

Power System Restoration with Renewable Participation

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Abstract—Power system restoration requires initial power sources to restart generators, energizing transmissions, and pick up critical loads. Sufficient initial power capacity is critical for restoration success and reducing outage duration. Due to the reliability requirement and high standby costs, black-start resources are scarce and expensive in areas where hydro power is not available. Variable renewable energy (VRE), whose fast-ramping capability and economical standby costs are suitable for black-start, is traditionally excluded from participation in system restoration because its uncertainty and variability could cause severe disturbance to the system that is already fragile during restoration. Recently, VRE is becoming a potential participant in system restoration as auxiliary black-start resources. This work will explore the potential benefits of renewable energy in restoration and potential ways for VRE to participate in system restoration. We propose two dispatch models for wind participation. The uncertainty of wind generation is handled by probabilistic constraints to guarantee a feasible restoration plan with a high probability. We perform computational experiments to demonstrate the effectiveness of proposed models and benefits of renewable participation in restoration with the two approaches.

Index Terms—wind dispatchability, data driven, chance constraint, mixed-integer linear program

I. INTRODUCTION

Power system resilience has become an important issue in recent years due to the increasing power outages caused by various disruptions. According to the U.S. Energy Information Administration, the observed power outage events, especially the weather-related outages, have increased by 400% from 2000 to 2012 and have incurred \$25-70 billion in costs annually [1]. Among all outage-causing weather events, hurricanes and/or tropical storms are the most damaging and widely spread ones, not only in terms of power lost (average 1.3 GW) and the number of customers affected (average 0.8 million), but also in terms of the duration of the outage and the difficulty of restoration. To mitigate the outage damages and reduce the economic and social costs, power systems must be restored to normal as quickly as possible. A typical restoration process is illustrated in Fig. 1, consisting of system

status assessment, system preparation, black-start operations, and load restoration. Note that there are variations depending on the characteristics of a specific power system. Power system restoration has been studied for many decades. However, it remains a challenging topic due to its complexity arising from the combinatorial operations (such as switch operations and start-up sequencing) and technical constraints (such as voltage security).



Fig. 1: Steps in a Typical Restoration Process

The system restoration has been studied from many perspectives. A good estimation of the restoration duration can better prepare the system operators of the electric grid and other dependent critical infrastructures. A probabilistic timing of restoration is proposed in [2]. The restoration can be performed in parallel in different islands of a system. To do this, the sectionalization of the system is important. Ref. [3] proposed a clustering-based network partitioning for parallel power system restoration. A strong formulation for system islanding and restoration was proposed in [4]. The generator start-up problem was studied in [5] and validated by an energization path search algorithm. The decreasing efficiency effect during the start-up procedure was considered in [6]. The model predictive control was employed in optimizing the start-up sequence in [7]. An online generator start-up framework was proposed in [8], where deep learning was used to predict the optimal sequence. Once the generator start-up sequence is determined, an optimal energization path should be calculated for the black-start generators to provide cranking power to non-black-start units. Additionally, a backbone transmission should be formed for online generators to pick up loads. Ref. [9] studied the skeleton-network reconfiguration to build new energization paths using discrete particle swarm optimization. An automatic restoration patch selection based on the power transfer distribution factor was proposed in [10]. A two-stage optimization was employed for recovering the network in [11]. Ref. [12] discussed the optimal skeleton-network restoration while considering generator start-up sequence and load pick-up. Once a backbone network is built with available online

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Power System Restoration

Kai Sun, Yunhe Hou, Wei Sun, Junjian Qi

Power System Restoration:

Power System Restoration IEEE Power Engineering Society. Power System Restoration Working Group, 1993 **Power System Restoration** M. M. Adibi, 2000-06-22 At a time when bulk power systems operate close to their design limits the restructuring of the electric power industry has created vulnerability to potential blackouts Prompt and effective power system restoration is essential for the minimization of downtime and costs to the utility and its customers which mount rapidly after a system blackout Power System Restoration meets the complex challenges that arise from the dynamic capabilities of new technology in areas such as large scale system analysis communication and control data management artificial intelligence and allied disciplines It provides an up to date description of the restoration methodologies and implementation strategies practiced internationally The book opens with a general overview of the restoration process and then covers Techniques used in restoration planning and training Knowledge based systems as operational aids in restoration Issues associated with hydro and thermal power plants High and extra high voltage transmission systems Restoration of distribution systems Power System Restoration is essential reading for all power system planners and operating engineers in the power industry It is also a valuable reference for researchers practicing power engineers and engineering students Sponsored by IEEE Power Engineering Society *The 37th Annual Conference on Power System and Automation in Chinese Universities (CUS-EPISA)* Pingliang Zeng, Xiao-Ping Zhang, Vladimir Terzija, Yi Ding, Yunxia Luo, 2023-04-24 This book includes original peer reviewed research papers from the 37th Annual Conference of Power System and Automation in Chinese Universities CUS EPISA held in Hangzhou China on October 23 25 2022 These papers cover topics as Evolution and development path of the power system Resilience assessment analysis and planning of power system Power system planning and reliability Modelling and simulation of novel power system Power electronic for power system stability analysis Power system relay protection and automation and so on The papers included in this proceedings share the latest research results and practical application examples on the methodologies and algorithms in these areas which makes the book a valuable reference for researchers engineers and university students **Modern Power System Analysis** Chee-Wooi Ten, Yunhe Hou, 2024-03-18 Step into the captivating world of power systems with Modern Power System Analysis Third Edition by acclaimed author Turan Gonen and revised and updated by Chee Wooi Ten and Yunhe Hou This illuminating book offers a comprehensive examination of power system analysis Whether you're a curious non specialist a voracious reader seeking knowledge or a librarian or bookseller searching for a valuable resource Gonen's masterpiece is sure to captivate you This book is an excellent source to begin your journey An in depth understanding of the concepts and techniques involved in power system analysis is provided in this comprehensive guide The book covers a wide range of topics including fundamental modeling of power transmission networks power flow analysis and fault analysis Gonen elucidates the mathematical foundations and computational methods necessary for analyzing and optimizing power systems Readers will gain insights

