
**UNIVERSITI PUTRA MALAYSIA**

# *SPECIAL PROTECTION AND CONTROL SCHEME BASED ON GENERATION RESCHEDULING USING DIFFERENTIAL EVOLUTION AND ELECTROMAGNETISM-LIKE ALGORITHM*

**MAHMOOD KHALID HADI**

# SPECIAL PROTECTION AND CONTROL SCHEME BASED ON GENERATION RESCHEDULING USING DIFFERENTIAL EVOLUTION AND ELECTROMAGNETISM-LIKE ALGORITHM

By

**MAHMOOD KHALID HADI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science**

**November 2016**

**DEDICATION**

I dedicate this work to the humanity, to my kind father and my beloved mother, to all my family, for their endless love, support and sacrifices.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

**SPECIAL PROTECTION AND CONTROL SCHEME BASED ON GENERATION RESCHEDULING USING DIFFERENTIAL EVOLUTION AND ELECTROMAGNETISM-LIKE ALGORITHM**

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**November 2016**

**Chairman: Mohammed Lutfi Othman, PhD**
**Faculty: Engineering**

A power system contingency phenomenon known as N−1 security criterion is a great concern in power system analysis as it involves loss of any of the system components such as line, transformer, and generator while having no loss of system demand. However, upgrading utility infrastructure including building new transmission lines to arrest the N−1 contingency condition is costly and time-consuming.

Accordingly, Special Protection Scheme (SPS) remedial strategies such as generation rescheduling, load shedding, phase shift transformers and transmission line switching can be adopted by utilities to reduce the impacts of risks caused by the line overloading without any infrastructure expansion. The main problem with the current generation rescheduling strategies, which is the main SPS technique implemented in this research, is their inefficiency in the sense that they are slow in corrective decision and costly.

The main objective of this research is designing a Special Protection and Control Scheme (SPCS) based on a hybrid approach of combining Differential Evolution (DE) and Electromagnetism-Like algorithms. This SPCS strategy, novel in the generation rescheduling application, is called as Differential Evolution with Adaptive Mutation (DEAM).

The specific aims in employing DEAM-based SPCS are to investigate a strategy to resolve the line overloading issue through the N-1 contingency based on the load flow analysis and the severity index develop SPCS scheme through the generation rescheduling strategy based on the hybrid DEAM algorithm.

The proposed algorithm is evaluated on the IEEE 30-bus test system. The performance of the proposed DEAM algorithm is validated with both the normal DE and Genetic

Algorithm (GA) in terms of the fitness convergence and generation fuel cost. The results showed that the DEAM based scheme gives better performance than DE and GA in terms of less generation fuel cost and faster fitness convergence.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PERLINDUNGAN KHAS DAN RANCANGAN KAWALAN BERDASARKAN PENGHASILAN PENJADUALAN SEMULA MENGGUNAKAN PEMBEZAAN PENILAIAN DAN KEELEKTROMAGNETAN ALGORITMA**

Oleh

**MAHMOOD KHALID HADI**

**November 2016**

**Pengerusi: Mohammad Lutfi Othman, PhD**
**Fakulti: Kejuruteraan**

Fenomena sistem kuasa kontingensi yang dikenali sebagai kriteria kawalan N-1 adalah sangat penting dalam analisis sistem kuasa kerana ia melibatkan kehilangan mana-mana komponen sistem seperti talian, transformer dan penjana, meskipun tidak melibatkan kehilangan kehendak sistem. Namun, menaik taraf prasarana utiliti termasuk membina talian penghantaran baru bagi menangani keadaan kontingensi N-1 adalah mahal dan memakan masa.

