UNIVERSITI PUTRA MALAYSIA

CONTROLLED ISLANDING STRATEGY FOR POWER SYSTEMS BASED ON FLEXIBLE SEMI-SUPERVISED SPECTRAL CLUSTERING

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CONTROLLED ISLANDING STRATEGY FOR POWER SYSTEMS BASED ON FLEXIBLE SEMI-SUPERVISED SPECTRAL CLUSTERING

By

FARSHAD AZADIAN

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

June 2014

DEDICATION

To my parents

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

CONTROLLED ISLANDING STRATEGY FOR POWER SYSTEMS BASED ON FLEXIBLE SEMI-SUPERVISED SPECTRAL CLUSTERING

By

FARSHAD AZADIAN

June 2014

Chairman : Mohd Amran Mohd Radzi, PhD

Faculty : Engineering

Many blackout occurrences such as those in USA, Canada, and Italy (2003), Brazil and Paraguay (2009), and India (2012) are some evidences proving the vulnerability of current electrical power systems. Having a preventive plan is necessary to protect systems from experiencing blackout. Intentional islanding is a self-healing method with the main goal is to prevent the system from cascading outages which lead to blackout. Islanding strategy is based on splitting power systems by means of cutting lines into several smaller isolated ones called islands, so that the cascading effects and disturbances flowing in the grid are stopped. However, without considering specific constraints, these islands will not be stable and will collapse soon and even the stability of the grid worsens.

Previous methods can minimize partitioning cutsets (either power imbalance or power disruption) while fully satisfying only one constraint (slow coherency). Thus, there is a possibility that by not considering other factors during islanding, the final suggested islands are not stable enough. The framework proposed in this research is capable of handling multiple constraints applied to the system. Furthermore, unlike prior spectral clustering methods which are not capable of satisfying a constraint partially, here it is possible to define degree of satisfaction. It is a value defined for the combined constraint specifying how much satisfied constraints should be. The combined constraint is the combination of all constraints built based on preferred factors such as slow coherency and minimal power imbalance. Hence, the proposed method is called flexible semi-supervised spectral clustering for controlled islanding. In this work, slow coherency is chosen as the first and most preferred constraint, so that generators are categorized in slowly coherent groups. To generate stable islands, minimal load-generation imbalance is computed which results the second constraint. As the final step, lines with lower power flow are discovered and chosen to find minimum power flow disruption.

In order to verify applicability of the proposed framework, it is applied to two IEEE test cases: 39-bus and 118-bus. By using this framework containing several constraints, it is shown that this method of islanding generates more stable islands by causing as few as possible power flow disruption and load shedding.

The obtained results clearly confirm that the proposed framework is able to find several cutsets based on the defined constraints. This new method generates islands while considering different factors of power systems simultaneously which is expected to lead to the most stable islands, and therefore save systems from blackouts.

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

STRATEGI PEMULAUAN TERKAWAL BAGI SISTEM KUASA BERDASARKAN KELOMPOK SPEKTRUM SEPARUH FLEKSIBEL TERSELIA

Oleh

FARSHAD AZADIAN

Jun 2014

Pengerusi : Mohd Amran Mohd Radzi, PhD

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Banyakkejadian putus bekalan seperti di Amerika Syarikat, Kanada, dan Itali (2003), Brazil dan Paraguay (2009), dan India (2012) adalah beberapa bukti menunjukkan kelemahan sistem kuasa elektrik semasa. Memiliki pelan mencegah adalah perlu untuk melindungi sistem daripada mengalami putus bekalan. Pemulauandengan niat adalah satu kaedah penyembuhan sendiri dengan matlamat utama untuk menghalang sistem daripada gangguan melata yang membawa kepada putus bekalan. Strategi pemulauan adalah berdasarkan kepada pemisahan sistem kuasa melalui pemotongan talian kepada beberapa kawasan lebih kecil,yang dipanggil pulau, supaya kesan gangguan melata yang mengalir di dalam grid dihentikan. Walau bagaimanapun, tanpa mengambil kira kekangan tertentu, pulau-pulau ini tidak akan stabil dan akan runtuh nanti dan juga kestabilan grid akan menjadi lebih teruk.

