstrate that the placement of FACTS toolbox was efficiently appropriate to discover the best values as well as the locations.

In 2014, Mohammad H. Moradi *et al.* [9] worked on three main factors, which was related with the multiple DG placement and sizing process was inspected by a multi-objective optimization method. These factors include power losses, voltage stability, as well as network voltage variations. To resolve the multi-objective optimization issue, the PFDE algorithm was exploited. Finally, the proposed approach was implemented and tested on 69, and 33-buses IEEE test systems and the outcomes exhibit that the proposed method shows higher effectiveness in finding best solutions and capability.

In 2016, Sai Ram Inkollu and, Venkata Reddy Kota [10] developed a method in order to optimize the FACTS devices. In the transmission of power systems, the stability of the voltage was maintained. In addition, PSO and the adaptive GSA approach were proposed to enhance the stability of the voltage for the transmission of the power systems. Optimal settings of the FACTS devices were determined by exploiting proposed approach. Moreover, the best sizing and location of FACTS controllers were determined by the proposed method.

In 2015, V.V.S.N. Murty and Ashwani Kumar [11] developed a VSI for best DG placement in RDS. For optimal placement, the proposed VSI technique was compared with two conventional techniques to minimize the losses of power and to enhance the profile of the voltage. The analysis was performed on dual folds of DG such as operating DG at optimal factor of power as well as operating DG at unity factor of power.

In 2017, A.S. Adail [12] presented an optimization method based on the best location of the FACTS. This method was utilized to attain the maximum electrical power quality of nuclear installations. In addition, the GA was employed for the optimal FACTS allocation issue. In IEEE 30-bus test system, the developed approach was tested; the outcomes demonstrate its efficiency, system voltage profile enhancement as well as minimize the power losses with a restricted number of FACTS.

In 2017, Rahul Agrawal *et al.* [13] proposed a novel optimization approach named TLBO. This method was exploited to determine the elective location as well as the rating of TCSC for the contemplated power system. It demonstrates a widespread approach for TLBO method. From the experimental analysis, it is evident in the power system that after the positioning of the TCSC, reactive and active loss of the power for the line was minimized as well as the voltages of the buses were enhanced.

In 2013, K. Ravi and M. Rajaram [14] proposed an Improved PSO for enhancing the performance of the power system. Recent times, the PSO approach was exploited to resolve the power engineering optimization issues, which shows enhanced outcomes than the conventional approaches. However, the PSO fails to provide global outcomes because of the slow convergence as well as the local minima. Hence, an application of IPSO was proposed to overcome aforementioned disadvantages for best allocation and STATCOM sizing and reduces the deviations of voltages in a power system at all the buses.

In 2017, K. Kavitha and Neela [15] proposed novel solution techniques for the best allocation of FACTS device. Additionally, it was exploited under deviating load of the system for improvement of system security. For improving the power system security, the competence of the best positioning of SVC, UPFC, TCSC, as well as combined TCSC-SVC, with respect to reducing the loading of line and deviations of load voltage. For the best location of several FACTS devices, the developed methods on standard IEEE bus test systems were examined by performing case studies.

## III. DETAIL SURVEY ON OPTIMAL LOCATION AND SIZING OF FACTS DEVICE

In power system, both the static and the dynamic performance can be improved using FACTS devices. Nevertheless, optimal sizing and location of the FACTS devices are used to determine the performance of the system in a cost effectual way.

### *A. Classifications of different methodologies*

Fig. 1 illustrates the taxonomy classification so as to solve the best location and sizing of the FACTS devices. Here, the classification is mostly done on the basis of the metaheuristic approach. The goal of the meta-heuristic methods is to discover the optimal position of a given number for the FACTS devices for minimization loss. Numerous metaheuristic algorithms are adopted such as Hybrid Modified Shuffled Frog Leaping and DE Algorithm [1], BSOA [3], ABC algorithm [6], GA [7] [8] [12], PSO [10] [14] [15], GSA [10] and Evolutionary optimization techniques [13]. However, the other methods are used for the optimal location and sizing is ICA [2], Min-cut algorithm [4], Hybrid approach [6], Pareto Frontier Differential Evolution [9] and VSI [11].\