Oleh itu, strategi pemulihan Skim Perlindungan Khas (SPS), seperti penjadualan semula penjanaan, penyisihan beban, alatubah peranjakan fasa, pengalihan talian penghantaran boleh diambil oleh utiliti bagi mengurangkan impak risiko yang disebabkan oleh lebihan talian tanpa sebarang penambahan prasarana. Masalah utama strategi penjadualan semula penjanaan, yang merupakan teknik SPS utama yang dijalankan dalam penyelidikan ini, adalah ketidakcekapan iaitu lambat dalam keputusan pembetulan dan mahal.

Objektif utama kajian ini adalah mereka bentuk Skim Perlindungan dan Kawalan Khas (SPCS) berdasarkan kepada pendekatan hibrid dengan mengabungkan Algoritma Evolusi Pembeza (DE) dan seperti-Keelektromagnetan. Strategi SPCS ini yang terkini dalam aplikasi penjadualan semula penjanaan adalah dikenali sebagai Evolusi Pembeza berserta Mutasi Adaptasi (DEAM).

Matlamat saitifik dalam penggunaan SPCS berdasarkan DEAM adalah untuk mengkaji strategi untuk menyelesaikan isu talian lebih beban dengan menggunakan kontingensi N-1 berdasarkan kepada analisis aliran beban dan skim SPCS berdasarkan indeks keamatan melalui strategi penjadualan semula penjanaan berdasarkan algoritma DEAM hibrid.

Algoritma yang dicadangkan dinilai ke atas sistem uji IEEE 30-bus Prestasi algoritma DEAM yang dicadangkan telah divarikasi dengan DE normal dan Algoritma Ginetik (GA) dari segi penumpuan kebugaran dan kos bahan api penjanaan. Hasil kajian menunjukkan bahawa skim yang berasaskan DEAM memberikan prestasi yang lebih baik daripada DE dan GA dari segi kos bahan api dan penumpuan kebugaran yang pantas.

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In the name of Allah, the Most Merciful, the Most Beneficent

All praises and thanks are due to my Almighty Allah (SWT) for providing me this opportunity and granting me the capability to proceed successfully.

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My deepest gratitude and special thanks goes to my great parents, for their help and continuous moral support, continued patience and encouragement throughout my study. The help and encouragement provided by my brothers, my sisters, my wife and my children (Mustafa and Ali) are greatly appreciated, without which I would not have been able to complete my research.

I certify that a Thesis Examination Committee has met on 25 November 2016 to conduct the final examination of Mahmood Khalid Hadi on his thesis entitled "Special Protection and Control Scheme Based on Generation Rescheduling using Differential Evolution and Electromagnetism-Like Algorithm" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science .The members of the Supervisory Committee were as follows:

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| | |
|---|---|
| ACO | Ant Colony Optimization |
| ANN | Artificial Neural Network |
| BCA | Bee Colony Algorithm |
| BCGA | Binary Coded Genetic Algorithm |
| BFO | Bacterial Foraging Optimization |
| CPU | Central Processor Unit |
| DE | Differential Evolution |
| DEAM | Differential Evolution with Adaptive Mutation |
| DISCOs | Distribution Companies |
| DSM | Demand Side Management |
| EA | Evolutionary Algorithm |
| EM | Electromagnetism-Like |
| EP | Evolutionary Programming |
| FACTS | Flexible AC Transmission System |
| GA | Genetic Algorithm |
| GENCOs | Generation Companies |
| GP | Genetic Programming |
| ISO | Independent System Operator |
| OPF | Optimal Power Flow |
| PSO | Particle Swarm Optimization |
| RAS | Remedial Action Scheme |
| RCGA | Real Coded Genetic Algorithm |

| | |
|---|---|
| RSA | Random Search Method |
| SA | Simulated Annealing |
| SI | Severity Index |
| SPCS | Special Protection and Control Scheme |
| SPS | Special Protection Scheme |
| STATCOM | Static Synchronous Compensator |
| TRANSCOs | Transmission Companies |
| UFLS | Under Frequency Load Shedding |
| UPFC | Unified Power Flow Controller |
| UVLS | Under Voltage Load Shedding |

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview of the power system contingencies

Electrical energy is produced by electric power systems. Supplying continuous electrical energy to meet the system load demand is a complex technical task and involves real time estimation of a system status along with control as well as coordination of system generation units aimed to deliver electric power in a secure manner to the load. Consequently, power system network security is a worldwide considerable concern.

