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ETPL PS - 001	Power Quality Improvement of PMSG-Based DG Set Feeding Three-Phase Loads

This paper presents power quality improvement of a permanent-magnet-synchronous-generator-based diesel generator (DG) set feeding three-phase loads using a static compensator (STATCOM). A three-leg voltage-source converter (VSC) with a capacitor on the dc link is used as a STATCOM. The reference source currents for the system are estimated using an Adaline-based control algorithm. A pulse width modulation current controller is used for generation of gating pulses of insulated-gate bipolar transistors of the three-leg VSC of the STATCOM. The STATCOM is able to provide voltage control, harmonics elimination, power factor improvement, load balancing, and load compensation. The performance of the system is experimentally tested on various types of loads under steady-state and dynamic conditions. A three-phase induction motor with variable-frequency drive is used as a prototype of diesel engine with the speed regulation. Therefore, the DG set is run at constant speed so that the frequency of supply remains constant irrespective of loading condition.

ETPL PS - 002	Optimal Distributed Generation and Reactive Power Allocation in Electrical Distribution Systems

Optimal and simultaneous siting and sizing of distributed generators and capacitor banks in distribution systems have attracted a lot of attention from distribution companies. The placement and capacity of these devices have direct effects on the system's performance. This paper presents a model for the simultaneous allocation of capacitor banks and distributed generation, which takes into account the stochastic nature of distributed generation. To solve the model presented, we propose an efficient hybrid method based on Tabu search and genetic algorithms. The hybrid method is applied to a well-known system in literature.

ETPL PS - 003	Optimal PMU Placement for Numerical Observability Considering Fixed Channel Capacity—A Semidefinite Programming Approach

This letter presents a 0-1 semidefinite programming (SDP) approach to solve the problem of optimal placement of phasor measurement units (PMUs), considering the existence of conventional measurements and zero injections as well as the impact of PMU channel limits. The proposed formulation can prevent the wasteful utilization of different PMUs observing incident branch current phasors at a given bus more than once. The method is tested on the IEEE 57-bus test system.

ETPL PS - 004	Economic Dispatch of Power Systems with Virtual Power Plant Based Interval Optimization Method

Load prediction and power prediction uncertainties are inevitable aspects of a virtual power plant (VPP). In power system economic dispatch (ED) modeling, the interval is used to describe prediction uncertainties. An ED model with interval uncertainty is established in this paper. The probability degree definition is adopted to convert the interval-based economic dispatch model into a deterministic model for the purposes of solving the modeling problem. Simulation tests are performed on a 10-machine system using professional optimization software (LINGO). The simulation results verify the validity of the proposed interval-based scheme for the economic dispatch of a power system with VPP.

ETPL PS - 005	Multiple Solutions of Optimal PMU Placement Using Exponential Binary PSO Algorithm for Smart Grid Applications.

For smart grid execution, one of the most important requirements is fast, precise, and efficient synchronized measurements, which are possible by phasor measurement unit (PMU). To achieve fully observable network with the least number of PMUs, optimal placement of PMU (OPP) is crucial. In trying to achieve OPP, priority may be given at critical buses, generator buses, or buses that are meant for future extension. Also, different applications will have to be kept in view while prioritizing PMU placement. Hence, OPP with multiple solutions (MSs) can offer better flexibility for different placement strategies as it can meet the best solution based on the requirements. To provide MSs, an effective exponential binary particle swarm optimization (EBPSO) algorithm is developed. In this algorithm, a nonlinear inertia-weight-coefficient is used to improve the searching capability. To incorporate previous position of particle, two innovative mathematical equations that can update particle's position are formulated. For quick and reliable convergence, two useful filtration techniques that can facilitate MSs are applied. Single mutation operator is conditionally applied to avoid stagnation. The EBPSO algorithm is so developed that it can provide MSs for various practical contingencies, such as single PMU outage and single line outage for different systems.

ETPL PS - 006	Optimal PMU Placement for the System Observability Based on System Topology Model

In order to improve the synchronous phasor measurement unit (PMU) configuration efficiency and enlarge its application in the large-scale system, a novel PMU configuration method based on the system topology model and considering zero injection buses is proposed. This proposed method considers different cases of buses connection including leaf nodes, buses with the most and same number of connection branches and buses with two branches. For the buses with the most number of connection branches, the degree of links between buses is proposed to determine PMU placement. In addition, in the process of PMU configuration, the observable and unobservable buses are directly obtained by topology model, which avoids matrix operations and speeds up the speed. The proposed method is tested on the three systems and the results show the proposed method is correct and effective.