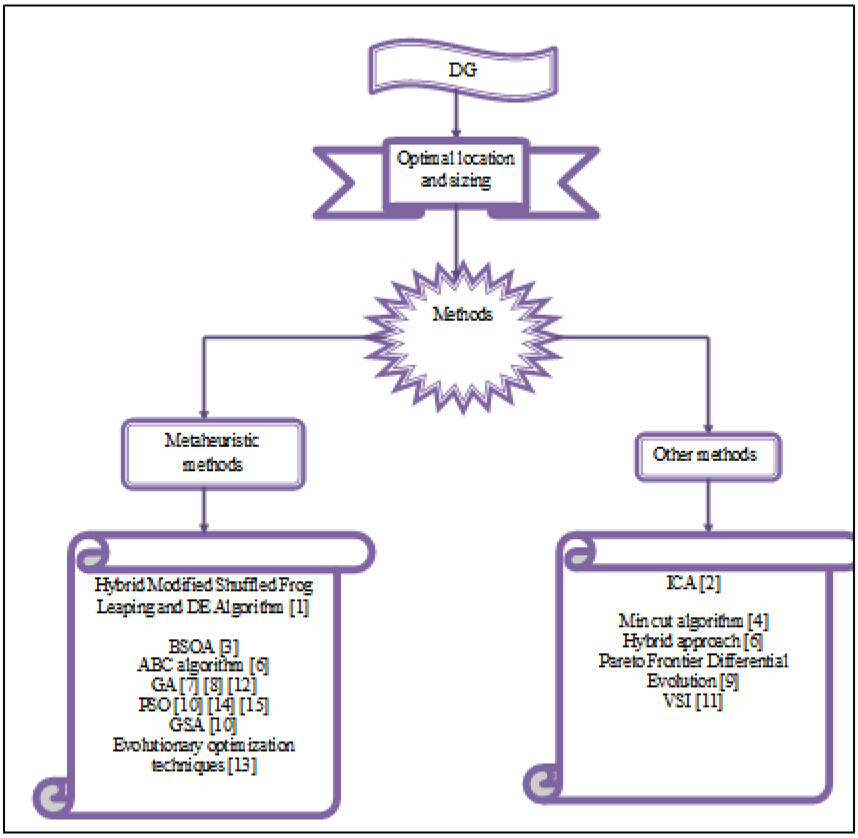


Fig. 1. Taxonomy Classification of different methodologies to solve the optimal location and sizing problems in FACTS devices

*B. Performance Analysis of the state-of-art-Metrics*

In the literature, various measures are reported to comprehend the performance of the best position as well as sizing of the FACTS devices. This review discusses some well-known measures that obtained a huge interest in the past decade among the researchers. The measures exploited in the literature are discussed in Table I. Here, the optimization methods have played a crucial role. The most important measures contemplated by many researchers are power loss, cost of energy, voltage stability, voltage deviation, system loadability, optimal installation cost and bus voltage.

Among the measures, the power loss is exploited by 53% researchers as well as the voltage deviation by 27% researchers. The next widely exploited measures such as cost of energy, network scheduling, load variations, voltage stability and bus voltage, which contribute 13% and 41% in the literature.

TABLE I. ONLY USED METRICS TO INVESTIGATE THE PERFORMANCE OF THE FACTS DEVICES

| Citation | Power loss | Cost of energy | Network scheduling, | Load variations | Voltage deviations | Optimal installation cost | Voltage stability | Bus voltage | Others |
|---|---|---|---|---|---|---|---|---|---|
| [1] | √ | √ | | | | | | | |
| [2] | | | √ | √ | | | | | |
| [3] | √ | | | | √ | | | | |
| [4] | | | | | | √ | | | √ |
| [5] | √ | | | | | | | | |
| [6] | √ | | | | | | | | |
| [7] | | | | | | √ | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| [8] | | | | | | | | | √ |
| [9] | √ | | √ | | | | √ | | |
| [10] | √ | | | | | | | √ | |
| [11] | √ | √ | | | | | | √ | |
| [12] | | | | | | | √ | | |
| [13] | √ | | | | √ | √ | | | |
| [14] | | | | | √ | | | | √ |
| [15] | | | | √ | √ | | | | |

