Grid Inertia And Frequency Control In Power Systems With

The installed power capacity of DG is increasing; many of distributed generators are connected to a grid by inverters. The DC/AC inverters are controlled by a Phase Locked Loop (PLL) so they can be synchronized with power system frequency. If this capacity becomes larger, the grid power system become unstable, because the inverter is controlled to follow the power grid frequency. Performance of a photovoltaic generation (PV) plant with an integrated battery energy storage system (BESS) is examined under different system conditions. Although the penetration of distributed renewable energy sources into the traditional grid has risen over the past decade, the potential negative impact of this integration can never be overemphasized. The proposed scheme is evaluated in system studies under fluctuating levels of solar irradiation related to the weather conditions. As the changes in irradiation and temperature occur, the dc link voltage changes due to the changes in power produced, the inverter ac power is controlled to regulate the dc voltage. This research models are energy management system which is based on a hysteresis control algorithm for the battery, which limits the abrupt charging/discharging of the battery, thus increasing battery lifespan which also compensating for change in PV output and power system conditions. The PV source does not have significant energy storage. However, it can supply small quantity of energy for the grid system because it has dc capacitor located in the dc link. Separate energy storage, such as a battery, can work with a PV source to supply energy for the frequency control. In addition, with increasing penetration of the inverter based power generation, there is decrease in inertia due to the fast frequency tracking of the PLL, which speed up dynamic behavior and stability problems on the power grid. To mitigate this problem, the integration of virtual synchronous generators (VSG) based on the photovoltaic (PV) generation plus energy storage is proposed. This research implemented the VSG control based on the swing equation model of a synchronous generator. The VSG can be designed to aid the integration of large-scale photovoltaic generation into the power grid. Through this concept, it is plausible for the DG to exhibit the characteristics and behavior of synchronous generators (SG) such as inertia behaviour, droop functions and damping. These factors make it possible for the PV to contribute to the control and stability of the power grid.The work also presents a proposed a simple method calculating approximate for approximating battery sizing with respect to power and energy by providing emulation inertia in order to meet the target system inertia and power/frequency characteristics. Three cases were simulated in order to calculate the amount of the battery energy sizing needed to support the power grid inertia which reduces the rate of change of frequency deviation. These models are designed and simulated in the electromagnetic alternate transients program (ATP) to simulate the power system. The power grid is testing with the ATP program and validated with powerworld simulator.

Undoubtedly, the energy sector is moving towards a more renewable and sustainable path. This means renewable energy will increase their penetration into the electric power grid. Wind Energy, in particular Offshore Wind Energy, is becoming the leader of the renewable energy in terms of future possibilities, and their technology is evolving to a more controllable devices. Double Fed Induction Generator Wind Turbines (DFIG), also known in the industry as Type 3 Wind Turbines, and Fully Rated Converter-based Wind Turbines, Type 4, use power electronics to decouple the generator from the grid. Type 3 does this partially and Type 4 decouples completely the generator from the system. This allows variable wind speed operation and higher controllability for grid support. They improve the grid support provided by Fixed Wind Speed Turbines, except for the Fast Primary Frequency Response which is related directly with the inertia stored in the system. These types of wind turbines are not able to provide natural inertia response due to their decoupling from the grid. If we increase the penetration of this kind of wind turbines without giving a solution to the Fast Primary Frequency Response we will be lowering the Frequency Response and enable disturbances in the grid. This project proves how the Frequency control improves Frequency Response of the system in front of a sudden frequency drop even when the Percentage of Wind Energy Penetration is at the 30% level. We also prove how Control values of inertia constant, Droop and operational wind speeds affects the Frequency Response, being a fundamental step to take into account the operational point of the turbine depending on the working wind speed and the tune of the Frequency control values depending on the turbine characteristics.

Discover new challenges and hot topics in the field of penetrated power grids in this brand-new interdisciplinary resource Renewable Integrated Power System Stability and Control delivers a comprehensive exploration of penetrated grid dynamic analysis and new trends in power system modeling and dynamic equivalencing. The book summarizes long-term academic research outcomes and contributions and exploits the authors' extensive practical experiences in power system dynamics and stability to offer readers an insightful analysis of modern power grid infrastructure. In addition to the basic principles of penetrated power system modeling, model reduction, and model derivation, the book discusses inertia challenge requirements and control levels, as well as recent advances in visualization of virtual synchronous generators and their associated effects on system performance. The physical constraints and engineering considerations of advanced control schemes are deliberated at length. Renewable Integrated Power System Stability and Control also considers robust and adaptive control strategies using real-time simulations and experimental studies. Readers will benefit from the inclusion of: A thorough introduction to power systems, including time horizon studies, structure, power generation options, energy storage systems, and microgrids An exploration of renewable integrated power grid modeling, including basic principles, host grid modeling, and grid-connected MG equivalent models A study of virtual inertia, including grid stability enhancement, simulations, and experimental results A discussion of renewable integrated power grid stability and control, including small signal stability assessment and the frequency point of view Perfect for engineers and operators in power grids, as well as academics studying the technology, Renewable Integrated Power System Stability and Control will also earn a place in the libraries of students in Electrical Engineering programs at the undergraduate and postgraduate levels who wish to improve their understanding of power system operation and control.