ETPL PS - 007	Distributed Optimal Coordination for Distributed Energy Resources in Power Systems

Based on the brushless dc motor driven by a four-switch three-phase inverter (FSTPI), a current control scheme is proposed to reduce the current ripple of both the normal conduction region and the commutation region. Assuming c-phase winding is connected to the middle point of a dc-link capacitance, in the normal conduction region when a-phase and b-phase windings conduct, the current of c-phase may not be zero because of c-phase back electromotive force. The proposed strategy adds two regulating vectors into each control cycle based on the traditional PWM scheme, and controls the c-phase current to be zero by controlling the working time of the regulating vectors in each control cycle. In the commutation region, the noncommutated phase or the outgoing phase switch is modulated by comparing the change rate of the incoming and outgoing phase currents to maintain the noncommutated phase current constant. Compared with the traditional current control strategy, good control effect is kept in both the normal conduction region and the commutation region by accurately controlling the working time of the voltage vectors. The proposed strategy does not need to adjust the parameters of the controller, and it is simple and easy to implement. The experimental results prove the correctness and effectiveness of the control strategy.

ETPL PS - 008	Multi-objective distributed wind generation planning in an unbalanced distribution system

In addition to increasing penetration of distributed generation (DG), the distribution system power flow may be significantly impacted by direction and magnitude. This paper proposes a method for optimal placement of wind DG considering the unbalanced operation of distribution systems. The objective function includes static voltage stability index, three-phase unbalance index, system reliability index, and DG investment cost. The untransposed distribution lines and unbalanced load are modelled, and corresponding static voltage stability index and system reliability considering DG penetrations are derived. The expected and stochastic daily distributed generation and demand profiles in four seasons are calculated to improve the accuracy. To solve this multi-objective optimization model, a fuzzy membership function is used to integrate the four individual objectives, and a sensitivity-based method is proposed to solve the model efficiently. Case study on IEEE 13-bus distribution 3-phase networks and 123-node test feeder successfully verifies the performance of the proposed approach.

ETPL PS - 009	Reliability Optimization of Automated Distribution Networks With Probability Customer Interruption Cost Model in the Presence of DG Units

Distribution automation systems in terms of automatic and remote-controlled sectionalizing switches allows distribution utilities to implement flexible control of distribution networks, which is a successful strategy to enhance efficiency, reliability, and quality of service. The sectionalizing switches play a significant role in an automated distribution network, hence optimizing the allocation of switches can improve the quality of supply and reliability indices. This paper presents a mixed-integer nonlinear programming aiming to model the optimal placement of manual and automatic sectionalizing switches and protective devices in distribution networks. A value-based reliability optimization formulation is derived from the proposed model to take into consideration customer interruption cost and related costs of sectionalizing switches and protective devices. A probability distribution cost model is developed based on a cascade correlation neural network to have a more accurate reliability assessment. To ensure the effectiveness of the proposed formulation both technical and economic constraints are considered. Furthermore, introducing distributed generation into distribution networks is also considered subject to the island operation of DG units. The performance of the proposed approach is assessed and illustrated by studying on the bus 4 of the RBTS standard test system. The simulation results verify the capability and accuracy of the proposed approach.

ETPL PS - 010	Placement of large-scale utility-owned wind distributed generation based on probabilistic forecasting of line congestion

Integration of large-scale utility-owned distributed generation (DG) units can be a vital technique in relieving transmission line congestion and improving the reliability of the power grid. However, the impact of DG installation on line congestion management is significant at locations where transmission lines are most heavily loaded. This study presents a novel probabilistic method to forecast the most heavily loaded lines in the transmission network that might be at a higher risk of congestion. The proposed method can be utilised for determining candidate lines to install DG with the objective of relieving line congestion. The proposed method adopts the cumulative probability distribution function that accounts for the uncertainty of line loading. Furthermore, a congestion improvement ratio is developed to investigate the DG location impact on line congestion. The forecasting method is tested on a small modified IEEE 5-Bus system. In order to demonstrate the proposed forecasting method on a larger and more complex system with several generators, the method is also tested on IEEE 30-Bus test system. The simulation results have confirmed the effectiveness of the proposed method.

