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Recent Trends on Security Constrained Economic Dispatch: A Bibliographic Review

Shewit Tsegaye, Fekadu Shewarega

***Abstract*—**This paper presents a survey of articles, books and reports, which articulate the recent trends and aspects of Security Constrained Economic Dispatch (SCED). The period under consideration is 2008 through 2018. This is done to provide an up-to-date review of the recent major advancements in SCED, the state-of-the-art since 2008, identify further challenging developments needed in smarter grids, and indicate ways to address these challenges. This study consists of three areas of interest, which are very important and relevant for articulating the recent trends of SCED. These areas are: (i) SCED of power system with integrated renewable energy sources (IRES), (ii) SCED with post contingency corrective actions and (iii) Artificial intelligence based SCED.

***Keywords*—**Security constrained economic dispatch, SCED of power system with IRES, SCED with post contingency corrective actions, artificial intelligence based SCED, IRES.

I. Introduction

POWER system networks are expected to be secure, reliable and economical which is the primary task of power system operation and planning. The most frequently asked question in power system operation and planning is what output power at each generating unit should be during each dispatch in order to ensure secure and economic power supply for a specific demand [1], [2]. It is possible to answer this question by SCED.

SCED is defined as the process of allocating generation levels to the generating units in the mix, so that the system load can be supplied entirely and most economically while satisfying different security constraints [3], [4]. SCED is one of the most important optimization problems of power system operation. Several methods such as iterative method, gradient based techniques, interior point's method, linear programming and dynamic programming have been used to solve this problem since it was introduced [4]

SCED has been studied as security constrained optimal power flow (SCOPF) and there are still no clear differences between them [5], [6]. Alizadeh et al. [6] clearly articulate the definition and terminologies and discuss the latest flexibility treatments in their review. In addition, a comprehensive literature review regarding recent progresses on emerging additional flexibility requirements in power systems due to significant uncertainty and variability from increasing penetration rate of non-dispatch able generating units is presented.

In this paper a general survey of the present status of SCED is done subsequent to the comprehensive surveys done by [5]-[7]. The state-of-the-art of research in connection to multi-objective evolutionary algorithms (MOEAs), economic dispatch (ED), dynamic EED problems, EED problems incorporating wind power, EED problems incorporating electric vehicles and EED problems within micro-grids are surveyed in [8]. Several authors studied SCED with the perspective of multi-objective optimization problem [9]-[11] while others approached it with perspective of stochastic programing [4], [12]-[15].

Regardless of the differences in terminology, these authors have chronicled the major developments of optimal loading and generation scheduling [16]. In this paper, we present SCED's recent developments and altered optimization techniques to adopt a smarter grid in line with three different perspectives.

From the decomposition of SCED optimization problem perspective, there have been a development towards optimality condition decomposition (OCD) [15] and improved Bender's decomposition with contingency filtering techniques [17].

A substantial number of articles reported SCED in the perspective of artificial intelligence [18] and IRES and post disturbance corrective actions [19]. Frank et al. [18] examine the recent trend towards stochastic, or non-deterministic, search techniques and hybrid methods for OPF.

Floudas and Gounares [20] present a review on non-deterministic optimization methods developed and applied to global optimization problems to overcome the weak global search capabilities of many conventional deterministic optimization algorithms.

Researchers and graduate scholars are nowadays being interested in reviews, surveys and critics of a particular topic to help them understand state of the art and identify research direction of that particular topic. The contribution of this review is therefore, in the presentation and discussion of articles, books and reports published in the years 2008 to 2018.

Articulation of research gaps, providing an up-to-date review of the recent advancements in the SCED state-of-the-art since 2008, identification of further challenging developments needed in smarter grids, and indicating ways to address these challenges altogether with their recommendation are also the novelty of this review.

Some of the papers discussed in the following sections are under three important areas of study and these are:

Shewit Tsegaye is with the jimma institute of technology, Jimma university, Jimma, Ethiopia (corresponding author, phone: +2519 20427005; e-mail: shewit.tsegaye@ ju.edu.et or tsegayshewit@yahoo.com).