The Power Electronics, Drive Systems, and Technologies Conference (PEDSTC) aims to bring together academic scientists, leading engineers, industry researchers, and scholar students to exchange and share their experiences and research results about all aspects of power electronics and electrical drives

Artificial Intelligence and Heuristics for Smart Energy Efficiency in Smart Cities

Case Study : Tipasa, Algeria

Microgrid Dynamics and Control

Practical Management of Variability, Uncertainty, and Flexibility in Power Grids

"The State of Technological Innovation Related to the Electric Grid"

This open access book presents papers displayed in the 2nd International Conference on Energy and Sustainable Futures (ICESF 2020), co-organised by the University of Hertfordshire and the University Alliance DTA in Energy. The research included in this book covers a wide range of topics in the areas of energy and sustainability including: • ICT and control of energy;• conventional energy sources;• energy governance;• materials in energy research;• renewable energy; and• energy storage. The book offers a holistic view of topics related to energy and sustainability, making it of interest to experts in the field, from industry and academia.

Nowadays, most of the ancillary services such as reserve capacity, inertia and frequency control relies on large conventional power plants. Approaching future power systems with high penetration of renewable energy sources (RES) has resulted in imperative need for the evaluation of ancillary services. This research focuses on the frequency stability which must be ensured in order to maintain the grid stability against imbalances between generation and load. This large conventional power plants that provide ancillary services are called "must-run" units. These facilities are generation power plants necessary during certain operating conditions and they are responsible for providing enough ancillary services to ensure a reliable operation of power systems. Given a high RES penetration in the future, must-run units are expected to be reduced or totally decommissioned reducing the power system inertia. This may result in insecure operation threatening the reliability of the power supply. This project investigates the frequency stability support from renewable energy generation such as wind power plants (WPPs) and solar photovoltaic systems (SPVSs) in future power systems with high penetration of RES and without must-run units. Sensitivity studies for frequency stability are performed on a simulated 2030 scenario for western Denmark (DK1) power system. The objective of this master thesis is to study the DK1 power system to analyse the ability of modern controllable WPPs to provide frequency stability without must-run units in a future scenario dominated by RES generation. This project examines the primary frequency control in DK1 simulating an overfrequency event islanding DK1 from the CE power system with high wind forecast. The main results of this project reveal that the fast deploy of active power by the RES generation counterbalances the reduced inertia in the power system, which can operate without a lack of stability of the power supply for overfrequency events without must-run units. However, there are technical capabilities and limitations that curtail the RES penetration. Recommendations on the parameters of the WPPs frequency control are made according to the droop, the ramp rate and the RES penetration. The virtual inertia is recommended for frequency control of WPPs and increases its importance when the RES penetration is high. The support of HVDC interconnections is an interesting facility to increase the RES penetration allowing the power system to operate with even less inertia online maintaining a stable supply. Although, the measurement and communication delay by the frequency controllers increases its importance when increasing the RES penetration as faster power deploy is needed.

Renewable Energy Integration is a ground-breaking new resource - the first to offer a distilled examination of the intricacies of integrating renewables into the power grid and electricity markets. It offers informed perspectives from internationally renowned experts on the challenges to be met and solutions based on demonstrated best practices developed by operators around the world. The book's focus on practical implementation of strategies provides real-world context for theoretical underpinnings and the development of supporting policy frameworks. The book considers a myriad of wind, solar, wave and tidal integration issues, thus ensuring that grid operators with low or high penetration of renewable generation can leverage the victories achieved by their peers. Renewable Energy Integration highlights, carefully explains, and illustrates the benefits of advanced technologies and systems for coping with variability, uncertainty, and flexibility. Lays out the key issues around the integration of renewables into power grids and markets, from the intricacies of operational and planning considerations, to supporting regulatory and policy frameworks Provides global case studies that highlight the challenges of renewables integration and present field-tested solutions Illustrates enabling and disruptive technologies to support the management of variability, uncertainty and flexibility

Rapid deployment of wind and solar energy generation is going to result in a series of new problems with regards to the reliability of our electrical grid in terms of outages, cost, and life-time, forcing us to promptly deal with the challenging restructuring of our energy systems. Increased penetration of fluctuating renewable energy resources is a challenge for the electrical grid. Proposing solutions to deal with this problem also impacts the functionality of large generators. The power electronic generator interactions, multi-domain modelling, and reliable monitoring systems are examples of new challenges in this field. This book presents some new modelling methods and technologies for renewable energy generators including wind, ocean, and hydropower systems.

