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EPRO PS - 001	Active Voltage Control for DFIG-based Wind Farm Integrated Power System by Coordinating Active and Reactive Powers under Wind Speed Variations

Large-scale wind farms are generally integrated by long-distance transmissions, but power grids cannot sufficiently support the access point voltage of these wind farms. The access point voltage undergoes a stability problem under wind speed variations. However, the reactive power compensation device cannot reconcile the requirements of response speed and compensation capacity. Despite their fast power decoupling control, the reactive power capability of doubly fed induction generators is restricted by active power output. To satisfy the reactive power demand of system under wind speed variations, coordinating the reactive power capability and active power output of wind farm is the key solution, based on which a novel active control idea is proposed. The reactive power capability of wind farm and the reactive power demand of system are both studied, and the controllable conditions of access point voltage are analyzed. Active voltage control strategies, including active adjustment of reactive power reference, active speed control, and active pitch angle intervention according to wind speed ranges, are proposed. In the simulation, the method is verified to adequately consider the reactive power demand, and excavate the wind farm reactive power capability. The method also effectively suppresses the change of grid voltage under wind speed variations.

EPRO PS - 002	A Multiple Improved Notch Filter Based Control for Single Stage PV System Tied to Weak Grid

In this paper, a control scheme based on improvement in a generalized integrator is implemented on a three-phase single-stage grid-tied solar photovoltaic system with the distribution static compensator capabilities under grid abnormal conditions of voltage distortion and voltage unbalance. The photovoltaic voltage-source converter system compensating for the reactive power consumed by nonlinear load at point of common coupling provides load balancing and mitigates harmonics. The proposed multiple-improved-notch-filter-based quadrature signal generator control approach extracts the load current fundamental component, independent of the grid voltage. This control has better dc offset and harmonics component rejection capability in comparison to a conventional second-order generalized integrator algorithm. The perturb and observe-based maximum power point tracking algorithm is applied for the extraction of maximum power from the photovoltaic array. The system is analyzed under different abnormal conditions of voltage distortions, voltages unbalance, voltage swell, voltage sag, load currents unbalance, and insolation change on a prototype developed in the laboratory. The system performance is found to be satisfactory, within limits as described in an IEEE-519 standard while feeding active power to distribution network and connected loads.

EPRO PS - 003	GI based Control Scheme for Single Stage Grid Interfaced SECS for Power Quality Improvement

This paper presents an improved generalized integrator (GI)-based control with a frequency locked loop for multifunctional three-phase single-stage grid interfaced solar energy conversion system for power quality enhancement of the distribution network under abnormal grid conditions. The perturb and observe-based maximum power point tracking technique is utilized to obtain peak power from solar photovoltaic array under varying atmospheric conditions. This control scheme provides unity power factor operation, load balancing, harmonics mitigation, and reactive power compensation. The improved GI control algorithm has an advantage of better dc offset and harmonics rejection capabilities as compared to a conventional second-order GI algorithm. To substantiate the control scheme, tests are performed on a paradigm in the research laboratory for manifold operating conditions. Test results show the satisfactory behavior under steady state and dynamic operating scenario such as unbalanced load, solar irradiations variation, voltage sag, and swell and distorted voltage grid. The total harmonic distortions of the grid voltages-currents are achieved within constraints of grid code compliance of an IEEE 519 and 1564 standards.

EPRO PS - 004	Design and Optimization of a Solar Power Conversion System for Space Applications

This manuscript details a design method for a 500 kW solar power based microgrid system for space applications. The design method utilizes multiobjective optimization with the genetic algorithm considering four parameters that characterize solar power based microgrids (battery voltage, photovoltaic (PV) maximum power, PV maximum power point voltage, and number of panels per string). The final optimization metric is the ratio of daily average deliverable power to total system mass (W/kg) metric. The microgrid system is composed of a number of modular dc-dc microconverters, of which four topologies (buck, boost, buck-boost, and non-inverting buck-boost) are evaluated and compared. The non-inverting buck-boost converter is determined to be the best candidate, and the optimal system characteristics are provided and analyzed. The final system design achieves a specific power of 35.56 W/kg, with optimized result of 743.7 V battery voltage, 439.5 W PV maximum power, 182.7 V PV maximum voltage, and three panels per string. Based on the optimizations results, a prototype is designed, tested, and analyzed in terms of efficiency and low-temperature reliability. The converter achieved a peak efficiency of 98.4%, a power density of 3.54 W/cm ^{3} , a specific power of 3.76 W/g, and operated for over 267 h of 11-min low-temperature cycles from 0 to -140 °C.