Fekadu Shewarega is with technical university of Duisburg Essen, 47048 Duisburg, Germany (e-mail: fekadu.shewarega@luni.du.de).

i. SCED of power system with IRES
ii. SCED with post contingency corrective actions,
iii. Artificial intelligence based SCED

II. SCED of Power System with IRES

The contribution of renewable resources to the energy portfolio across the world has been steadily increasing over the past few years [21]. IRES can be described as a system that harnesses two or more forms of locally available renewable energy resources to supply a variety of energy uses in efficient, cost effective and practical way [22].

One of the main challenging aspects of power system is that electrical energy cannot be economically stored in significant amounts. Therefore, a power system with IRES requires instantaneous balance between generation and demand i.e. generation scheduling, in order to alleviate the mismatch between load and availability of resources [1], [4]

Due to the increasing level of uncertainties introduced by renewable energy sources (RESs) such as wind and solar energy, traditional deterministic decision making in the electric power industry is gradually shifting towards stochastic decision making which explicitly takes into account the uncertainty in the power output of RES generators [2].

The integration of intermittent and non-dispatch able renewables like wind and solar exhibits sub-hourly fluctuations. This motivates the need for optimization at multiple timescales. RESs are highly site-specific, stochastic in nature and are fairly evenly distributed around the world with little or no costs. They are greatly dependent on the climatic conditions, geographical factors and seasons of the site under consideration [23].

The main objective in power systems operation is to supply consumers with electric power in a reliable way i.e. optimal loading is required to alleviate this mismatch. The most often used and easily available renewable resources as inputs to IRES are: Biomass, hydro, solar, wind and geothermal.

A substantial number of renewable integration studies have focused on optimization requirements of power system with high renewable penetration such as wind [24], gas [25], natural gas [26], photovoltaic (PV) [27].

Bilil et al. [27] formulated a multi-objective problem that allows optimization of both the annualized renewable energy cost and the system reliability defined as the renewable energy - load disparity (RELD). This takes into account the lack of energy as well as the exceeded weight by a penalty factor. The instability created by the integration of variable RESs made SCED complex optimization problem [14], [28], [29]. Regarding wind energy penetration, several methods have been used to solve this problem [30], [31].

Frank et al. [32] generally give state of the art, recent developments and future trends of power flow. In addition, they examines the recent trend towards stochastic, or non-deterministic, search techniques and hybrid methods for OPF. The following section presents survey of papers reported in connection to the perspective of SCED with post contingency corrective actions.

TABLE I
Papers on SCED of Power System with IRES

Ref.	Optimization Type/ tools	Objective function	Case study/Test system
[11]	MOSCOPF, HPSO-APO	Minimize total production cost, Minimize active power loss and Maximize security level	IEEE 30 bus system an Practical Indian 75 Bus system
[23]	MOSCED,	Minimize deviation of transactions and Minimize operating cost of generation	IEEE 24 Bus system
[26]	SCED, GAMS, SNOPT	Minimize production cost and Maximize security level	IEEE 30 Bus system
[2]	MO SCED-EA,HOMER, MATLAB	Minimize cost of electricity Maximize utilization of resources	IEEE test systems
[27]	MO RELD-(NSGA-II)	Optimize annualized cost and Optimize RELD	Belgium's electricity transmission system
[15]	MOSMPC SCED-OCD	Optimize operating cost and Optimize security level	Modified WECC 9-bus test system
[24]	SCED-IRESIO	Optimize operating cost and Optimize security level	IEEE 39 Bus system

III. SCED with Post Contingency Corrective Actions

With the increasing penetration of renewable generation in modern power systems, uncertainty has become one of the biggest challenges in power system operation [33]. Due to massive integration of variable generation, system operators have been enduring considerable unplanned disturbances and outages [34], [35]. SCED with post contingency corrective actions is proposed for avoiding these disturbances at the post contingency state [36].

SCED is commonly classified into two different types: preventive SCED (PSCED) and corrective SCED (CSCED). In post contingency states, PSCED does not consider rescheduling of control variables. On the other hand, CSCED can correct rescheduling within a certain limit to satisfy more contingency scenarios. To deal with the contingencies, recent advances have been made along two major avenues: (i). Contingency filtering (CF) techniques [19], [37], [38] to effectively reduce the problem size and (ii). Decomposition and parallel algorithms [39], [40] to obtain approximate global solutions efficiently.