Emulated Inertia

Renewable Power Systems Dynamic Security

Wind Power in Power Systems

Renewable Energy Integration

Short-Term Forecasting of Inertial Response from a Wind Power Plant

The various efforts of promoting the use of renewables has resulted in a steady growth of electricity coming from renewable energy sources which is expected to continue even further into the future. From a physics point of view, many of these renewable energy sources behave quiet differently from the synchronous generators installed in conventional power plants. Synchronous generators have mechanical inertia and are therefore capable of storing kinetic energy in their rotating mass. Moreover, since the terminals of these generators are directly linked with the network, this energy is inherently exchanged with the system during disturbances which makes the network less prone to frequency fluctuations in case of an imbalance between generation and load. Renewable generation units (mainly photovoltaic solar and wind power) on the other hand, are equipped with a power electronic converter which decouples the generator from the grid and as such provide no inertia to the system. As it is projected that many of the conventional power plants will be gradually displaced by these renewable energy sources, the total inertia perceived by the system will thus decrease. As discussed in this study, it expected that inertia related issues will mainly arise in terms of frequency control as low system inertia results in high rate of change of frequency (ROCOF) values and substantial frequency deviations which can lead to instability of the system including load shedding or even a blackout. There are however many possible solutions available to cope with these issues, which are all described in more detail in the report, ranging from a simple redispatch to a modified control approach for converters. Within Europe, many efforts have already been made by ENTSO-E to deal with the inertia issues in a coordinated and harmonized way though their operational guidelines, network codes and system studies. However, as most of the guidelines and network codes related to system inertia are non-exhaustive, there is still a wide variety in the way each TSO implement them. TSOs in large interconnected synchronous areas, such as the Continental European system, currently only adapt the allowed ROCOF relay settings or include a ROCOF withstand capability (for new units) in their grid code. Island systems on the other hand, such as Ireland and GB, are already a step ahead as they expect to encounter high levels of converter penetration. Currently they mostly try to limit the ROCOF by limiting the largest credible loss or keeping the inertia above a certain minimum value. However, to reach even higher penetration levels, new system services will need to be procured. A prognosis of the future system inertia in 2030 within the synchronous area of Continental Europe is made based on the generation capacities of the EUCO30 scenario. Although it expected that there will be a substantial increase in converter connected penetration by 2030, the analysis shows that there remains enough inertia in the system to cope with imbalance which are much higher than the current reference incident. Nevertheless, in accordance with the operation guidelines of ENTSO-E, it is recommended that a tool to monitor and forecast the inertia at operational level is gradually put into place within the Continental European System. Furthermore, to be future proof, it is also necessary to already draft procedures to cope with a possible lack of inertia. In this respect, it is important to take into account the operational experience gained by TSOs in smaller systems such as the one of Ireland.

This handbook serves as a guide to deploying battery energy storage technologies, specifically for distributed energy resources and flexibility resources. Battery energy storage technology is the most promising, rapidly developed technology as it provides higher efficiency and ease of control. With energy transition through decarbonization and decentralization, energy storage plays a significant role to enhance grid efficiency by alleviating volatility from demand and supply. Energy storage also contributes to the grid integration of renewable energy and promotion of microgrid.

Modern Aspects of Power System Frequency Stability and Control describes recently-developed tools, analyses, developments and new approaches in power system frequency, stability and control, filling a gap that, until the last few years, has been unavailable to power system engineers. Deals with specific practical issues relating to power system frequency, control and stability Focuses on low-inertia and smart grid systems Describes the fundamental processes by which the frequency response requirements of power systems in daily operation are calculated, together with a description of the actual means of calculation of these requirements

The increased penetration of renewable energy resources particularly those connected via inverters to the electric grid like wind and solar, has resulted in the displacement of traditional synchronous generators. This has subsequently led to a decline in the available rotational inertia from these synchronous generators that provides immediate frequency response in the event of a disturbance to the grid. The result is a larger increase in the frequency deviation, rate of change of frequency, and a slower settling time, all of which can lead to frequency instability and an eventual collapse of the grid. This network condition has been termed low-inertia power systems. The aim of this dissertation is to design control and optimization algorithms that will enable these inverter-based resources participate effectively and optimally in providing frequency control response in a low-inertia power systems by controlling their inverter interfaces. The first part of this dissertation focuses on optimizing the performance of the popular virtual synchronous machine control structure for inverter-based resources, by developing an algorithm to optimally design the inertia and damping gain coefficient of its frequency control loop. This enables these inverter-based resources to participate efficiently in the inertia response portion of primary frequency control, by producing active power proportional to frequency measurements, in response to a power imbalance or disturbance to the grid, just like a synchronous generator. The second part of this dissertation focuses on designing a novel inverter-based resource control strategy termed inverter power control, which is based on model predictive control, to directly determine the optimal active-power set-point for the inverter-based resources in the event of a power imbalance or disturbance in the system. This proposed control framework alleviates a fundamental drawback of the virtual synchronous machine approach that constrains the inverter-based resources to behave like synchronous machines when responding to a frequency event thereby limiting the potentials of these fast acting and flexible inverter-based resources.