ETPL PS - 011	Optimal placement and sizing of distributed generation-based wind energy considering optimal self VAR control

The impact of distributed generation (DG) units on the voltage stability has become a challenging issue especially when squirrel cage induction generator (SCIG)-based wind DGs are utilised. Optimisation methods are tools which can be used to place and size the DG units in the distribution system, so as to utilise these units optimally within certain constraints. This study aims to optimally size and allocate advanced wind energy based DG technology with innovative reactive power capability, reduced capital cost, and improved energy capture capability to improve voltage stability. Therefore, a new combination of SCIG and doubly-fed induction generator (DFIG) based DG configuration is proposed. In this configuration, the reactive power absorbed by SCIG is supplied by DFIG, and therefore, the combined system operates at unity power factor, which makes it feasible to comply with the IEEE 1547 standard. A methodology is proposed to optimally size and allocate the DG system with an objective function to improve the voltage profile considering numerous technical and economic constraints. The performance of the proposed DG configuration is compared with DGs that utilise SCIG with a parallel reactive power compensation. IEEE 30-bus test system is used to demonstrate the effectiveness of the proposed methodology.

ETPL PS – 012	Multiple Solutions of Optimal PMU Placement Using Exponential Binary PSO Algorithm for Smart Grid Applications

For smart grid execution, one of the most important requirements is fast, precise, and efficient synchronized measurements, which are possible by phasor measurement unit (PMU). To achieve fully observable network with the least number of PMUs, optimal placement of PMU (OPP) is crucial. In trying to achieve OPP, priority may be given at critical buses, generator buses, or buses that are meant for future extension. Also, different applications will have to be kept in view while prioritizing PMU placement. Hence, OPP with multiple solutions (MSs) can offer better flexibility for different placement strategies as it can meet the best solution based on the requirements. To provide MSs, an effective exponential binary particle swarm optimization (EBPSO) algorithm is developed. In this algorithm, a nonlinear inertia-weight-coefficient is used to improve the searching capability. To incorporate previous position of particle, two innovative mathematical equations that can update particle's position are formulated. For quick and reliable convergence, two useful filtration techniques that can facilitate MSs are applied. Single mutation operator is conditionally applied to avoid stagnation. The EBPSO algorithm is so developed that it can provide MSs for various practical contingencies, such as single PMU outage and single line outage for different systems.

ETPL PS - 013	Optimal phasor measurement units placement for full observability of power system using improved particle swarm optimization

Penetration of renewable, advanced metering capabilities, and the urge for situational awareness, all calls for power system state estimation (SE). The SE with phasor measurement units (PMUs) is a powerful technique for full system observability. The results of the SE are more accurate, when using PMUs with optimal locations in the complex power systems. In this study, a proposed technique for optimal PMUs placement is discussed and implemented. The optimal PMUs locations will be determined using improved particle swarm optimization algorithm. This study also presented an optimisation solution technique for the problem of SE using the weighted least square method, improved and based on optimal PMUs placement. A numerical observability analysis is also presented to check the validity of the proposed technique in power system SE based on gain matrix factorisation. The technique applies to the standard IEEE 14-, 30-, and 118-buses systems. The results showed high efficiency and good performance in power system SE when using optimal PMUs locations with full observability.

ETPL PS - 014	General optimal substation coverage algorithm for phasor measurement unit placement in practical systems

The primary objective of the conventional optimal phasor measurement unit (PMU) placement problem is the minimisation of the number of PMU devices that, when placed in a power system, measure all bus voltages. However, due to advancements in the field of relay technology, digital relays can now act as PMUs. This has significantly reduced device costs. Moreover, although the goal is to observe all the buses, the devices themselves can only be placed in substations, whose upgrade costs are much higher than those of the devices. Considering these factors, the approach proposed here simultaneously optimises the number of substations where traditional PMUs and dual-use line relay PMUs can be placed. The general optimal substation coverage (GOSC) algorithm presented in this study is also able to incorporate practical requirements such as redundancy in the measurement of critical elements of the system, and estimation of the tap ratios of the transformers present. Simulation results indicate that the GOSC algorithm provides significant techno-economic benefits.

ETPL PS - 015	Integrated Model Considering Effects of Zero Injection Buses and Conventional Measurements on Optimal PMU Placement

The main requirements of the wide-area monitoring system is to acquire the real-time measurement of state variables that can be provided by phasor measurement units (PMUs). The optimal PMU placement is the leading object of this paper, which is presented as an integer linear programming problem. The zero injection buses (ZIBs) and conventional measurements (CMs) enhance the system observability. In this paper, a novel integrated model is presented to consider the effects of the ZIBs and CMs for PMU placement. The proposed model considers limitations caused by ZIBs and CMs that have not been studied earlier. The single branch and single PMU outage, as two common contingencies, are also separately and simultaneously taken into account. The proposed method is applied to five different IEEE test systems (14, 30, 39, 57, and 118 bus) in order to demonstrate its effectiveness. The obtained results are compared with that of the other studies.