into advanced topics such as power system harmonics transient stability and power system protection Furthermore the book explores emerging areas like renewable energy integration smart grid technologies and the application of artificial intelligence in power system analysis G nen s meticulous approach combines theoretical explanations practical examples and real world case studies to provide readers with a comprehensive and up to date resource With its focus on modern techniques and advancements this book is an invaluable reference for engineers researchers and students venturing into the exciting realm of power system analysis The text also includes a new chapter on power system restoration which reviews methodologies corresponding to different utilities and practices A cutting edge compilation of the latest developments in power system analysis is presented in this book While the challenges and issues have evolved the text emphasizes the enduring importance of classical methods as the foundation for understanding It integrates today s advancements and addresses contemporary issues and provides readers with a comprehensive grasp of the most current techniques and approaches for analyzing optimizing and managing complex power systems With practical examples real world case studies and a strong focus on emerging areas like renewable energy integration and smart grids this invaluable resource empowers engineers researchers and students to navigate the dynamic landscape of modern power system analysis confidently

Power System Control Under Cascading Failures Kai Sun,Yunhe Hou,Wei Sun,Junjian Qi,2019-01-29 Offers a comprehensive introduction to the issues of control of power systems during cascading outages and restoration process Power System Control Under Cascading Failures offers comprehensive coverage of three major topics related to prevention of cascading power outages in a power transmission grid modelling and analysis system separation and power system restoration The book examines modelling and analysis of cascading failures for reliable and efficient simulation and better understanding of important mechanisms root causes and propagation patterns of failures and power outages Second it covers controlled system separation to mitigate cascading failures addressing key questions such as where when and how to separate Third the text explores optimal system restoration from cascading power outages and blackouts by well designed milestones optimised procedures and emerging techniques The authors noted experts in the field include state of the art methods that are illustrated in detail as well as practical examples that show how to use them to address realistic problems and improve current practices This important resource Contains comprehensive coverage of a focused area of cascading power system outages addressing modelling and analysis system separation and power system restoration Offers a description of theoretical models to analyse outages methods to identify control actions to prevent propagation of outages and restore the system Suggests state of the art methods that are illustrated in detail with hands on examples that address realistic problems to help improve current practices Includes companion website with samples codes and examples to support the text Written for postgraduate students researchers specialists planners and operation engineers from industry Power System Control Under Cascading Failures contains a review of a focused area of cascading power system outages

addresses modelling and analysis system separation and power system restoration **Advances in Integrated Energy Systems Design, Control and Optimization** Josep M. Guerrero,Amjad Anvari-Moghaddam,2018-03-23 This book is a printed edition of the Special Issue Advances in Integrated Energy Systems Design Control and Optimization that was published in Applied Sciences **Strategic Planning for Power System Restoration** ,2011 **Applications of Modern Heuristic Optimization Methods in Power and Energy Systems** Kwang Y. Lee,Zita A. Vale,2020-04-14 Reviews state of the art technologies in modern heuristic optimization techniques and presents case studies showing how they have been applied in complex power and energy systems problems Written by a team of international experts this book describes the use of metaheuristic applications in the analysis and design of electric power systems This includes a discussion of optimum energy and commitment of generation nonrenewable renewable and load resources during day to day operations and control activities in regulated and competitive market structures along with transmission and distribution systems Applications of Modern Heuristic Optimization Methods in Power and Energy Systems begins with an introduction and overview of applications in power and energy systems before moving on to planning and operation control and distribution Further chapters cover the integration of renewable energy and the smart grid and electricity markets The book finishes with final conclusions drawn by the editors Applications of Modern Heuristic Optimization Methods in Power and Energy Systems Explains the application of differential evolution in electric power systems active power multi objective optimal dispatch Includes studies of optimization and stability in load frequency control in modern power systems Describes optimal compliance of reactive power requirements in near shore wind power plants Features contributions from noted experts in the field Ideal for power and energy systems designers planners operators and consultants Applications of Modern Heuristic Optimization Methods in Power and Energy Systems will also benefit engineers software developers researchers academics and students **Tiet.com-2000.** Surekha Bhanot,2000 **Computational Advancement in Communication Circuits and Systems** Koushik Maharatna,Maitreyi Ray Kanjilal,Sukumar Chandra Konar,Sumit Nandi,Kunal Das,2019-07-25 This book gathers the proceedings of the International Conference on Computational Advancement in Communication Circuits and Systems ICCACCS 2018 which was organized by Narula Institute of Technology under the patronage of the JIS group affiliated with West Bengal University of Technology The book presents peer reviewed papers that highlight new theoretical and experimental findings in the fields of electronics and communication engineering including interdisciplinary areas like Advanced Computing Pattern Recognition and Analysis and Signal and Image Processing The respective papers cover a broad range of principles techniques and applications in microwave devices communication and networking signal and image processing computations and mathematics and control The proceedings reflect the conference s strong emphasis on methodological approaches and focus on applications within the domain of Computational Advancement in Communication Circuits andSystems They also address emerging technologies in electronics and communication together with the latest

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