Renewable Energy in Power Systems

International Conference on Intelligent Computing and Smart Communication 2019

Preprint

Phase-Locked Loop Control In Low-Inertia Grid-Connected Voltage-Source Converters

Robust Power System Frequency Control

Over the last century, energy storage systems (ESSs) have continued to evolve and adapt to changing energy requirements and technological advances. Energy Storage in Power Systems describes the essential principles needed to understand the role of ESSs in modern electrical power systems, highlighting their application for the grid integration of renewable-based generation. Key features: Defines the basis of electrical power systems, characterized by a high and increasing penetration of renewable-based generation. Describes the fundamentals, main characteristics and components of energy storage technologies, with an emphasis on electrical energy storage types. Contains real examples depicting the application of energy storage systems in the power system. Features case studies with and without solutions on modelling, simulation and optimization techniques. Although primarily targeted at researchers and senior graduate students, Energy Storage in Power Systems is also highly useful to scientists and engineers wanting to gain an introduction to the field of energy storage and more specifically its application to modern power systems.

An up to date account of renewable sources of electricity generation and their integration into power systems With the growth in installed capacity of renewable energy (RE) generation, many countries such as the UK are relying on higher levels of RE generation to meet targets for reduced greenhouse gas emissions. In the face of this, the integration issue is now of increasing concern, in particular to system operators. This updated text describes the individual renewable technologies and their power generation characteristics alongside an expanded introduction to power systems and the challenges posed by high levels of penetrations from such technologies, together with an account of technologies and changes to system operation that can ease RE integration. Features of this edition: Covers power conditioning, the characteristics of RE generators, with emphasis on their time varying nature, and the use of power electronics in interfacing RE sources to grids Outlines up to date RE integration issues such as power flow in networks supplied from a combination of conventional and renewable energy sources Updated coverage of the economics of power generation and the role of markets in delivering investment in sustainable solutions Considers the challenge of maintaining power balance in a system with increasing RE input, including recent moves toward power system frequency support from RE sources Offers an insightful perspective on the shape of future power systems including offshore networks and demand side management Includes worked examples that enhance this edition's suitability as a textbook for introductory courses in RE systems technology Firmly established as an essential reference, the Second Edition of Renewable Energy in Power Systems will prove a real asset to engineers and others involved in both the traditional power and fast growing renewables sector. This text should also be of particular benefit to students of electrical power engineering and will additionally appeal to non-specialists through the inclusion of background material covering the basics of electricity generation.

This book emphasizes the role of micro-grid systems and connected networks for the strategic storage of energy through the use of information and communication techniques, big data, the cloud, and meta-heuristics to support the greed for artificial intelligence techniques in data and the implementation of global strategies to meet the challenges of the city in the broad sense. The intelligent management of renewable energy in the context of the energy transition requires the use of techniques and tools based on artificial intelligence (AI) to overcome the challenges of the intermittence of resources and the cost of energy. The advent of the smart city makes an increased call for the integration of artificial intelligence and heuristics to meet the challenge of the increasing migration of populations to the city, in order to ensure food, energy, and environmental security of the citizen of the city and his well-being. This book is intended for policymakers, academics, practitioners, and students. Several real cases are exposed throughout the book to illustrate the concepts and methods of the networks and systems presented. This book proposes the development of new technological innovations--mainly ICT--the concept of "Smart City" appears as a means of achieving more efficient and sustainable cities. The overall goal of the book is to develop a comprehensive framework to help public and private stakeholders make informed decisions on smart city investment strategies and develop skills for assessment and prioritization, including resolution of difficulties with deployment and reproducibility

This book provides a thorough understanding of the basic principles, synthesis, analysis, and control of virtual inertia systems. It uses the latest technical tools to mitigate power system stability and control problems under the presence of high distributed generators (DGs) and renewable energy sources (RESs) penetration. This book uses a simple virtual inertia control structure based on the frequency response model, complemented with various control methods and algorithms to achieve an adaptive virtual inertia control respect to the frequency stability and control issues. The chapters capture the important aspects in virtual inertia synthesis and control with the objective of solving the stability and control problems regarding the changes of system inertia caused by the integration of DGs/RESs. Different topics on the synthesis and application of virtual inertia are thoroughly covered with the description and analysis of numerous conventional and modern control methods for enhancing the full spectrum of power system stability and control. Filled with illustrative examples, this book gives the necessary fundamentals and insight into practical aspects. This book stimulates further research and offers practical solutions to real-world power system stability and control problems with respect to the system inertia variation triggered by the integration of RESs/DGs. It will be of use to engineers, academic researchers, and university students interested in power systems dynamics, analysis, stability and control.