ETPL PS - 016	Integrated Evaluation of Reliability and Stability of Power Systems

This paper investigates the impacts of transient instability on power system reliability. Traditionally, composite system reliability evaluation has been performed based on steady-state estimation of load curtailments; system dynamics have often been ignored, mostly due to computational complexity. In this paper, three probabilistic transient stability indices are proposed to assess system robustness against dynamic contingencies and to account for system instability in computing reliability indices. A direct method is utilized for transient stability assessment based on computing the energy margin of the system under fault events (energy margins measure the ability of a system to withstand contingencies). Energy margins along with the probability of occurrences of the events are used to update the probabilistic transient stability indices. The dependencies of reliability and stability indices on the fault clearing time are also evaluated. This method is applied on the reduced Western Electricity Coordinating Council and the New England 39 bus test systems. The results indicate the importance of considering the effect of stability in reliability evaluation.

ETPL PS - 017	Voltage Stability-Constrained Optimal Simultaneous Placement of PMUs and Channels Enhancing Measurement Reliability and Redundancy

In this paper, a channel-oriented method is proposed for optimal placement of phasor measurement units (PMUs) with the objective function of explicit cost of PMUs and their channels. PMU measurement channels are treated as optimization binary variables, and a PMU installed at a bus assigns channels to observe its adjacent buses only if it is economically justified. Since power system substations have different reliability levels, in order to enhance reliability of the measurement system, PMUs and their channels are encouraged to be employed at more reliable buses and branches. In addition, in order to monitor fragile areas of power systems for prevention of voltage collapse, PMUs and their channels are assigned to observe buses with vulnerable voltage stability status. Furthermore, in order for a more economical and practical solution, the most probable contingencies are identified using the Monte Carlo simulation to be incorporated in the problem. Also, PMU failures and branch outages are modeled with a technique resulting in a less cost than existing methods. Channel failure is also modeled as a new type of contingency. The efficiency of the proposed method is evaluated by testing it on standard and practical large-scale test systems.

ETPL PS - 018	Analysis of the Impact of Microgrid Penetration on Power System Dynamics

The paper proposes a stochastic model to analyse the dynamic coupling of the transmission system, the electricity market, and microgrids. The focus is on the impact of microgrids on the transient response of the system and, in particular, on frequency variations. Extensive Monte Carlo simulations are performed on the IEEE 39-bus system, and show that the dynamic response of the transmission system is affected in a nontrivial way by both the number and the size of the microgrids.

ETPL PS - 019	Frequency regulation control strategy for PMSG wind-power generation system with flywheel energy storage unit

To enhance the frequency regulation capability of direct-drive permanent magnet synchronous generator (PMSG)-based wind-power generation system, the frequency regulation control strategy for wind-power system with flywheel energy storage unit (FESU) based on fuzzy proportional plus differential (PD) controller is proposed in this study. According to the mathematical model of PMSG-based wind-power generation system with FESU, the small-signal model of the whole system is deduced in detail. In addition, the eigenvalue loci of the system are investigated to obtain the appropriate ranges of FESU's PD controller parameters for ensuring the system stable operation. Meanwhile, the impact of system equivalent inertia and damping on system frequency stability is analysed. Furthermore, a fuzzy PD controller of FESU is designed to dynamically regulate the system equivalent inertia and damping, leading to improved grid frequency characteristics. Finally, simulation studies on a 2 MW PMSG-based wind-power generation system with 400 kW FESU verify the validity of the proposed control strategy, contributing to enhance the frequency stability of power grid.

ETPL PS - 020	A hybrid dynamic demand control strategy for power system frequency regulation

The rapid increase in renewable energy integration brings with it a series of uncertainty to the transmission and distribution systems. In general, large-scale wind and solar power integration always cause short-term mismatch between generation and load demand because of their intermittent nature. The traditional way of dealing with this problem is to increase the spinning reserve, which is quite costly. In recent years, it has been proposed that part of the load can be controlled dynamically for frequency regulation with little impact on customers' living comfort. This paper proposes a hybrid dynamic demand control (DDC) strategy for the primary and secondary frequency regulation. In particular, the loads can not only arrest the sudden frequency drop, but also bring the frequency closer to the nominal value. With the proposed control strategy, the demand side can provide a fast and smooth frequency regulation service, thereby replacing some generation reserve to achieve a lower expense.

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