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Power Electronics

Titles & Abstract

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EPRO_PE_001

A Power Adaptive Impedance Reshaping Strategy for Cascaded DC System With Buck-Type Constant Power Load

It is well-known that the low-frequency negative input impedance of the constant power load (CPL) is the major cause of the cascaded system instability, and the heavier the power, the worse the stability. In this article, a power adaptive load-side parallel virtual impedance (PALPVI) control strategy is proposed to improve the stability of the cascaded dc system with buck-type CPL. First, a parallel impedance with power adaptability is derived followed up with the derivation of the corresponding compensation controller transfer function to realize it virtually. Considering that the compensation controller is highly dependent on the circuit parameters and needs extra current sensors to acquire the power information, a simplification of the compensation controller is made based on the open-loop characteristics of the buck-type CPL. The final PALPVI control strategy does not require the circuit parameters or any current sensor and has almost no side effect on the dynamic performance. Finally, a 48–24–12 V cascaded dc system is fabricated to verify the feasibility and effectiveness of the proposed PALPVI control strategy.

EPRO_PE_002

Power-Electronics-Based Mission Profile Emulation and Test for Electric Machine Drive System—Concepts, Features, and Challenges

In the last decade, significant progress has been made in electrification, especially in the applications of electrical vehicles, renewable energies, and industry automations, which imposed much more complicated working conditions to electric machines as well as the drive converters. More advanced features, such as the control strategies, functionality, stability, and reliability of machine drive systems, need to be characterized and validated. Thus, there is an emerging need to accurately recreate the behaviors of electric machine drive systems from more aspects for comprehensive tests. This article aims to foster and investigate the mission profile emulation technologies for the testing of electric machine drive systems. The key factors of the system to be emulated are first clarified, and then different testing concepts are summarized and compared, including dynamometer test, controller hardware-in-the-loop simulation, power hardware-in-the-loop simulation, and power-electronics-based emulation. The features of power-electronics-based emulation, which is considered as a promising trend, will be further discussed with respect to the degrees of coupling with the drive converter, electric machine models, and control structures. Finally, challenges in the field of mission profile emulation for electric machine drive systems are discussed.

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EPRO_PE_003

Deadbeat Power Distribution Control of Single-Stage Multiport Inverter-Fed PMSM Drive for Hybrid Electric Vehicles

Single-stage multiport inverter (SSMI)-fed motor drives are promising solutions for multisource hybrid electric vehicles (HEVs) since the dc–dc converter is removed and all the active power is delivered within a single power conversion stage. However, this topology presents inherent coupled issues in the controller design because the power distribution should be achieved simultaneously in addition to the stator current control. To address this issue, an equivalent two-level model is proposed to achieve decoupled control of the SSMI, where the stator current control is achieved by regulating the active vectors, and the power distribution is achieved by regulating the zero vectors. A deadbeat power distribution scheme is developed under the equivalent two-level model. The proposed scheme provides these advantageous features: fewer computational burdens without complicated sector selection and dwell time calculation under the unevenly distributed voltage vector diagram, fewer adjusted parameters, and fast dynamic response. Moreover, the power distribution capability of the SSMI with the proposed scheme is also analytically revealed. A series of experimental results demonstrate the excellent performance of the proposed deadbeat power distribution control scheme.

EPRO_PE_004

High Gain Magnetically Coupled Single Switch Quadratic Modified SEPIC DC-DC Converter

This article proposes, analyzes, and tests an improved high voltage gain dc-dc converter based on a single-ended primary-inductor converter (SEPIC). The proposed magnetically coupled quadratic modified SEPIC converter (MCQ-MSC) employs a coupled transformer with an optimized design to obtain a high voltage boost factor by controlling the transformer's turn ratio along with the switching duty cycle. Thanks to the unique structure of the coupled transformer, high voltage gain is obtained at low turns ratio, which is highly desirable for high voltage applications and the compact size of the converter. In addition to the coupled transformer, a voltage- boosting module is utilized to achieve a very high output voltage for a low switching duty cycle. The proposed inverter has a single switch with a wide control range of duty cycle ($0 < D < 1$), causing low conducting losses and high efficiency. Furthermore, a clamping circuit is successfully designed to remove the leakage inductance effects of the coupled transformer on the power switch. The proposed MCQ-MSC drains a continuous current from the input dc source, which makes it a suitable choice for renewable energy sources (RES). The hardware prototype of the proposed converter is tested to verify the mathematical expressions and theoretical results

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EPRO_PE_005

Prediction of Solar Irradiance One Hour Ahead Based on Quantum Long Short-Term Memory Network