Control of an Offshore Wind Power Plant

Power Electronic Converter Configuration and Control for DC Microgrid Systems

Microgrid Protection and Control

2019 IEEE PES Asia Pacific Power and Energy Engineering Conference (APPEEC)

Energy Storage in Power Systems

The wind power penetration into the system, as other intermittent energy sources, have impacts in grid frequency performance that lead to increase system reserve and to reduce the power extraction in the wind turbines. In this document, an integration analysis of the Battery Energy Storage System (BESS) is presented with its dynamics characteristics, This in order to identify the optimal size of an aggregated system in order to support frequency regulation. Once the large potential for the provision of frequency control services is identified, in this document the batteries are used to increase the frequency performance of the grid. The primary frequency control presented takes into account the dynamic response of the integrated system with wind turbines and BESS, while the LFC have a robust performance due to system inertia uncertainties.

This book presents innovative techniques and approaches to maintaining dynamic security of modern power systems that have a high penetration of renewable energy sources (RESs). The authors propose a number of frequency control strategies and schemes to address and evade stability problems in system frequency and voltage that can lead to power interruption and power failure/blackout. The book includes case studies aimed at validating the effectiveness of the techniques and strategies presented, and will be a valuable resource for researchers working in electrical power engineering, power system stability, dynamics and control, and microgrids.

Microgrid Protection and Control is the result of numerous research works and publications by R&D engineers and scientists of the Microgrid and Energy Internet Research Centre. Through the authors long-routed experience in the microgrid and energy internet industry, this book looks at the sophisticated protection and control issues connected to the special nature of microgrid. The book explains the different ways of classifying types of microgrids and common misconceptions, looking at industrial and research trends along with the different technical issues and challenges faced with deploying microgrid in various settings. Forecasting short-term demand and renewable generation for optimal operation is covered with techniques for accurate enhancement supported with practical application examples. With chapters on dynamic, transient and tertiary control and experimental and simulation tests this reference is useful for all those working in the research, engineering and application of microgrids and power distribution systems. Contains practical examples to support the research and experimental results on microgrid protection and control Includes detailed theories and referential algorithms Provides innovative solutions to technical issues in protection and control of microgrids

To integrate renewable energy, converter-interfaced sources (CISs) keep penetrating into power systems and degrade the grid frequency response. Control synthesis towards guaranteed performance is a challenging task. Meanwhile, the potentials of highly controllable converters are far from fully developed. With properly designed controllers the CISs can not only eliminate the negative impacts on the grid, but also provide performance guarantees. First, the wind turbine generator (WTG) is chosen to represent the CISs. An augmented system frequency response (ASFR) model is derived, including the system frequency response model and a reduced-order model of the WTG representing the supportive active power due to the supplementary inputs. Second, the framework for safety verification is introduced. A new concept, region of safety (ROS), is proposed, and the safe switching principle is provided. Two different approaches are proposed to estimate the largest ROS, which can be solved using the sum of squares programming. Third, the critical switching instants for adequate frequency response are obtained through the study of the ASFR model. A safe switching window is discovered, and a safe speed recovery strategy is proposed to ensure the safety of the second frequency dip due to the WTG speed recovery. Fourth, an adaptive safety supervisory control (SSC) is proposed with a two-loop configuration, where the supervisor is scheduled with respect to the varying renewable penetration level. For small-scale system, a decentralized fashion of the SSC is proposed under rational approximations and verified on the IEEE 39-bus system. Fifth, a two-level control diagram is proposed so that the frequency of a microgrid satisfies the temporal logic specifications (TLSs). The controller is configured into a scheduling level and a triggering level. The satisfaction of TLSs will be guaranteed by the scheduling level, and triggering level will determine the activation instant. Finally, a novel model reference control based synthetic inertia emulation strategy is proposed. This novel control strategy ensures precise emulated inertia by the WTGs as opposed to the trial and error procedure of conventional methods. Safety bounds can be easily derived based on the reference model under the worst-case scenario.

Modern Aspects of Power System Frequency Stability and Control

Grid Integration and Dynamic Impact of Wind Energy

Advances in Modelling and Control of Wind and Hydrogenerators

Proceedings of ICSC 2019

Power System Stability and Control

This book discusses relevant microgrid technologies in the context of integrating renewable energy and also addresses challenging issues. The authors summarize long term academic and research outcomes and contributions. In addition, this book is influenced by the authors ' practical experiences on microgrids (MGs), electric network monitoring, and control and power electronic systems. A thorough discussion of the basic principles of the MG modeling and operating issues is provided. The MG structure, types, operating modes, modelling, dynamics, and control levels are covered. Recent advances in DC microgrids, virtual synchronousgenerators, MG planning and energy management are examined. The physical constraints and engineering aspects of the MGs are covered, and developed robust and intelligent control strategies are discussed using real time simulations and experimental studies.

This book presents different aspects of renewable energy integration, from the latest developments in renewable energy technologies to the currently growing smart grids. The importance of different renewable energy sources is discussed, in order to identify the advantages and challenges for each technology. The rules of connecting the renewable energy sources have also been covered along with practical examples. Since solar and wind energy are the most popular forms of renewable energy sources, this book provides the challenges of integrating these renewable generators along with some innovative solutions. As the complexity of power system operation has been raised due to the renewable energy integration, this book also includes some analysis to investigate the characteristics of power systems in a smarter way. This book is intended for those working in the area of renewable energy integration in distribution networks.

