UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

DYNAMIC ECONOMIC DISPATCH FOR POWER SYSTEM

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in partial fulfilment of the requirements for the degree of Master of Electrical Engineering (Industrial Power)**

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2016

DECLARATION

I declare that this dissertation entitled “Dynamic Economic Dispatch for Power System” is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Saif Tahseen Hussein

Date : 16 / 06 / 2016

APPROVAL

I hereby declare that I have read this dissertation and in my opinion, this dissertation is sufficient in terms of scope and quality as a partial fulfillment of Master of Electrical Engineering (Industrial Power).

Signature	:	
Supervisor Name	:	Datuk Prof. Dr. Mohd Ruddin Bin Ab Ghani
Date	:	16 / 06 / 2016

DEDICATION

I dedicate my dissertation work to my family. A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears. My brothers have never left my side and are very special.

ABSTRACT

The research work in this dissertation deals with dynamic economic dispatch problem for large power systems. The work mathematically proves the dynamicity of the economic dispatch. Many physical and operational constraints were considered in the model of the dynamic economic dispatch problem. The problem is to optimize the total generation costs while satisfying the operational constraints. Through an appropriate utilization of the structural features of the model, a solution algorithm based on Particle Swarm Optimization is developed. The performance of the PSO-based developed algorithm was tested on simple case studies with a small number of generation units and limited constraints, and then on more complex case studies with a large number of variables and complicated constraints. The solution algorithm based on a constraint relaxation and period-by-period is developed and tested. The last part of the dissertation is dedicated to the comparison of solution results obtained by using PSO method and the Dantzig-Wolfe decomposition method for different cases of size and complexity. This research finds large variable size DED problems can be easily implemented, PSO method is reliable and is suitable for real-time analysis. Also, time-segmentation of the solution, or as known as a period by period solution, always results in sub-optimality, while, only by solving the optimization problem in totality can lead to an optimal solution. By modifying constraints, the method can provide alternate solutions to the dispatcher. Trade-offs between the level of convergence to the global solution and the required execution time necessitate finding a mean to enhance the social component and determine an appropriate value that leads to limiting the search space of the swarm.

ABSTRAK

Kerja-kerja penyelidikan dalam disertasi ini berkaitan dengan dinamik masalah penghantaran ekonomi bagi sistem kuasa besar. Kerja-kerja ini secara matematik membuktikan dynamicity daripada penghantaran ekonomi. Banyak kekangan fizikal dan operasi telah dipertimbangkan dalam model masalah penghantaran ekonomi yang dinamik. Melalui penggunaan yang sesuai ciri-ciri struktur model, algoritma penyelesaian berdasarkan Particle Swarm Optimization dibangunkan. Prestasi algoritma maju yang berpangkalan di PSO telah diuji ke atas kajian kes mudah dengan sebilangan kecil unit penjanaan dan kekangan terhad, dan kemudian pada kajian kes yang lebih kompleks dengan sejumlah besar pembolehubah dan kekangan rumit. Algoritma penyelesaian berdasarkan kelonggaran kekangan dan tempoh demi tempoh dibangunkan dan diuji. Bahagian terakhir disertasi didedikasikan kepada perbandingan keputusan penyelesaian diperolehi dengan menggunakan kaedah PSO dan kaedah penguraian Dantzig-Wolfe bagi kes-kes yang berbeza saiz dan kerumitan. Kajian ini mendapati saiz berubah-ubah besar masalah DED boleh dilaksanakan dengan mudah, kaedah PSO boleh dipercayai dan sesuai untuk analisis masa nyata. Juga, masa segmentasi daripada penyelesaian, atau dikenali sebagai tempoh oleh penyelesaian tempoh, sentiasa menghasilkan sub-optimaliti, manakala, hanya dengan menyelesaikan masalah pengoptimuman pada keseluruhan boleh membawa kepada satu penyelesaian yang optimum. Dengan mengubahsuai kekangan kaedah PSO ini dapat menyediakan penyelesaian alternatif penghantaran ekonomik. Keseimbangan antara tahap penumpuan kepada penyelesaian global dan masa pelaksanaan yang diperlukan memerlukan Malaysia mencari satu cara untuk meningkatkan komponen sosial dan menentukan nilai yang sesuai yang membawa kepada mengehadkan ruang carian daripada kawanan.