EPRO PS - 005	Grid-Connected Wind-Photovoltaic Cogeneration Using Back-to-Back Voltage Source Converters

This paper introduces a new topology, yet simple and efficient, for a grid-connected wind-solar cogeneration system. A permanent magnet synchronous generator-based full-scale wind turbine (FSWT) is interconnected to the utility-grid via back-to-back (BtB) voltage-source converters (VSCs). The dc-link capacitor has been utilized to directly intertie a photovoltaic (PV) solar generator. No dc/dc conversion stages are required, and hence the hybrid system is simple and efficient. Moreover, the proposed topology features an independent maximum power point tracking for both the wind and the solar generators to maximize the harvesting of the renewable energy. The regulation of the VSCs is achieved via the vector control in the rotating reference frame. The detailed small-signal models for the system components are developed to characterize the overall stability. The influence of the utility-grid faults on the performance of the proposed system is also investigated. Nonlinear time-domain simulation results under different operating conditions are presented to validate the effectiveness of the proposed topology.

EPRO PS - 006	A Dual-Window DC Bus Interacting Method for DC Microgrids Hierarchical Control Scheme

Hierarchical control schemes have been commonly employed in DC microgrid controls, which combine local control, DC bus voltage coordination and communication links to guarantee smart operation of DC microgrids. Conventional DC bus voltage regulation cannot conduct signal exchange. Therefore, external communication links are usually needed for hierarchical control schemes. However, once the communication link fails, the hierarchical control system will lose its ability to coordinate the distributed power smartly. This paper proposed a dual-window DC bus interacting (DBI) method to exchange information between the distributed energy sources, for the situations where communication link fails or is not available. A small-scale DC microgrid experimental system was setup, and a simple Master-Slave control scheme is implemented without communication link to demonstrate the feasibility of the proposed DBI method for DC microgrid controls. The expandability and immunity of the proposed DBI method were also evaluated.

EPRO PS - 007	A Series-Connected Offshore Wind Farm Based on Modular Dual-Active-Bridge (DAB) Isolated DC-DC Converter

This paper investigates an offshore wind farm based on modular dual-active-bridge (DAB) isolated DC-DC converter. The DAB converter is adopted due to its compact design and the galvanic isolation between its input and output terminals. The synchronous generator in each wind turbine is operated individually with the generator-side rectifier to maximize the power production. The output terminals of multiple DAB converters are connected in series so that the high voltage for DC transmission is achieved and the expensive offshore step-up substation is eliminated. The DC transmission voltage is excluded from the primary side of the DAB transformer by its galvanic isolation. To balance the power sharing among the DAB converters, their input terminals are connected in parallel. In addition, the droop voltage balancing control is presented for the series offshore wind farm. As a result, the input and output voltages of each DAB converter are governed by the same droop characteristic, and the DAB converters' output voltages are kept balanced. The time-domain simulation results show that the DC voltages of each DAB converter and the high voltage direct current (HVDC) transmission system remain stable during the temporal and spatial variations in the wind power generation.

EPRO PS - 008	Design and Stability Analysis of DC Microgrid with Hybrid Energy Storage System

This paper deals with the design and stability analysis of a DC microgrid employing battery-supercapacitor based hybrid energy storage system. The effect of widely varying supercapacitor voltage on the stability of DC microgrid is less discussed in the literature. The conventional design method reported in the literature considers the rated supercapacitor voltage in the modeling and design of controllers. However, the super capacitor unit can discharge as low as 10% of its rated voltage due to self-discharge. It is observed that the conventional method of controller design can potentially make the system unstable or introduce ringing in some of the practical operating conditions. The location of poles and zeros in the model of the DC microgrid system changes with the operating conditions and therefore, the designed controller should be able to operate the system stably in all operating modes. In this work, the sensitivity of DC microgrid stability with respect to supercapacitor voltage variation is analyzed, an optimal supercapacitor voltage to be considered in the design is identified and a design method is proposed to ensure the stability of DC microgrid in all operating modes. The stability of the DC microgrid with controllers designed using the proposed method is evaluated with simulation and experimental studies.

EPRO PS - 009	Design and Control of Micro-Grid fed by Renewable Energy Generating Sources

This paper presents a micro-grid at an isolated location fed from solar and wind energy sources. DFIG (Double Fed Induction Generator) equipped with MPPT (Maximum Power Point Tracking Technology) is used to harness wind energy. A crystalline solar photovoltaic (PV) system is used to convert solar power which is evacuated at the common DC bus of DFIG. The solar power is fed through DC-DC boost converter which is also equipped with MPPT algorithm to extract maximum solar energy. A battery bank is connected at the common DC bus of the DFIG which acts as buffer storage for exchange of energy. The system is designed for complete automatic operation taking consideration of all the practical conditions. The system is also provided with a provision of external power support for battery charging. The voltage and frequency are controlled through a modified indirect vector control of the load side converter which is incorporated with droop characteristics. It alters the frequency setpoint based on the energy level of the battery. The system is modeled in Sim-Power System tool box of MATLAB and its performance is simulated under varying conditions e.g. unavailibity of wind or solar energy, unbalanced and nonlinear loads has been presented.