The second edition of the highly acclaimed Wind Power in Power Systems has been thoroughly revised and expanded to reflect the latest challenges associated with increasing wind power penetration levels. Since its first release, practical experiences with high wind power penetration levels have significantly increased. This book presents an overview of the lessons learned in integrating wind power into power systems and provides an outlook of the relevant issues and solutions to allow even higher wind power penetration levels. This includes the development of standard wind turbine simulation models. This extensive update has 23 brand new chapters in cutting-edge areas including offshore wind farms and storage options, performance validation and certification for grid codes, and the provision of reactive power and voltage control from wind power plants. Key features: Offers an international perspective on integrating a high penetration of wind power into the power system, from basic network interconnection to industry deregulation; Outlines the methodology and results of European and North American large-scale grid integration studies; Extensive practical experience from wind power and power system experts and transmission systems operators in Germany, Denmark, Spain, UK, Ireland, USA, China and New Zealand; Presents various wind turbine designs from the electrical perspective and models for their simulation, and discusses industry standards and world-wide grid codes, along with power quality issues; Considers concepts to increase penetration of wind power in power systems, from wind turbine, power plant and power system redesign to smart grid and storage solutions. Carefully edited for a highly coherent structure, this work remains an essential reference for power system engineers, transmission and distribution network operator and planner, wind turbine designers, wind project developers and wind energy consultants dealing with the integration of wind power into the distribution or transmission network. Up-to-date and comprehensive, it is also useful for graduate students, researchers, regulation authorities, and policy makers who work in the area of wind power and need to understand the relevant power system integration issues.

The total inertia stored in all rotating masses (synchronous generators, induction motors, etc.) connected to a power system grid is an essential force that keeps the system stable after disturbances. Power systems have been experiencing reduced inertia during the past few decades [1]. This trend will continue as the level of renewable generation (e.g., wind and solar) increases. Wind power plants (WPPs) and other renewable power plants with power electronic interfaces are capable of delivering frequency response (both droop and/or inertial response) by a control action; thus, the reduction in available online inertia can be compensated by designing the plant control to include frequency response. The source of energy to be delivered as inertial response is determined by the type of generation (wind, photovoltaic, concentrating solar power, etc.) and the control strategy chosen. The importance of providing ancillary services to ensure frequency control within a power system is evidenced from many recent publications with different perspectives (manufacturer, system operator, regulator, etc.) [2]-[6]. This paper is intended to provide operators with a method for the real-time assessment of the available inertia of a WPP. This is critical to managing power system stability and the reserve margin. In many states, modern WPPs are required to provide ancillary services (e.g., frequency regulation via governor response and inertial response) to the grid. This paper describes the method of estimating the available inertia and the profile of the forecasted response from a WPP.

Frequency Variations in Power Systems

Enabling Wind Turbine Generators to Participate in Power Grid Frequency Regulation for Enhanced Stability

2020 11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)

BESS for Frequency Control in Systems with High Penetration of Wind Energy

Modelling and Simulation of Power Electronic Converter Dominated Power Systems in PowerFactory

The aim of the conference is to provide a premier platform for electrical engineers and researchers to present their works and to share experiences and ideas in power and energy engineering with experts and scholars from around the world Started in Wuhan in 2009, APPEEC is now an annual power engineering conference organized in Asia Pacific Region

Author's abstract: As the integration of renewable energy on the grid increases, the number of voltage-source converters (VSC) installed also does. VSC controls both switch turn-on and turn-off, allowing a dc voltage source to be switched between phases. For the converter to accurately synchronize with the grid, a phase-locked loop (PLL) is used for the frequency measurements of the grid. However, the implementation of PLL with measurement delay introduces harmonics, noise, high frequency, and voltage oscillation to the system due to its dynamics. The dynamics introduced to the grid can be ignored under stiff grid conditions, but power from renewable sources decreases the grid inertia creating a weak-grid condition. Older grids accommodate this by using generators that compensate for the rate of change of frequency (RoCoF). Modern grids have less generator to accommodate the RoCoF, so there is a desideratum to implore a robust controller that responds quickly to the RoCoF, disturbance/ distortion rejection, and noise immunity to the grid. In recent literature, the effect of the PLL dynamics on a weak grid has been of great concern because of its unmodeled dynamics that destabilizes the converter under the weak-grid condition. This thesis proposes showing the impact of the weak-grid on the VSC as the dynamic of the grid changes. It also provides remedies to the grid instability and high-power injection levels. The detailed PLL dynamics model, including the ac-bus voltage dynamics with constant frequency, is developed and linearized. Even at a fixed frequency, various factors play a role in grid instability, and this tremendously affects the ability of the VSC to control the grid efficiently. The effect of the PLL gain under the weak-grid condition is analyzed.