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LIST OF ABBREVIATIONS

ABC	Artificial Bee Colony
ACO	Ant colony optimization
AIWF	Adaptive Inertia Weight Factor
APSO	Adaptive PSO
CEED	Combined Economic Emission Dispatch
CEED	Cost and Emission Economic Dispatch
CF-IW	Constriction Factor and Inertia Weight
CO2	Carbon Dioxide
CPSO	Canonical PSO or Chaotic PSO
DED	Dynamic Economic Dispatch
D-W	Dantzig-Wolfe
ECD POZ	Economic Cost Dispatch with Prohibited Operating Zone
ECD-MF	Economic Cost Dispatch with Multiple Fuel
ECD-VPL	Economic Cost Dispatch – Valve Point Loading
ECD-VPL-MF	Economic Cost Dispatch – Valve Point Loading-Multiple Fuel
ED-POZ	Economic Dispatch with Prohibited Operating Zone
EPSO	Enhanced PSO
GA	Genetic Algorithms
G_best	Global best
GCPSO	Global vision of PSO with Constriction Factor
GWPSO	Global vision of PSO with Inertia Weight

HDE	Hybrid Differential Evolution
HGPSO	hybrid gradient search PSO
LCPSO	Local vision of PSO with Constriction Factor
LWPSO	Local vision of PSO with Inertia Weight
MAED	Multi-Area Economic Dispatch
MAEED	Multi-Area Emission Economic Dispatch
MIPSO	Multi-Pass Iteration PSO
MOPSO	Multi-Objective Particle Swarm Optimization
MPSO	Modified Particle Swarm Optimization
NO2	Nitrogen Dioxide
NPSO	New PSO
OPF	Optimal Power Flow
P_best	Personal best
POZ	Prohibited Operating Zones
PQCF	Piecewise Quadratic Cost Function
PSO	Particle Swarm Optimization
PSO-CF-IW	PSO with Inertia Weight and Constriction Factor
PSO-LVIW	Particle Swarm Optimization - Linearly Varying Inertia Weight
PSO-LVIW	Particle Swarm Optimization-Linearly Decreasing Inertia Weight
RRL	Ramp Rate Limits
SO2	Sulphur Dioxide
SPLS	Synchronous Particle Local Search
SQP	Sequential Quadratic Programming
UC	Unit Commitment
VURMFIPSO	Velocity Update Relaxation Momentum Factor-Induced PSO

LIST OF PUBLICATIONS

The following publications have been achieved by this research work:

Journals:

1. Mohd Ruddin Ab Ghani, **Saif Tahseen Hussein**, M.T. Mohamad, & Z. Jano, (2015), "An Examination of Economic Dispatch Using Particle Swarm Optimization", *Magnt Research REPORT*, 3 (8), pp.193-209. **(ISI).**

2. **Saif Tahseen Hussein**, Mohd Ruddin Ab Ghani, & Zanariah Jano, (2016), "Dynamic Economic Dispatch Problems: PSO Approach", *Indian Journal of Science and Technology (INDJST*), **(ISI/Scopus).** *(Under Review).*

3. Mohd Ruddin Ab Ghani, **Saif Tahseen Hussein**, Zanariah Jano, & Tole Sutikno, (2016), "Particle Swarm Optimization Performance: Comparison of Dynamic Economic Dispatch with Dantzig-Wolfe Decomposition", *TELKOMNIKA (Telecommunication Computing Electronics and Control)*. **(Scopus).** *(Under Review).*

CHAPTER 1

INTRODUCTION

1.1 Introduction

The study of economic dispatch problem is of crucial importance as the significant amount of cost can be saved by proper allocation of power generation from different power plants in meeting the demands of the consumer. The economic dispatch problem is challenging since the demand is not static but varies with time. Thus, the supply from different generators needs to be evaluated optimally so as to meet the demand. The pragmatic, dynamic economic dispatch optimization problem has to deal with a number of constraints such as ramp rate limits, group and emission constraints. Plethora of solution techniques has been reported to solve such dynamic problems. In this study, Particle Swarm Optimization PSO technique is used to solve some complex but practical economic dispatch problems.

1.2 Power System Economic Operation

More than three-fourth of power generated in this world is through non-reusable resources like coal and gas. As these resources are limited, there is need to spend them judiciously. Thus, optimization plays a key role in the thermal generation problem. In this problem, fuel cost is minimized, and supply-demand matching is the equality constraint. This is referred to as the economic dispatch problem. In the 1920s, such problems were treated as static where the demand remained fixed for a given time (Happ, 1977).