At any point of time, the power system operating conditions should be stable, secure in case of the event of any credible contingency, and meeting different operational criteria to keep acceptable voltages and power flows as well. The challenge of maintaining power system stability in pre and post contingency conditions has been one of the main concerns during a power system operation in order to transfer the electricity from suppliers to consumers.

Numerous power system blackouts that are caused by system instability have raised the prominence of this phenomenon (Guedes *et al.*, 2005). These issues could vary from one utility to another relying on size of a power system and the strength of the transmission infrastructure. However, the exhausted operating conditions due to some factors such as increased demand in line with continuous growth of interconnections in addition to using of modern technologies and controls which lead to emergence of other forms of the system operation instability like frequency instability, voltage instability as well as rotor angle instability. Thus, the system instability due to contingency conditions can be obvious in different patterns based on the nature of the system operating conditions, types and positions of the system disturbances (Yong *et al.*, 2006).

However, power system is being operated close to its maximum loadability according to deregulation and environmentally constraints that face the expansion of the transmission infrastructure from handling the growth of future load. Therefore, a power system is more vulnerable to critical contingencies such as failures on major system equipment and this leads to system collapses or blackouts. Accordingly, there is a necessity to install various control schemes by utilities for reducing the impacts of these risks. These schemes are called Special Protection Schemes or System Protection Schemes (SPSs) and also referred to Remedial Action Schemes (RASs) (McCalley *et al.*, 2010).

Experts all over the world have addressed that the system protection is the major concern to the transmission infrastructure. During system operation and power delivery, transmission issues are fundamentally associated with the overloading problem to the transmission network which is considered as one of the protection

challenges since utilities have limited their transmission capabilities as they were constructed primarily to serve specific demands in a specific area (Awais *et al.*, 2015).

Protecting of transmission lines against overloading (i.e. congestion) during extreme undesired disturbances is an important challenge that needs to be taken into consideration. Line overload issue may be resulted from such reasons as load perturbations, line and/or transformer outages. The overloading challenge of any transmission infrastructure based on N−1 security criteria means that the loss of any one of the power system components may lead to cascade outage or system collapse. Consequently, there is a necessity to design and install various protection and control schemes by utilities in order to relieve the impacts of these risks.

SPS schemes are designed in order to find out abnormal system situations that are associated with a contingency condition and as a result, not only isolation the faulted element, but also take pre-determined corrective actions to mitigate the consequences resulted from these conditions.

The main purposes from executing SPS schemes are specified as the following (Seyedi and Sanaye-Pasand, 2009):

i. To operate the power systems within their acceptable loadability limits.
ii. To increase power system security operation especially during severe contingencies, and
iii. To improve the power system operating conditions within the activation of control schemes due to pre-planned preventive actions.

## 1.2 Problem statement

During the power system operation and power delivery, utility transmission risks are mainly related to the overloading problem to a transmission network which considers as one of the protection challenges from system's point of view since utilities have limited their transmission capabilities as they constructed primarily in order to serve specific demand in specific zone (Awais *et al.*, 2015).

Protecting of transmission network against the overloading risk during extreme disturbances is an important challenge which needs to be taken into consideration. As mentioned previously, SPSs come into play in order to manage and overcome the power system overloading situations in N−1 contingency conditions. This is necessary since building new transmission grids to overcome the N−1 contingency conditions is costly and time-consuming (Talukdar *et al.*, 2005). Furthermore, some of the currently practiced SPS schemes that are needed to manage the generation rescheduling pattern, which is the main strategy in this research work for mitigating the power system overloading, are not efficient in the sense that they are slow and costly. Therefore, it is envisaged that a more efficient and intelligent Special Protection and Control Scheme (SPCS) has to be developed using a suitable artificial intelligence technique in place of the conventional SPS scheme to manage the generation rescheduling more efficiently.