The theme of the seventeenth power systems conference is Intelligent Systems Applications in Smart Grid Advanced Metering, Artificial Intelligence, Big Data Analytics, Communication, Computing, Control, Cyber physical system, Distributed Resources, Machine Learning, and Protection among other topics will be emphasized

Energy storage systems have been recognized as the key elements in modern power systems, where they are able to provide primary and secondary frequency controls, voltage regulation, power quality improvement, stability enhancement, reserve service, peak shaving, and so on. Particularly, deployment of energy storage systems in a distributed manner will contribute greatly in the development of smart grids and providing promising solutions for the above issues. The main challenges will be the adoption of new techniques and strategies for the optimal planning, control, monitoring and management of modern power systems with the wide installation of distributed energy storage systems. Thus, the aim of this book is to illustrate the potential of energy storage systems in different applications of modern power systems, with a view toward illuminating recent advances and research trends in storage technologies. This exciting new volume covers the recent advancements and applications of different energy storage technologies that are useful to engineers, scientists, and students in the discipline of electrical engineering. Suitable for the engineers at power companies and energy storage consultants working on energy storage field, this book offers a cross-disciplinary look across electrical, mechanical, chemical and renewable engineering aspects of energy storage. Whether for the veteran engineer or the student, this is a must-have for any library.

Allowing Distributed Generation to Improve Power System Stability by Applying Virtual Synchronous Machine Approach

More-Electronics Power Systems: Power Quality and Stability

Challenges and Solutions

Energy Storage for Modern Power System Operations

Frequency Control in Power Systems Without Must-run Units

The DC/AC microgrid system is a crucial empowering technology for the integration of various types of renewable energy sources (RES) accompanied by a smart control approach to enhance the system reliability and efficiency. This book presents cutting-edge technology developments and recent investigations performed with the help of power electronics. Large-scale renewable energy integration presents challenges and issues for power grids. In particular, these issues include microgrid adaption to RES, AC machines, the new configuration of AC/DC converters, and electrification of domestic needs with optimal cost expenses from domestic standalone microgrids. Furthermore, this book elaborates cutting-edge developments in electric vehicle fast charging configuration, battery management, and control schemes with renewable energies through hardware-in-loop testing and validation for performance durability in real-time application. Overall, the book covers the diverse field of microgrids, allowing readers to adopt new technologies and prepare for future power demands with sustainable green engineering.

Frequency Variations in Power Systems: Modeling, State Estimation and Control presents the Frequency Divider Formula (FDF); a unique approach that defines, calculates and estimates the frequency in electrical energy systems. This authoritative book is written by two noted researchers on the topic. They define the meaning of frequency of an electrical quantity (such as voltage and current) in non-stationary conditions (for example the frequency is not equal to the nominal one) and pose the foundation of the frequency divider formula. The book describes the consequences of using a variable frequency in power system modelling and simulations, in state estimation and frequency control applications. In addition, the authors include a discussion on the applications of the frequency divider in systems where part of the generation is not based on synchronous machines, but rather on converter-interfaced energy resources, such as wind and solar power plants. This important book: Offers a review that clearly defines and shows how the Frequency Divider Formula can be applied Discusses the link between frequency and energy in power systems Presents a unified vision that accurately reveals the common thread that links modelling, control and estimation Includes information on the many implications that "local frequency variations" have on power system dynamics and control Contains several numerical examples Written for researchers, academic staff members, students, specialised consultants and professional software developers, Frequency Variations in Power Systems questions the conventional transient stability model of power system and proposes a new formulation.

Grid Integration and Dynamic Impact of Wind Energy details the integration of wind energy resources to the electric grid worldwide. Authors Vijay Vittal and Raja Ayyanar include detailed coverage of the power converters and control used in interfacing electric machines and power converters used in wind generators, and extensive descriptions of power systems operation and control to accommodate large penetration of wind resources. Key concepts will be illustrated through extensive power electronics and power systems simulations using software like MATLAB, Simulink and PLECS. The book addresses real world problems and solutions in the area of grid integration of wind resources, and will be a valuable resource for engineers and researchers working in renewable energy and power.

This book gathers high-quality research papers presented at the First International Conference, ICSC 2019, organised by THDC Institute of Hydropower Engineering and Technology, Tehri, India, from 20 to 21 April 2019. The book is divided into two major sections – Intelligent Computing and Smart Communication. Some of the areas covered are Parallel and Distributed Systems, Web Services, Databases and Data Mining Applications, Feature Selection and Feature Extraction, High-Performance Data Mining Algorithms, Knowledge Discovery, Communication Protocols and Architectures, High-speed Communication, High-Voltage Insulation Technologies, Fault Detection and Protection, Power System Analysis, Embedded Systems, Architectures, Electronics in Renewable Energy, CAD for VLSI, Green Electronics, Signal and Image Processing, Pattern Recognition and Analysis, Multi-Resolution Analysis and Wavelets, 3D and Stereo Imaging, and Neural Networks.