In the present scenario, the problem is more complex as demand varies with time resulting in suitable adjustment by each power plant to supply accordingly. Such time-varying demand-supply problems are termed as dynamic economic dispatch (DED) problems. Using optimization, a significant amount of power and cost can be saved. *There is a saying, power saved is power produced.*

1.2.1 Unit Commitment

Unit commitment (UC) attributed to optimizing production level and schedule for power systems. The optimization task for each generating unit in the power systems over a given period of time are constrained to satisfying device and operating conditions (Ab Ghani, 1989) and (Ruiz et. al., 2009).

The aims of UC study is to find functional schedules for generation units to optimize the operation of power systems. Nevertheless, many researches solving approaches differently, especially in the stochastic approaches, which complicate their engagements and makes it difficult for new researchers to quickly comprehend the main idea.

The dynamic nature of generating unit operation span from fuel cost fluctuations, dynamicity of capacity margins due to generation and transmission, adding the fact of delays for new generation equipment to be installed. In addition to that, new plant design with higher efficiency and the provisions for alternative fuels countered with the ageing of equipment have made the unit commitment UC a very important parameter in the economy of energy market. Adding to that, the increased popularity of co-generation, the change of minimum-maximum demands profile impose a stringent constraint on the response of power equipment to meet the required load with all these stochastic and dynamic features.

To implement and realize the goals of power generation in an economically viable environment, unit commitment UC have to be optimized accordingly and to map hourly, the operation schedule of all units or groups involved to meet different operational, design, specification, and environment constraints.

Figure 1.1, illustrates the position of UC within the power generation process. UC are located between long-term planning and real-time operation.

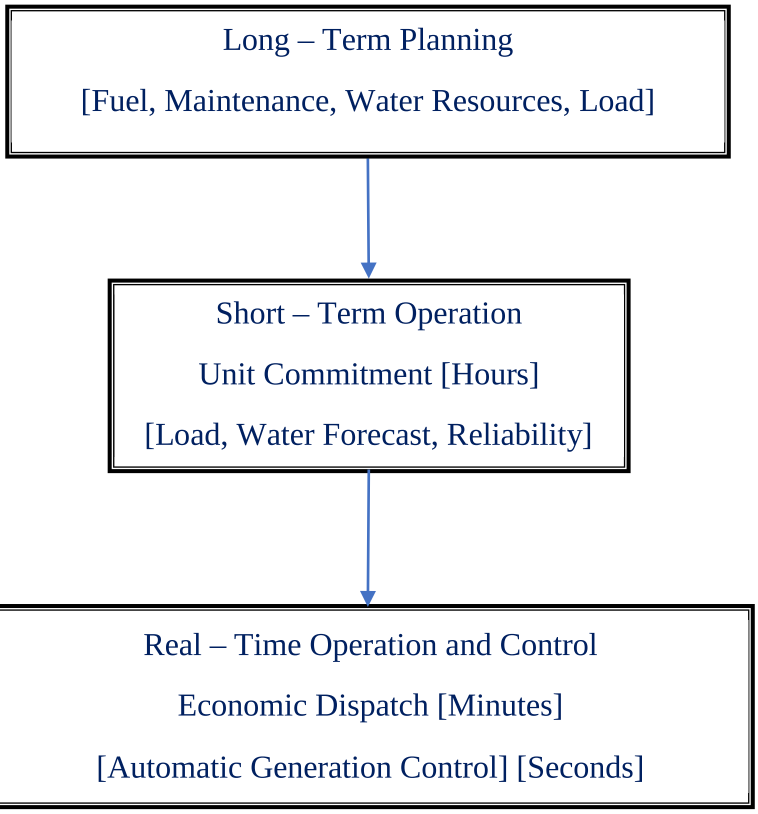

Figure 1.1 : Power system economic operation function

The definition of unit commitment in the literature span between narrow definition which pinpoint the status of the issue, in other words, only address the ON/OFF status of generators for a specified period, followed by economic dispatch ED where the time step reduced to minutes to define operation (Wright, 2013). However, broad definition of UC necessitates the determination of production level in addition to the aforementioned status (Ruiz et. al., 2009).