Kaedah terdahulu boleh mengurangkan pembahagian set potong (ketidakseimbangan kuasa atau gangguan kuasa) sambil memuaskan sepenuhnya hanya salah satu kekangan(kejelasan perlahan). Oleh itu, terdapat beberapa kemungkinan bahawa dengan tidak mempertimbangkan parameter lain semasa pemulauan, pulau-pulau terakhir yang dicadangkan tidak cukup stabil. Rangka kerja yang dicadangkan dalam kajian ini mampu mengendalikan pelbagai kekangan yang digunakan untuk sistem berkenaan. Tambahan pula, tidak seperti kaedah kelompok spektrum sebelumnya yang tidak mampu memuaskan kekangan sebahagiannya, di sini ia boleh menetapkan tahap kepuasan kekangan. Ia adalah satu nilai yang ditetapkan bagi kekangan tergabung yang menyatakan bagaimana banyak sepatutnya kekangan yang memuaskan. Kekangan tergabung tersebut merupakan gabungan semua kekangan yang dibina berdasarkan kepada faktor-faktor pilihan seperti kejelasan perlahan dan ketidakseimbangan kuasa yang minimum. Oleh itu, kaedah yang dicadangkan dipanggil kelompok spektrum separuh fleksibel terselia untuk pemulauan terkawal.

Dalam kerja ini, kejelasan perlahan dipilih sebagai kekangan pertama dan yang paling penting, supaya penjana dapat dikategorikan dalam beberapa kumpulan kejelasan perlahan. Untuk menghasilkan pulau yang stabil, ketidakseimbangan beban-penjaanan akan dikira yang menjadikannya kekangan kedua. Sebagai langkah terakhir, talian dengan aliran kuasa yang lebih rendah diselidiki dan dipilih untuk mencari ganguan aliran kuasa yang minimum.

Untuk mengesahkanrangka kerja yang dicadangkan dapat digunakan, ia dilaksanakan dalam dua kes ujian IEEE: 39-bas dan 118-bas. Dengan menggunakan rangka kerja ini yang mengandungi beberapa kekangan, ia menunjukkan bahawa kaedah pemulauan ini menghasilkanpulau yang lebih stabil sambil menyebabkan kemungkinan gangguan kuasa dan tumpahan beban sekurang mungkin.

Keputusan yang diperolehi dengan jelas mengesahkan bahawa rangka kerja yang dicadangkan mampu untuk mencari beberapa set potong berdasarkan kekangan yang ditakrifkan dan tahap kepentingannya. Kaedah baru ini menjana pulau-pulau sambil mempertimbang ciri-ciri yang berbeza pada sistem kuasa dalam masa yang sama yang dijangka membawa kepada pulau-pulau yang paling stabil, dan oleh yang demikian melindungi sistem daripada putus bekalan.

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Finally, an honorable mention goes to my family for their love, understandings, and supports on me in completing this project.

Without helps of the particular mentioned above, I would have faced many difficulties while the progress of this thesis.

I certify that a Thesis Examination Committee has met on 26 June.2014 to conduct the final examination of Farshad Azadian on his thesis entitled "Controlled Islanding Strategy for Power Systems Based on Flexible Semi-Supervised Spectral Clustering" 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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DECLARATION

Declaration by graduate student

I hereby confirm that:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
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Signature	______________________	Signature	______________________
Name of Chairman of Supervisory Committee:	**Mohd Amran Mohd Radzi, PhD**	Name of Member of Supervisory Committee:	**Noor Izzri Abdul Wahab, PhD**

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LIST OF ABBREVIATIONS

NP	Non-deterministic Polynomial
BFS	Breadth First Search
DFS	Depth First Search
NERC	North American Electric Reliability Council
RMS	Root Mean Square
PMU	Phasor Measurement Unit
DYRNED	Dynamic Reduction
OBDD	Ordered Binary Decision Diagrams
FSE	Fault Section Estimation
MLRGPA	Multilevel Reduced Graph Partitioning Algorithm

CHAPTER 1

INTRODUCTION

1.1 Background

Rapid population growth and industrial development have caused a steep growth in energy demand. The main share of this need is provided in the form of electrical energy. To satisfy this increasing demand, power systems have to be merged and united together in order to form larger interconnected network of lines connecting loads and generators to each other [1].