*C. Performance Measures of Objective Functions*

In recent years, many researchers are focused on best sizing and placement of the FACTS devices in order to enhance the reliability. In this section, a lot of research work is reported based on the best placement as well as sizing with the conventional objective function by considering its performance measures, which is shown in Table II. The optimal installation is solved by various researchers exploiting various metaheuristic approaches, and its maximum value is 321.165. The load variation maximizes the load carrying capacity of the lines that assist to enhance the reliability of distribution system. The majority of the research works reported on optimal placement of FACTS devices, which focuses mainly on power loss and very less work is reported on voltage stability and bus voltage. Few of the reported work on reliability enhancement in FACTS device is focused on few objective functions namely the optimal installation cost as well as network scheduling. Effect of line loss, system loadability and convergence rate is not addressed by many researchers.

TABLE I. MAXIMUM VALUES OF DIFFERENT METRICS FOR OPTIMAL SIZING AND LOCATION OF FACTS DEVICES

| Citation | Measures | Maximum value |
|---|---|---|
| [1] [3] [5] [6] [9] [10] [11] [13] | Power loss | 0.0335 |
| [1] [11] | Cost of energy | 2361.89 |
| [2] [9] | Network scheduling, | 0.523 |
| [2] [15] | Load variations | 560.603 |
| [14] [3] [15] [13] | Voltage deviations | 0.2852 |
| [4] [7] [13] | Optimal installation cost | 321.165 |
| [9] [12] | Voltage stability | 1.05 |
| [10] [11] | Bus voltage | 12.9151 |
| [8] | Line loss | 0.8 |
| [9] | System loadability | 0.368 |
| [14] | Convergence rate | 34 |

## IV. RESEARCH GAPS AND CHALLENGES

The determination of the best sizing as well as placement of FACTS device are considered as one of the important issues in the distribution network. In addition, the optimal positioning and sizing of the FACTS sources are intensely impacted by the losses of power in a distribution network. Several research works is performed on optimal location as well as sizing of the FACTS devices in distribution systems to attain different objectives, concurrently. Here, the voltage profile is the vital objective for the development of the quality power, which is presented by the deviation of the voltage from the voltage base. To enhance the voltage stability, the FACTS devices are positioned in the receptive buses. A multi-objective problem based on the improved reliability, enhanced voltage profile as well as reduction loss of power is needed to determine the optimal placement of the FACTS devices. Some FACTS devices require batteries to avert fluctuations of power, which results from deviations of the weather condition.

The main issue in optimal sizing, as well as placement of FACTS devices over the transmission networks, is the non-local nature of power flows as well as the requirements to regard as the wide system effects of the location of the FACTS devices. In fact, the system-wide optimization usually experiences from the “curse of dimensionality” the endeavor to precisely calculate outcomes by the record of all potential placements of FACTS devices scales exponentially with the size of the system as well as the number potential FACTS locations. However, it is impossible to implement such direct methods for huge transmission systems that comprise various components.

## V. CONCLUSION

The optimal DG placement consists of attaining the best placement as well as and sizing of the DGs to be positioned. For optimal DG placement, several techniques and approaches were exploited to attain the optimal possible outcomes hitherto with varying objectives and results. This paper presents a general idea of the research as well as the development of the metaheuristic approaches for the optimal placement and sizing issues in FACTS device, by validating and examining the various models and techniques in this field. Review of published research literature for optimal location and sizing addresses the several aspects namely losses of power minimization, improvement of stability of the voltage and deviation of the voltage, reduction of optimal installation cost, minimization of cost of energy, improvement of bus voltage, etc. Nevertheless, various researchers are concentrated on optimal positioning and sizing of FACTS devices in order to enhance the reliability. In literature, a lot of research work was reported on optimal placement and sizing with the existing objective function given power losses and investments. Moreover, this study will be more helpful for many researchers those are working with the optimal location and sizing of FACTS devices in power system.

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