Considering security issue, UC classifications can vary depending on the parameters to be included. For example; conventional UC addresses security constrained within the subset of network constraints like “line outage and transmission line capacity”, while ignoring the rest of network constraints, (Pinto et. al., 2006). Market’s perspective may play an important role in defining the categories of UC (Richter, 2000), recognizing two distinctive scheduling categories based on the environment’s context; the first one deal with what is referred to as “vertically integrated environment” with cost minimization is the objective or in a what is now as “deregulated environment” where the target is to maximize the benefit, (Dai et. al., 2015). As for future’s event treatment issue, UC falls within deterministic and stochastic categories. Stochastic programming presents a natural and viable environment to solve the UC problem because the method involves a multistage decision process like UC (Wood and Wollenberg, 1996).

Summarizing this problem, unit commitment (UC) is an optimization problem used to determine the operation schedule of the generating units at every hour interval with varying loads under different constraints and environments. Many algorithms have been developed in the past five decades for optimization of the UC problem, nevertheless researchers are still working to better rationalize the problem and hybridize the solution (Saravanan et. al., 2013).

1.2.2 Economic Dispatch

The optimization problem not only has supply demand equality constraint but has to meet a number of inequality constraints as well (Ab Ghani and Hindi, 1989). The ramp rate constraint ensures safe operations of thermal generators. Some other important constraints for the DED problems are (Dai et. al., 2015; Wright, 2013; Pinto et. al., 2006; Richter, 2000; Bechert and Kwatny, 1972; Gaing, 2004);

i. Spinning reserve requirements: In addition to meeting the demand, the power plant should generate additional reserves in anticipation of a sudden surge in power demand or failure of the one or more generators.

ii. Generation capacity: Due to the limiting value of temperature and pressure conditions in a boiler, thermal power plants are constrained by the maximum capacity they can deliver.

iii. Group constraints: Due to practical considerations, often certain power stations need to be combined together in generating certain power. If one of the power plants in the group has to be shut down due to technical reasons or otherwise, the performance of other plants in that group gets degraded.

iv. Emission constraints: The thermal power plants produce gasses like carbon dioxide, carbon monoxide, sulphur dioxide. The emission content has to be restricted to specified values.

v. Security constraints: To avoid transmission lines getting overloaded, line flow limits must be added to DED problems for maintain system security.

Attempts have been made to solve the dynamic economic dispatch problem as an optimization problem for each time step. However, this approach results in sub-optimal solution (Ab Ghani, 1989). Thus, there is a need to solve DED problem as a whole optimization problem. The DED problem should also have the capability to look ahead and predict power demand at a future time.

The DED problem was first solved using the optimal control formulation (Ruiz et. al., 2009). In this approach, state equations are provided, and co-state equations need to be derived. Further, if more constraints are added or deleted, optimal control technique requires a reworking of the formulation. This is the major drawback of this method. At present, DED problems are solved using both gradient based (like, sequential quadratic programming) and stochastic methods (like Particle Swarm Optimization and Genetic Algorithm), (Ab Ghani et. al., 2015).

1.3 Research Motivation

The main objective of this study is to develop a methodology which reliably predicts optimal solution for a DED problem. The study has following practical significance:

i. The optimal solution generated will result in a significant cost saving of power generation.
ii. Alternate feasible solutions are also provided.
iii. It ensures power reserves for the dispatcher.Lower switching losses.
iv. The method helps in the automatic scheduling of the grids, and manual preparations of schedule can be avoided. This helps in saving money.
v. The method is reliable and is suitable for real-time predictions.

1.4 Problem Statement

The dynamic economic dispatch DED the problem is to minimize the objective function, which is fuel cost while satisfying several equality and inequality constraints. Generally, the problem is formulated as follows.

Regardless of the technique employed, conventional or modern, to optimize the generation level over the entire periods and with a constraining assumption, we shall examine a fundamental form of dynamic economic dispatch problem involving main types of limiting factors categorized as equality and inequality constraints.

Load demand balance is considered as equality constraints that need to be satisfied by the generation level to meet the required demand for the entire period range. The spinning reserve can augment equality constraints to account for sudden power surge and have been considered in this research study. While ramp rates are considered as inequality constraints presented to control the rate of loading and deloading of the generating units during production managements and according to the variation of the load profile of the committed units.

Other inequality constraints are also considered for more complex problems to handle several issues like the network security, bus capacity, and other regulations; this is called ‘group constraints.' Other types of constraints exist like emission control, but it has not been examined because it is outside the scope of this dissertation. Finally, Safe and stable operation range of the generation unit dictates another form of constraint which is defined by the lower and upper generation limit. These boundary conditions are considered as production envelope or generation capacity as inequality constraints.