Although electrical energy is supplied more efficiently in this type of network, its construction, operation and maintenance are excessively intricate and several parameters should be analyzed in order to control and guarantee its performance. Having acceptable performance in steady-state mode is necessary. However, it is essential for power systems to withstand sudden and unpredicted disturbances such as loss of some major lines, loads or generations which can completely change their power flow pattern. Power security is one of the major abilities of a network. It is defined as the ability of an electrical system to survive through sudden disturbances and catastrophic outages [2].

In the near future, there will be several factors that affect maintenance and control procedure of power systems. Distributed generation as a new form of power generation, advent of new electrical vehicles (undoubtedly future transportation will be based on electricity), and other cutting edge technologies make the control and maintenance procedure even more difficult. Thus, power systems are more vulnerable and of course recent blackouts (which are listed in detail later in Table 2.1) have proved that current power systems are not ready yet for the future demands. Specially, the blackout in U.S. and Canada in year 2003 was an eye-opening experience. Afterwards, numerous studies focused on blackouts to find their reasons, behaviors, and processes.

Generally, security concept can be divided into two main categories [2], [3]:

1- Preventive strategies: network switching, reactive compensation, and generation rescheduling.
2- Emergency control strategies: direct or indirect load shedding, generation shedding, and controlled islanding (network splitting).

Most power systems only rely on preventive strategies for their security. A comprehensive survey covering 111 different Special Protection Schemes (SPSs) in

17 countries, revealed that only 6.3% are controlled islanding schemes [4]. Furthermore, most of those schemes are predefined based on off-line study and do not represent real-time system states and operating conditions. Hence, there is a high possibility that they will not be effective enough to prevent blackouts. This investigation proved the urgent need to design and implement proper islanding strategies for power systems.

1.2 Problem statement

Islanding strategy is the last step to prevent a widespread blackout. In this strategy, the disturbed large-scale power system is forced to be split into relatively smaller isolated systems called islands. With a proper islanding method, not only all possible power is supplied for loads and major blackout is prevented, but also disturbances and their impacts are blocked from propagate into the rest of the power network. Thus, saving the power system and then having an appropriate restorative plan are totally depending on effectiveness of the islanding strategy applied to the system.

To form stable islands, the islanding strategy must consider several factors such as coherency of generators, load-generation balance, thermal limits, transient stability and power flow pattern of the system and so forth. It would be too intricate to search for islands in large-scale power systems and satisfying all those constraints. It is considered as a Non-deterministic Polynomial time (NP) hard problem. It is not even possible to anticipate whether such solutions exist. However, by considering only a sub-set of those factors, for example slow coherency and load-generation balance, now it is feasible to find proper islanding solutions by using heuristic methods. This approximation makes it possible to find islanding solutions in reasonable time.

In terms of objective functions, existing methods can be classified in two groups; considering either minimal power imbalance or minimal power-flow disruption. The first group tries to minimize the difference between load and generations in each island. While the second group, tries to minimize the implication of islanding on power flow pattern of the system. Moreover, it is observed that after disturbances, coordination between generators will be changed and some of them tend to swing together. Neglecting this phenomenon will result in unstable islands with non-coherent generators within them which will collapse soon. Therefore, it is crucial to consider the coherency between generators in each island.

One group of islanding methods are to find proper islands based only on either minimal power imbalance [5]–[7] or minimal power flow disruption [8], [9] without considering slow coherency. Since slow coherency of generators is not considered in these works, their final islands may contain non-coherent group of generators which is not desirable. Some heuristic methods are proposed to improve final answers by creating islands based on either minimal power imbalance [10]–[17], or minimal power flow disruption [18], [19] while considering slow coherency as the only constraint. Although the final solutions are more stable in these attempts, obviously several important constraints are still left unsatisfied. The first group does not consider the power flow pattern of the system during their search for proper islands. Therefore, the islanding process itself (due to quick change of flow pattern) can cause significant disruption in the system and leads to islands collapse. The second group neglects load-generation imbalance in each island which may results in islands collapse due to overloading, and unnecessary generation trimming or load shedding. Unfortunately, since it is not possible to define more than one constraint in those works, they cannot be developed any further. Obviously, it is necessary to propose a new method with the ability of handling several constraints to solve the problem. Moreover, the previous works are not able to define all types of constraints or control them. Finally, it is necessary to prepare a flexible islanding method so that final solutions can be regulated and systemized due to situation and conditions of the system.