The short-term forecasting of photovoltaic (PV) power generation ensures the scheduling and dispatching of electrical power, helps design a PV-integrated energy management system, and enhances the security of grid operation. However, due to the randomness of solar energy, the output of the PV system will fluctuate, which will affect the safe operation of the grid. To solve this problem, a high-precision hybrid prediction model based on variational quantum circuit (VQC) and long short-term memory (LSTM) network is developed to predict solar irradiance 1 hour in advance. VQC is embedded in LSTM to iteratively optimize the weight parameters of four gates (forgetting gate, input gate, cell state, and output gate) to improve prediction accuracy. To evaluate the prediction performance of this model, five solar radiation observatories located in China are selected, together with widely used models including seasonal autoregressive integrated moving average, convolution neural network, recurrent neural network (RNN), gate recurrent unit, (GRU), and LSTM; comparisons are made under different seasons and months.

EPRO_PE_006

Enhance Unobservable Solar Generation Estimation via Constructive Generative Adversarial Networks

Power distribution grids experiences proliferation of solar photovoltaics (PV) at the system edge. However, its counterpart of sparse meter deployment provides insufficient monitoring of PVs, for which the potential violations challenge the operators for energy management and stable operation. Some previous works use satellite imagery to detect distributed PVs for the easy access of data. However, their PV localization methods rely on label-rich area with unitary background/environment to implement well; even further/harder, they do not provide precise metered-PV detection and quantification to estimate/know PV generation outputs in unobservable area, which is essential to prevent the edge from excessive two-way power flow and other violations. Thus, we combine the two steps of detecting PV existence and quantify PV amount into one classification task. To boost the classification performance in unobservable edge area, we construct a generative adversarial network that simultaneous augments the diversity of labelled PV satellite images and embed distinct PV characteristics/features for training the classifier.

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EPRO_PE_007

Three-Leg DC–DC Converter for Efficient Inductive Power Transfer of Electric Vehicles for Wide-Range Battery Applications

The design of an inductive power transfer system for different electric vehicle (EV) models with widely varied battery pack voltages has been a challenging task. The majority of modern EV models are equipped with 400 or 800 V battery packs. To charge both batteries efficiently, an additional dc–dc converter on the receiver side is employed, which reduces the overall system efficiency and also increases the cost. This letter proposes a reduced switch count novel converter to charge distinct EV models without degrading the efficiency of the system. The proposed converter has two operating modes, a voltage doubler mode to charge an 800 V battery and a current doubler mode to charge a 400 V battery at the same power level. MATLAB/Simulink simulations have been carried out to verify the performance of the three-leg converter for both 400 and 800 V batteries at
7.2 kW. Furthermore, a laboratory prototype of the proposed converter for 500 W has been built using the silicon carbide (SiC) devices, and the results obtained are provided.

EPRO_PE_008

Deep Reinforcement Learning-based Hierarchical Energy Control Strategy of a Platoon of Connected Hybrid Electric Vehicles through Cloud Platform

Due to the features of strong non-linearity and hybrid driving with multi-power sources, a novel deep reinforcement learning(DRL)-based hierarchical energy control architecture is presented for a group of connected hybrid electric vehicles (HEVs) in the platoon through cloud platform. Firstly, a higher-level model predictive control (MPC) law is designed to determine the desired acceleration of connected HEVs in a platoon. Secondly,a reward function with the change of state of charge (SOC) and instantaneous fuel consumption as independent variables is constructed, and the expert knowledge-based deep deterministic policy gradient (DDPG) method with prioritized experience replay (PER) is used for designing the lower-level energy management strategy of connected HEVs platooning. Then, to illustrate the rationality of decision-making by the presented DDPG strategy, the influence of state variables such as vehicle speed, desired acceleration and battery SOC on the agent action values of presented DDPG method is discussed. Finally, the test results show that the proposed control scheme can reasonably allocate the engine and motor powers in real time, and finally achieve the safe and energy-saving driving of connected HEVs in the platoon.

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EPRO_PE_009

Battery Safety Risk Assessment in Real-World Electric Vehicles Based on Abnormal Internal Resistance Using Proposed Robust Estimation Method and Hybrid Neural Networks

Battery safety issue is developing as one of the main hinders restricting the further application of real-world electric vehicles (EVs). Internal resistance (IR) is one of the important parameters to reflect battery safety, because bigger abnormal IR will cause more heat generation and make the battery easier to cross the critical condition of thermal runway. Safety risk assessment based on abnormal IR can locate these kind unsafe batteries and ensure the safe operation of EVs. In this regard, a method is proposed to detect unsafe battery, thereby predicting the thermal runaway. The method can be divided into three parts, i.e., IR estimation, normal IR prediction, and IR evolution law construction and safety risk assessment. First, we propose a robust method to estimate the IR only based on sparse voltage and current. Second, a novel hybrid neural network model is designed and trained to predict normal IRs inputted by temperature, mileage, and state-of-charge. The model combines the advantages of different neural network structures to improve the performance. Finally, the safety boundary indicated by IR is formed and the IR evolution law is constructed, then a strategy is proposed to make residual evaluation for safety risk assessment.