2020 Clemson University Power Systems Conference (PSC)

Penetration of Renewables and Reduction of Synchronous Inertia in the European Power System

Virtual Inertia Synthesis and Control

Proceedings of 2nd ICESF 2020

Energy and Sustainable Futures

This book aims to investigate emerging power quality and stability problems as well as their solutions in more-electronics power systems. The majority of methods presented here are validated through simulation and/or experimental results, thereby improving their credibility. The ultimate objective of these methods is to achieve secured operation of modern power systems with increased (up to 100%) renewable energy penetration, which is an emerging topic in this field. Readers will not only learn about the knowledge of more-electronics power systems but also the step-by-step process of how they can implement this to their research work or industrial practice. This book caters to engineers and academics working in the field of power systems with the main focus of improving power quality and stability.

ENERGY STORAGE for MODERN POWER SYSTEM OPERATIONS Written and edited by a team of well-known and respected experts in the field, this new volume on energy storage presents the state-of-the-art developments and challenges for modern power systems for engineers, researchers, academicians, industry professionals, consultants, and designers. Energy storage systems have been recognized as the key elements in modern power systems, where they are able to provide primary and secondary frequency controls, voltage regulation, power quality improvement, stability enhancement, reserve service, peak shaving, and so on. Particularly, deployment of energy storage systems in a distributed manner will contribute greatly in the development of smart grids and providing promising solutions for the above issues. The main challenges will be the adoption of new techniques and strategies for the optimal planning, control, monitoring and management of modern power systems with the wide installation of distributed energy storage systems. Thus, the aim of this book is to illustrate the potential of energy storage systems in different applications of modern power systems, with a view toward illuminating recent advances and research trends in storage technologies. This exciting new volume covers the recent advancements and applications of different energy storage technologies that are useful to engineers, scientists, and students in the discipline of electrical engineering. Suitable for the engineers at power companies and energy storage consultants working in the energy storage field, this book offers a cross-disciplinary look across electrical, mechanical, chemical and renewable engineering aspects of energy storage. Whether for the veteran engineer or the student, this is a must-have for any library. AUDIENCE Electrical engineers and other designers, engineers, and scientists working in energy storage

This updated edition of the industry standard reference on power system frequency control provides practical, systematic and flexible algorithms for regulating load frequency, offering new solutions to the technical challenges introduced by the escalating role of distributed generation and renewable energy sources in smart electric grids. The author emphasizes the physical constraints and practical engineering issues related to frequency in a deregulated environment, while fostering a conceptual understanding of frequency regulation and robust control techniques. The resulting control strategies bridge the gap between advantageous robust controls and traditional power system design, and are supplemented by real-time simulations. The impacts of low inertia and damping effect on system frequency in the presence of increased distributed and renewable penetration are given particular consideration, as the bulk synchronous machines of conventional frequency control are rendered ineffective in emerging grid environments where distributed/variable units with little or no rotating mass become dominant. Frequency stability and control issues relevant to the exciting new field of microgrids are also undertaken in this new edition. As frequency control becomes increasingly significant in the design of ever-more complex power systems, this expert guide ensures engineers are prepared to deploy smart grids with optimal functionality.

"This dissertation focuses on wind farm frequency regulation capability to maintain the grid frequency stability. Wind plant power controllers are designed and tested for participation in grid frequency restoration. The small signal stability on sub-optimal operating points is analyzed and a de-loaded operating point is proposed. In the first paper, a new frequency regulation scheme is developed for the wind turbine/generator/converter trio that will provide the capability to participate in restoring frequency in a way similar to the droop response of conventional generators. Output active power adjustment can be realized by both converter and pitch angle control in addition to inertial response of the wind turbine. This helps in maintaining instantaneous power balance as well as in longer term frequency regulation. In the second paper, Inertia controller, pitch angle controller and rotor speed controller are introduced for wind plant output active power adjustment. The control schemes are developed for wind generators to equip them with the capability to participate in restoring gird frequency. With the proposed controllers, the wind plant can operate as a synchronous generator and is able to output larger or smaller amounts of power as required so as to contribute to grid frequency restoration. The controllers are tested on a wind plant operating in a 4-bus test system for verification of the grid frequency performance under various system dynamic conditions. In the third paper, a reduced-3rd order doubly fed induction generator (DFIG) wind turbine dynamic model is described in details. This model along with an active power controller integrated with a power system is investigated for small signal dynamic stability for both sub- and super-synchronous operating conditions. Assuming constant wind speed and blade pitch angle the mechanical power of the machine is modeled as a function of the rotor speed. The system is initialized and linearized around the sub- and super-synchronous operating points. The eigenvalues and participation factors are calculated for a constant power reference as well as 90% P max reference. Both the open loop and closed loop controls on DFIG active power are applied for eigenvalue calculation. The results show that the DFIG operating at the sub-synchronous operating points is unstable"--Abstract, leaf iv.

Analysis and Solutions

Hearing Before the Committee on Energy and Natural Resources, United States Senate, One Hundred Fourteenth Congress, First Session ... March 17, 2015

Handbook on Battery Energy Storage System

Renewable Energy

Frequency Stability in Low-inertia Power Systems