EPRO PS - 010	Different Influence of Grid Impedance on Low- and High- frequency Stability of PV Generators

Recently, the stability issues when renewable energy sources are connected to weak grid have obtained great attention. The popular view thinks that the grid impedance is adverse to the system stability when renewable energy sources are connected to weak grid. However, in this paper, it is first found that for the photovoltaic (PV) generator, the grid impedance has different influence on the system stability depending on the frequency range when the complete model of the PV generator is taken into consideration. That is, the increase of gird impedance can suppress the low-frequency (<50 Hz) oscillation, while the increase of gird impedance degrades the high-frequency (>300 Hz) stability. Concretely, for the low-frequency range mainly dominated by the power loop and voltage loop of the PV generator, the describing function method is adopted to overcome discontinuity and nonlinearity of the power loop. Then, the low-frequency dynamics like power oscillation can be analyzed accurately. For the high-frequency range mainly dominated by the phase-locked loop and current loop of the PV generator, the impedance analysis method is adopted to reveal the high-frequency instability mechanism. Through these analyses, the different influence of grid impedance on the low- and high-frequency stability of PV generators can be clearly distinguished. All the conclusions are verified through the real-time hardware-in-loop (HIL) tests.

EPRO PS - 011	Fault Characteristics of Distributed Solar Generation

Inverter-based distributed energy resources (DERs) are characterized with low fault current and negligible amount of negative and zero sequence currents. Understanding DER's fault characteristics is critical for fault analysis and protective relay setting. Despite the abundant work on DER modeling, few research studies have been done to analyze DER's fault behaviors during actual fault events. This paper explores recorded fault events collected by Dominion Energy. Fault magnitude, angle, and sequence components are analyzed to show that actual DER fault response may differ from previous understandings.

EPRO PS – 012	Fault Ride through Strategy of DFIG Using Rotor Voltage Direct Compensation Control under Voltage Phase Angle Jump

Wind power experiences fast development during recent years, and large-scale wind power connected to power grid will bring a lot of new challenges. Some new operation characteristics in power grid with doubly-fed induction generator (DFIG) may present, for example the voltage phase angle jump (VPAJ). VPAJ can potential make negative impacts on the fault ride through (FRT) performances of DFIG. Firstly, this paper investigates the physical mechanism and the operation characteristics of DFIG with VPAJ. It is noted that the current control strategies designed for the voltage amplitude change are not suitable for VPAJ. Then, the paper develops a FRT optimization control strategy under VPAJ. It can optimize operation characteristics, develop FRT capability of DFIG. Finally, the simulations of a 250MW wind farm are given to validate the proposed FRT strategy.

EPRO PS - 013	Design and Implementation of Lead–Carbon Battery Storage System

In this paper, we described a design scheme for a lead-carbon battery energy storage system (BESS). A two-stage topology of lead-carbon battery energy storage system was adopted. The number and connection structure of battery cells were designed based on the actual demand. The main circuit parameters of the BESS were determined according to the power transfer capability, harmonic suppression, and dynamic response capability. A state feedback linearization method in a nonlinear differential geometry theory was used for dq-axis current decoupling based on the mathematical model used in the dq coordinate system of the BESS. A control strategy based on filter capacitor current inner loop, grid current middle loop, and dc voltage outer loop was adopted to suppress the resonance peak and achieve the independent regulation of active power and reactive power. The PSCAD/EMTDC simulation results and physical prototype experiments showed that the lead-carbon BESS had a good dynamic and steady-state performance.

EPRO PS - 014	Active Voltage Control for DFIG-based Wind Farm Integrated Power System by Coordinating Active and Reactive Powers under Wind Speed Variations

Large-scale wind farms are generally integrated by long-distance transmissions, but power grids cannot sufficiently support the access point voltage of these wind farms. The access point voltage undergoes a stability problem under wind speed variations. However, the reactive power compensation device cannot reconcile the requirements of response speed and compensation capacity. Despite their fast power decoupling control, the reactive power capability of doubly fed induction generators is restricted by active power output. To satisfy the reactive power demand of system under wind speed variations, coordinating the reactive power capability and active power output of wind farm is the key solution, based on which a novel active control idea is proposed. The reactive power capability of wind farm and the reactive power demand of system are both studied, and the controllable conditions of access point voltage are analyzed. Active voltage control strategies, including active adjustment of reactive power reference, active speed control, and active pitch angle intervention according to wind speed ranges, are proposed. In the simulation, the method is verified to adequately consider the reactive power demand, and excavate the wind farm reactive power capability. The method also effectively suppresses the change of grid voltage under wind speed variations.