## 1.3 Research objectives

The main aim of this thesis is to design an intelligent Special Protection and Control Scheme (SPCS) through generation rescheduling philosophy in order to mitigate the consequences of the line overloading issue during system contingency conditions.
In order to achieve that, the specific objectives of this research have been identified and outlined as follows:

i. To investigate a strategy to resolve the overloading problem of a transmission line in a power system during post contingency conditions based on the load flow analyses for a system and the severity of a contingency condition.

ii. To develop an intelligent SPCS scheme by employing the generation rescheduling strategy based on a hybrid Differential Evolution (DE) with Electromagnetism-like (EM) algorithms. The hybrid algorithm is named as Differential Evolution with Adaptive Mutation (DEAM) to overcome system contingency conditions.

iii. To investigate the performance of the proposed method on the standard IEEE test topology as well as to validate the conducted approach analysis with another conventional artificial intelligence technique namely Genetic Algorithm (GA).

## 1.4 Scope of the study

In this work, an index called Severity Index (SI) has been used to determine the severity effects of a power system contingency condition and simulated with the aid of the load flow analysis by utilizing the Newton-Raphson method through the MATLAB environment. The load flow solution is mainly considered as the standard fundamental approach to analyze the power system situation due to specific disturbances.

The outcomes of the previously mentioned index are referenced to identify which transmission lines through the transmission corridor are overloaded under different types of disturbances such as line outages scenario via base load and increased load situations that have been carried out to the IEEE 30-bus power system in order to examine the performance and validity of the employed DEAM approach. Consequently, the data collected from the investigation are used to determine the magnitudes of the output of the system generation units in order to resolve the overloading issue of the transmission grid.

The proposed algorithms are based on the Differential Evolution (DE) with Electromagnetism-like (EM) algorithms, where their results are validated with the conventional technique namely Genetic Algorithm (GA) and all the implemented algorithms have been executed within MATLAB script file and specifically M.file.

## 1.5 Thesis contribution

The main contribution of this research work is the designing a Special Protection and Control Scheme (SPCS) based on the proposed DEAM algorithm incorporating the generation rescheduling strategy to alleviate the transmission line overloading issue. Differential Evolution technique has been incorporated with Electromagnetism-like algorithm to introduce a hybrid algorithm in order to enhance the mutation operation of the conventional DE algorithm. Simulation results are compared in terms of the speed of convergence and the generation fuel cost.

## 1.6 Thesis layout

This research thesis is organized into five chapters specified as following. Chapter 1 presents the general introduction and a principle overview of power system operation to meet system demand under contingency conditions and focuses on the research problem of the thesis, research objectives, and the scope of this study.

Chapter 2 introduces a detailed literature review on the SPS schemes and its applications. The most commonly used corrective actions like the generation rescheduling plan taken by SPS in conventional and intelligent schemes to relieve the line overloading problem have been covered. Summarized review on DE, EM and GA algorithms with its applications is also given.

Chapter 3 describes the overall research methodology and specific details of the algorithms implemented in this research. It provides and discusses the load flow analysis that utilized to perform the study along with the system constraints. This chapter also includes the severity index formulation in order to evaluate the severity of a system event. The algorithms that carried out in this research are also discussed in depth along with their related operations to achieve the specific work objectives.

Chapter 4 presents the study simulation results and an in depth discussion for the system contingency analysis under different types of disturbances especially for the line outage under base and increased load demand situations. Optimization results from the application of the DEAM, conventional DE, and GA algorithms are evaluated, compared and then discussed in detail to assess the objective function of this work. A comparison study was carried out to compare between the executed algorithms.

Finally, Chapter 5 provides conclusion remarks and presents the suggestions for the future work within this particular area of work.

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