EPRO_PE_010

Dynamical Model for Power Grid Frequency Fluctuations: Application to Islands With High Penetration of Wind Generation

We study the effects of a high share of wind generation on the frequency fluctuations of power grids on islands. We propose a dynamical model that includes conventional and variable renewable generation, as well as demand variations. Our model can assimilate load and generation data and reproduce frequency fluctuations with the current power mix with a high degree of accuracy, and it allows to simulate the frequency dynamics for different scenarios with a very high penetration of renewable energy. As a case study, we analyze the power grid of Gran Canaria island. We characterize the frequency fluctuations and propose a method to estimate the control needed to keep frequency deviations within reasonable limits.

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EPRO_PE_011

An Optimal Operation Strategy for Collaborative Flexibility Provision of a Carbon Capture and Utilization Process with Wind Energy

Improving power system flexibility by responsive demand is essential for integrating wind energy with a high level of variability in power systems. Carbon dioxide-based chemical processes as energy-intensive industrial loads may offer a vast potential of new forms of flexible operation due to their existing control infrastructure and storage capabilities. However, a collaborative decision model is needed for optimal energy sharing among the chemical plant and the grid under the variations and uncertainties of wind power. This study develops an optimal two-stage stochastic programming model for a novel flexible operation strategy of the chemical process coupled with wind turbines. In the proposed control scheme, a small-scale wind farm provides the power input of a chemical plant. Wind turbines are connected to the grid and actively participate in the day-ahead energy and reserve markets, considering the chemical plant as a source of flexibility. An equivalent scenario-based model of the proposed optimization problem is suggested using the Group Method of Data Handling (GMDH) for a data-driven prediction of stochastic variables.

EPRO_PE_012

Placement and Capacity of EV Charging Stations by Considering Uncertainties with Energy Management Strategies

At the present context, Plug-in electric vehicles (PEVs) are gaining popularity in the automotive industry due to their low CO2 emissions, simple maintenance, and low operating costs. As the number of PEVs on the road increases, the charging demand of PEVs affects distribution network features, such as power loss, voltage profile, and harmonic distortion. Furthermore, one more problem arises due to the high peak power demand from the grid to charge the PEVs at the charging station (CS). In addition, the location of CS also affects the behavior of EV users and CS investors. Hence, this paper applies CS investor, PEV user, and distribution network operator who could approach to CS's optimal location and capacity. Integrating renewable energy sources (RESs) at the charging station is suggested to lower the energy stress on the grid. Moreover, to keep down the peak power demand from the grid and utilize renewable energy more efficiently, energy management strategies (EMS) have been applied through the control of charging and discharging of the battery storage system (BSS). In addition, vehicle to grid (V2G) strategy is also applied to discharge the EV battery at charging station. Furthermore, the uncertainties related to PEV charging demand and PV power generation are addressed by the Monte Carlo Simulation (MCS) method.

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EPRO_PE_013

Neural Network Design for Impedance Modeling of Power Electronic Systems Based on Latent Features

Data-driven approaches are promising to address the modeling issues of modern power electronics-based power systems, due to the black-box feature. Frequency-domain analysis has been applied to address the emerging small-signal oscillation issues caused by converter control interactions. However, the frequency-domain model of a power electronic system is linearized around a specific operating condition. It thus requires measurement or identification of frequency-domain models repeatedly at many operating points (OPs) due to the wide operation range of the power systems, which brings significant computation and data burden. This article addresses this challenge by developing a deep learning approach using multilayer feedforward neural networks (FNNs) to train the frequency-domain impedance model of power electronic systems that is continuous of OP. Distinguished from the prior neural network designs relying on trial-and-error and sufficient data size, this article proposes to design the FNN based on latent features of power electronic systems, i.e., the number of system poles and zeros.