EPRO PS - 015	Time-varying interharmonics in different types of grid-tied PV inverter systems

Widely existing circuit topologies and inverter control strategies for PV systems allow customer flexibility but also introduce different kinds of interharmonics into the grid. A complete understanding of interharmonics from PV systems, with reasons behind their origin, remains needed. In addition, the time-varying nature of interharmonics and the potential impacts on other equipment are yet to be understood. In this paper, laboratory and field measurements are presented of seven different inverter types at multiple locations. A comprehensive analysis is performed to understand the existence, persistence, and propagation of interharmonics in PV systems on the DC side as well as grid side for different power levels. The origins of the interharmonics are established with experimental evidence and through a comparative analysis. A rural low voltage 6 customer network, with two different impedance profiles caused by the installation of PV, is considered to show the potential impact on customer voltage. To address the time-varying nature of interharmonics, a sliding window ESPRIT method is preferred over FFT based methods.

EPRO PS - 016	Power Conditioning of Distribution Networks via Single-Phase Electric Vehicles Equipped

This paper presents the design of a single-phase electric vehicle (EV) on-board bidirectional charger with the capability of power conditioning. This charger can control its charging/discharging active power based on the demand of EV battery/network or load. Also, it controls reactive power and harmonic current based on the characteristics of the nonlinear and linear loads. The topology of the proposed charger consists of the bidirectional ac/dc and buck–boost dc/dc converters, where it can operate in four quadrants in the active-reactive power plane with the capability of harmonic compensation. In the next step, this paper presents a suitable control strategy for the bidirectional charger according to the instantaneous active and reactive power (PQ) theory. Based on the PQ theory, the active and reactive power that includes average and oscillatory components obtained, based on the demand of nonlinear/linear loads and EV battery. Then, the reference current of ac/dc converter of the charger and battery is obtained, and in the next step, the situation of the charger switches is determined using output signals of the proportional–integral and proportional–resonant controllers and pulsewidth modulation. Finally, the proposed approach is validated and implemented in the OPAL-RT to integrate the fidelity of the physical simulation and the flexibility of the numerical simulations.

EPRO PS - 017	Analysis and Damping Control of Small-Signal Oscillations for VSC Connected to Weak AC Grid during LVRT

The instability issues of grid-connected voltage source converters (VSC) may easily occur during low voltage ride-through (LVRT), especially when connected to a weak AC grid. In this study, a small-signal model of the grid-connected VSC system was developed to deal with the stability problems during deep voltage sags. Based on the model, the interaction between the phase-locked loop (PLL) and current control has been illustrated. In addition, the eigenvalue and modal analysis method was employed to investigate the influencing factors of the VSC system stability, which include the bandwidths of the PLL and current control loop, grid strength, and voltage sags. Furthermore, on the basis of the interaction between PLL and current control loop, a novel additional damping controller which is placed in the active current control loop was proposed and designed. Finally, experiments were conducted to verify the theoretical analysis and proposed control strategy for enhancing VSC system stability during LVRT with a high impedance grid connection.

EPRO PS - 018	Converter-based Emulation of Battery Energy Storage Systems (BESS) for Grid Applications

Battery energy storage systems (BESSs) tend to be too costly, restrictive, and high-maintenance for experimental use, but power system tests often need their representation. As a solution, we propose an all-in-one, reconfigurable BESS emulation tool for grid applications that only requires one three-phase voltage source converter. This emulator provides chemistry-specific battery behavior like previous work, but it also includes the BESS's power electronics interface and control as well as automatic frequency and voltage support functions for the attached power system. Thus, it allows simple, plug-and-play BESS emulation for grid applications. This paper details the construction, verification, and use of the BESS emulator in an existing grid testbed and concludes that it provides an inexpensive, easy-to-use alternative to using real BESSs in power system experiments.

EPRO PS - 019	An Interleaved Bi-directional AC-DC Converter with Reduced Switches and Reactive Power Control

In this paper, a new interleaved AC-DC converter with a reduced number of semiconductor components for high power energy storage applications is proposed. The interleaved structure reduces the AC side current ripple as well as increases the overall current rating. Moreover, the proposed switching pattern reduces switching and the developed controller provides reactive power control during both power flow directions. The proposed structure is simulated and analyzed using MATLAB/Simulink software, and a 3.5kW prototype of the system has been implemented in the Lab. The results confirm the performance of the proposed topology. There is a seamless transition between operation with different power factors and the current ripple is significantly reduced.

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