1.3 Aims and objectives

The aim of this work is to propose an islanding framework which is capable of saving power systems from widespread blackout. In order to achieve this aim, the specific objectives are listed as follow:

1- To develop a framework for controlled islanding which can consider more than one constraint simultaneously while generating islands. Furthermore, this framework should be capable of handling both types of constraints namely full and partial constraints.
2- To develop a flexible islanding framework in which it is possible to define degree of satisfaction for constraints and find the splitting points based on them.
3- To prove the applicability and effectiveness of this new framework by applying it to IEEE 39-bus and IEEE 118-bus test cases.

1.4 Scope of work

This thesis is concerned with the preparation of a flexible multi-constraint method for controlled. To have a successful islanding strategy, three main problems should be solved. Those are:

1. Finding the appropriate time to initiate islanding.
2. Determining the best splitting points.
3. Suggesting a proper method to restore the system (also known as “black start”) after stabilizing the system.

In this thesis, it is intended to cope with the second issue. The other two issues are not in the scope of this thesis.

In order to find proper splitting points, slow coherency, minimal load-generation imbalance, and minimal power flow disruption are critical factors that should be considered to have a promising islanding. The scope of this work is to suggest a flexible multi-constraint framework for controlled islanding to consider all those parameters when determine boundaries of the created islands. In this work, it is discussed how a constraint should be defined, the proper method for creation combined constraint matrix, and how to provide a new method for controlled islanding based on flexible semi-supervised spectral clustering [20]. In this work, slow coherency and minimal load-generation imbalance (minimal power imbalance) are defined as constraints and the combined constraint is constructed based on them. Finally, minimal power flow disruption is computed as the objective function. The framework proposed here is completely independent of constraints' types, numbers, and methods used to compute them. Thus, methods which are used to compute those factors are not in the scope of this work. In this research, it is not intended to go deep in those methods or try to improve them for instance to make them faster or more precise. Methods used in this work are only suggestions and comparing them to other methods or prove their efficiency is not in the scope of this work. Finally, this research has no intention to judge about the importance of those factors. The flexibility of this method provides this option to have more than one result according to the users' preferences.

1.5 Thesis organization

A brief introduction has been presented in chapter 1. The remainder of this thesis is organized as explained further.

The literature review begins with introducing blackouts, reasons and process of blackouts, and history of major previous ones. Then, a brief discussion is brought about three closely related concepts in power systems namely power system security, power system stability, and power system reliability. After that, the controlled islanding is discussed thoroughly and important aspects of it are presented. Furthermore, previous methods of controlled islanding are reviewed. Since, the proposed method is based on graph theory and spectral clustering; these two fields are introduced and discussed in literature review. The background of spectral clustering and its development to constrained spectral clustering is reviewed. Lastly, flexible semi-supervised spectral clustering used in this research is introduced.

Chapter 3 describes application of the flexible semi-supervised spectral clustering in controlled islanding. The generator grouping based on slow coherency is utilized to obtain coherent groups. The procedure to define the result of each step as a constraint for future steps is demonstrated subsequently. Breadth First Search (BFS) algorithm is used to find the best boundaries for islands according to minimal power imbalance criterion which is the second constraint. To apply all constraints to the islanding process, a new method is defined which converts all of them into one combined constraint to be used in islanding. Lastly, based on power flow equations in power systems, while satisfying constraints; minimum power flow cutset is obtained.

The test cases for efficiency evaluation of this framework are presented in chapter 4. Two different IEEE test cases namely 39-bus and 118-bus are used to demonstrate the procedure of this strategy and to prove its efficiency in different conditions and scenarios.

Finally, chapter 5 provides the concluding remarks and proposed future works.

1.6 Summary

In this chapter, the concept of power systems security was briefly described and controlled islanding strategy and its importance to prevent cascading outages and widespread blackouts were reviewed. After presenting an overview of previous works, objectives and scope of this research work were declared and classified. At last, the layout of this thesis was described for each chapter.

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