EPRO_PE_014

Review of Fault Diagnosis and Fault-Tolerant Control Methods of the Modular Multilevel Converter Under Submodule Failure

Modular multilevel converters (MMCs) have attracted extensive research interests in various ac and dc conversion applications due to their modular structure and excellent harmonic performance. However, the large number of power switches increases the potential risk of submodule (SM) failure, which greatly challenges the safe and reliable operation of the MMC. This article presents a detailed review of fault diagnosis and fault-tolerant control methods of the MMC under SM failures. On this basis, comprehensive comparisons are conducted among different fault diagnosis methods, and verification results are provided to analyze the advantages and disadvantages of the popular fault-tolerant control methods. Finally, the review is concluded, and future trends and research opportunities are discussed.

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EPRO_PE_015

Power Electronics-Based Safety Enhancement Technologies for Lithium-Ion Batteries: An Overview From Battery Management Perspective

Safety enhancement for lithium-ion batteries (LIBs) has received a lot of attention from academic and industrial fields. However, there is a lack of overview from the perspective of the application power electronics (PEs) in the systems. This article gives an overview of PE-based safety enhancement technologies for LIBs, mainly focusing on battery management. It introduces the latest advances in battery protection, balancing, monitoring, and lifetime improvement, all based on PE technologies. Detailed discussion and future research opportunities are given. This article aims to provide a reference for PE researchers who want to make some efforts in LIB safety.

EPRO_PE_016

Improving the Efficiency of Deep Learning Models using Supervised Approach for Load Forecasting of Electric Vehicles

This research work proposes an Improved Supervised Learning (ISL)-based Deep Neural Network (DNN) for accurately forecasting the load demand of Electric Vehicles (EVs). This work incorporates Gated Recurrent Unit (GRU), Long Short Term Memory (LSTM), Recurrent Neural Network (RNN), Fully Connected (FC), and Convolutional Neural Network (CNN) architectures. The proposed ISL technique enhances prediction performance by refining the training process with additional features and information. Using a real-world EV charging dataset from Boulder City, USA, the simulations demonstrate consistent improvements in the GRU, LSTM, RNN, FC, and CNN models with the proposed ISL technique. Further, the proposed technique reduces the Normalised Root Mean Square Error (NRMSE) and Normalised Mean Absolute Error (NMAE) values. The accurate load demand predictions facilitated by the proposed models with ISL have significant implications for the planning and management of EV charging stations.

EPRO_PE_017

Electric Vehicles Charging Sessions Classification Technique for Optimized Battery Charge Based on Machine Learning

The fast increase in electric vehicle (EV) usage in the last 10 years has raised the need to properly forecast their energy consumption during charge. Lithium-ion batteries have become the major storage component for electric vehicles, avoiding their overcharge can preserve their health and prolong their lifetime. This paper proposes a Machine Learning model based on the K-Nearest Neighbors classification algorithm for EV charging session duration forecast. The model forecasts the duration of the charge by assigning the event to its correct class. Each class contains the charging events whose duration is comprised of a certain interval. The only information used by the algorithm is the one available at the beginning of the charging event (arrival time, starting SOC, calendar data). The model is validated on a real-world dataset containing records of charging sessions from more than 100 users, a sensitivity analysis is performed to assess the impact of different information given as input. The effectiveness of the model with respect to the benchmark models is demonstrated with an increase in performance.

EPRO_PE_018

Aggregated Representation of Electric Vehicles Population on Charging Points for Demand Response Scheduling

Charging electric vehicles (EVs), whose number is increasing, is a great challenge for the power grid due to the charging load variability. Coordinated charging and schedule optimization with seized demand response opportunities are well-known conceptual solutions to that. Still, the main challenge is to adequately predict availability and parameters of electric vehicles which is crucial for determining the charging schedule and the demand response potential. We propose a method to represent a population of electric vehicles that on the one hand enables prediction via machine learning and on the other it enables an accurate optimization of the charging schedule and demand response ability. The method essence is to use five discrete-time signals spanned over a prediction horizon period which are related to envelopes of feasible charging power and charging states for the EV population on that horizon. We also introduce a robust conversion of any sequence of these signals into individual EVs data

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EPRO_PE_019

The Impact of Considering State of Charge Dependent Maximum Charging Powers on the Optimal Electric Vehicle Charging Scheduling

Intelligent charging solutions facilitate mobility electrification. Mathematically, electric vehicle (EV) charging scheduling formulations are constrained optimization problems. Therefore, accurate constraint modeling is theoretically and practically relevant for scheduling. However, the current scheduling literature lacks an accurate problem formulation, including the joint modeling of the nonlinear battery charging profile and minimum charging power constraints. The minimum charging power constraint prevents allocating inexecutable charging profiles. Furthermore, if the problem formulation does not consider the battery charging profile, the scheduling execution may deviate from the allocated charging profile. An insignificant deviation indicates that simplified modeling is acceptable.

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