TABLE II
Papers on SCED with Post Contingency Corrective Actions

Ref.	Optimization Type/ tools	Objective function	Case study/Test system
[34]	SCED-SDP ACF-SDP	Maximize security level (Identify feasible post contingency operating point)	IEEE 30, 57 and 118 Bus systems
[13]	MRSCED-IBD, GAMS, CPLEX	Minimizing the maximum violation ,Maximize security level and Minimize operating cost	IEEE 30, 57 and 118 Bus systems
[35]	MOSCELD-MATLAB and CPLEX	Minimize operating cost	IEEE 30 Bus system, Finish Transmission system
[38]	CSCOPF, MCSCOP, ICF	Minimize operating cost Maximize security level	IEEE 300 Bus system, Chinese (Zhejiang Province)543-bus power grid system
[19]	SC-SCED, CPLEX, API	minimize the base-case ED cost, computing Scalable Managing infeasible contingencies and maximize security level	Polish 2383-bus system

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Approaches of increasing the security level of a power system in post contingency state have been reported. Bucher et al. [41] clearly chronicled the advantages and application of probabilistic N-1 security criterion. Kaplunovich and Turitsyn [42] deployed a method for fast selection of N-2 contingencies of online security assessment.

Nowadays, power system networks are almost completely becoming a network of IRES. This leads to complex and bulky mathematical representation of their SCED objective function.

Table II gives a summary of some selected papers that focus on SCED of power system with integrated variable and intermittent RESs. These papers are studied with special interest of: Optimization type, Type of objective function and Type of Test system.

IV. Artificial Intelligence Based SCED

For the last two decades, researches have been looking for an optimization method with better global optimum searching performance and fast convergence. This quest paved a way to the understanding of heuristic or random search, optimization methods. Many of these techniques have been applied to SCED problems, including Ant Colony Optimization (ACO) [43], Artificial Neural Networks (ANN) [44]-[47], Bacterial Foraging Algorithms (BFA) [48], Chaos Optimization Algorithms (COA) [49], [50], various Evolutionary Algorithms (EAs) [51], and Tabu Search (TS) [52].

Substantial authors have presented efficient algorithms in the applications of linear and nonlinear programming methods. A wide variety of intelligent techniques have been applied in solving the ELD problems including Genetic Algorithm (GA) [53]-[56], Particle Swarm Optimization (PSO) [57]-[60] and other learning/adapting based methods [61]-[67].

TABLE III
Papers on Artificial Intelligence Based SCED

Ref.	Optimization Type/ tools	Objective function	Case study/ Test system
[4]	MOSCED-LP, QP, NFP, NCLFP, GA	Minimize cost of generation, Minimize cost of power loss and Maximize security level	IEEE 5, 30 Bus systems
[72]	LMP SCED-GA	Minimize bus LMP and Minimize total fuel cost	IEEE 14 Bus system, Indian 75 Bus system New England 39 Bus system
[73]	ELD, CSO	Minimize total fuel cost	3-Generating Units, 6 Generating Units
[74]	PED, IIA MU	Minimize total operating cost	5- Unit system 15-Unit system
[27]	MO RELD-(NSGA-II)	Optimize annualized cost Optimize RELD	Belgium's electricity transmission system
[1]	MO SCED-HGAAPI	Minimize cost of generation and Maximize security level	Cyprus Power System

Several models of the economic load dispatch problem using population-based methods have also been addressed in some works of literature, including the use of methods such as PSO [68], Evolutionary Programming [8], Bacterial Flora, Harmony Search [69], Biogeography-based Optimization [70] [71] and Seeker Optimization Algorithm. Selected papers on artificial intelligence based SCED are given in Table III.

V. Discussions and Research Directions

Researchers and graduate scholars can use this review to help them understand state of the art and identify research direction of SCED. Fig. 1 depicts the general theme of this review.

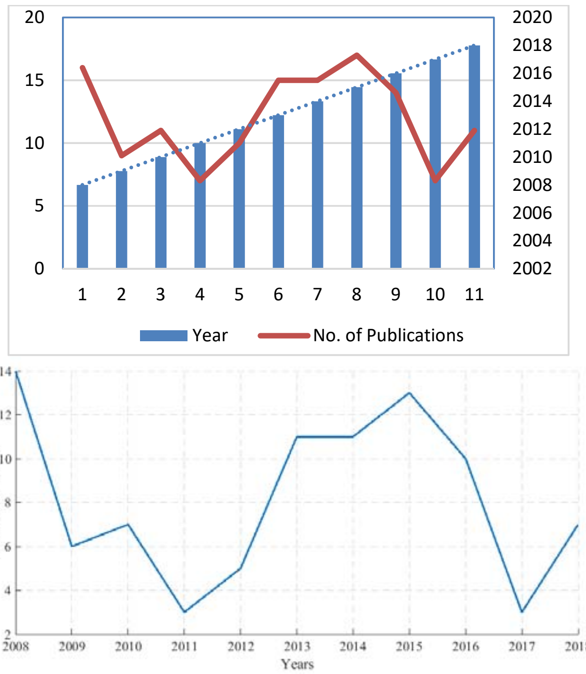

Fig. 1 State of the Art of SCED publications

In one decade, 82 papers of SCED have been reported. We have tried to include as much descriptions of the contents as possible in order to show the important and unique aspects of each paper.

Our attempt is not directed at evaluating and comparing relative performances of the existing algorithms but at presenting a clear picture of state of the art of SCED.

As it can be seen from Fig, 2, there is a growing interest on SCED with IRES and artificial intelligence based SCED. It is our belief that this trend will continue as long as faster computers and more efficient optimization algorithms keep evolving. It is obvious from this survey that SCED of a power system with IRES and artificial intelligence based SCED are important areas of future research.

Considering post disturbance corrective actions, formulating an intelligent searching algorithm with fast convergence, and taking into account the intermittency of all recently innovated RESs are some of the future research areas of SCED.

VI. Conclusions

This paper presents a survey of papers, books and reports that articulate the recent trends and aspects of SCED. The period under consideration is 2008 through 2018. This is done to provide an up-to-date review of the recent major advancements in the SCED. State-of-the-art since 2008, identifies further challenging developments needed in smarter grids and indicates ways to address these challenges are also part of this review.

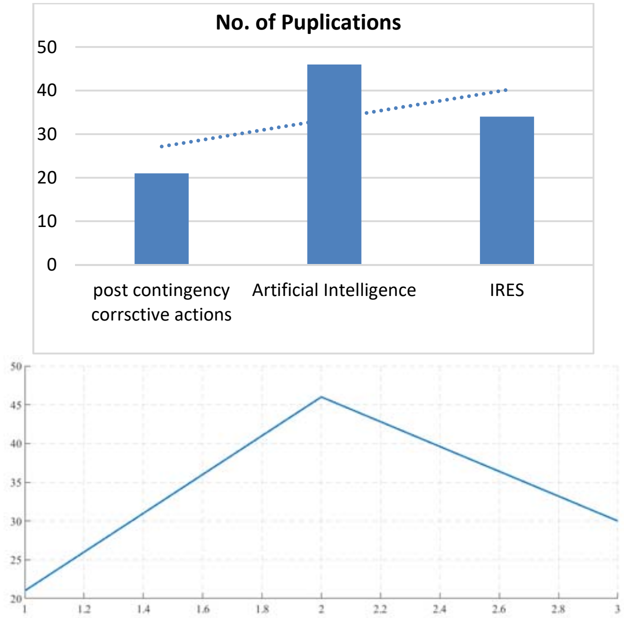

Fig. 2 No. of publications by area of interest

The study has been conducted in three categories of perspectives and areas of interest, which are very important and relevant for articulating the recent trends of SCED.

The novelty of this review lies on the articulation of research gaps, providing an up-to-date survey of the recent major advancements in the SCED state-of-the-art since 2008, identification of further challenging developments needed in smarter grids, and indicating ways to address these challenges altogether with their recommendation.

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Shewit Tsegaye received Bachelor of Science (B.Sc.) degree from Ethiopian institute of technology-Mekelle (EiT-M) in electrical and computer

engineering in 2013 and masters of Science degree in electrical power engineering from Jimma institute of technology in 2016. He is currently a PhD scholar of power systems engineering at the Addis Ababa University and Enel foundation/open Africa power fellow. His research interests are integrated renewable energy, artificial intelligence based optimization of power systems and power system economics.