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Novel Control Strategies for Smart Electrical Car Parks

by

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Certificate of Authorship/Originality

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Contents

List of Figures

List of Tables

Abbreviations

AEMO - Australia Energy Market Operator

DPC - Direct Power Control

DTC - Direct Torque Control

EV - Electric Vehicle

G2V - Grid-to-Vehicle

ICE - Internal Combustion Engine

IGBT - Insulated-Gate-Bipolar-Transistor

KVL - Kirchhoff's Voltage Law

MMPC - Modified Model Predictive Control

MPC - Model Predictive Control

MPDCC - Model Predictive Direct Current Control

MPDPC - Model Predictive Direct Power Control

MPPIC - Model Predictive Proportional Integral Control

MPSMC - Model Predictive Sliding Mode Control

PFC - Power Factor Correction

PHEV - Plug-in Electric Vehicle

PI - Proportional Integral

PLL - Phase Locked Loop

PWM - Pulse Width Modulation

SMC - Sliding Mode Control

SOC - State of Charge

SVC - Static Var Compensator

SVPWM - Space Vector Pulse Width Modulation

THD - Total Harmonic Distortion

UTS - University of Technology Sydney

VOC - Voltage Oriented Control

V2G - Vehicle-to-Grid

V2V - Vehicle-to-Vehicle

V4G - Vehicle-for-Grid

WPAN - Wireless Personal Area Networks

Symbols

m - the mth EV

M - the total number of EVs

n - the nth period

N - the total periods

N_m - the total parking periods of the mth EV

E_m^n - the energy of the mth EV in the nth period (kWh)

E_m - the current stored energy of the mth EV (kWh)

$E_{m,c}^n$ - the charging energy of the mth EV (kWh)

$E_{m,d}^n$ - the discharging energy of the mth EV (kWh)

C_m - the battery capacity of the mth EV (kWh)

$SOC_{m,fin}$ - the final SOC of the mth EV (%)

$SOC_{m,ini}$ - the initial SOC of the mth EV (%)

p_m^n - the charging/discharging power of the mth EV in the nth period (kW)

$p_{m,c,max}$ - the maximum charging power of the mth EV (kW)

$p_{m,c,max}$ - the maximum charging power of the mth EV (kW)

$p_{m,d,max}$ - the maximum discharging power of the mth EV (kW)

$\mathbf{S}_{\alpha\beta}$ - the switching states in the $\alpha\beta$ coordinate

$\mathbf{S_{abc}}$ - the switching state vector in the *abc* coordinate

$\mathbf{v}_{\alpha\beta}$ - the input voltage vector of the three-phase converter in $\alpha\beta$ coordinate

$\mathbf{v}_{\mathbf{g},\alpha\beta}$ - the grid voltage vector in the $\alpha\beta$ coordinate

$\mathbf{i}_{\mathbf{g},\alpha\beta}$ - the grid current vector in the $\alpha\beta$ coordinate

* - the complex conjugate

$\mathbf{i}_{\mathbf{g}}^*$ - the complex conjugate of grid current

ABSTRACT

Due to the clean energy imperatives and strong desire to reduce greenhouse gas emissions, electric vehicles (EVs) were introduced into the car market several decades ago. In 2016, electric cars hit a new record with over 750 thousand sales worldwide. China was the largest electric car market with more than 40% of all car sales in the world. With an increasing number of electric cars, private and publicly accessible charging infrastructure has also continued to grow. As most of the time these electric cars are parked in personal or public car parks. A car park with these parked electric vehicles can be regarded as a large energy storage system. These vehicle batteries can be used as energy storage devices to exchange the power between the grid and vehicles. With this idea, a new smart car park model is proposed, where the power flows among electrical vehicles, as well as between batteries and the main grid. Based on this model, an optimal charging/discharging scheme is developed to maximum the profits for the car park and reduce the cost for the car owners. The proposed smart electrical car park is able to buy or sell electricity in the form of active and/or reactive power, i.e. kWh and/or kVARh, from or to the main grid to improve the power quality. According to the current state of charge of the car battery bank, customer and grid demands, a control centre makes the decisions and sends the instructions for the specific charging/discharging mode to each charging station.

The model predictive control (MPC) method is distinguished for its several advantages: free of modulation, simple inclusion of system parameters, constraints and demands in the algorithm. With this MPC strategy, EV chargers are able to transmit the active and reactive power between the EV batteries and the power grid. When providing the reactive power from the EVs to the main grid, EV batteries can be regarded as static VAR compensators to improve the power quality. To improve the system performance, a modified MPC scheme is proposed for better performance. The modified MPC is based on the application of an optimal voltage vector chosen from an extended set of 20 modulated voltage vectors with a fixed

duty ratio. To solve the computational problem introduced by the increased voltage sets, a pre-selective algorithm is proposed for the MMPC method. Six voltage vectors are pre-selected from the 20 sectors. The conventional and proposed MPC methods are compared through numerical simulation and experimental test results via a two-stage two-level three-phase off-board charger. Better system performance can be achieved with the modified MPC method.

The conventional MPC method, however, produces a large overshoot/undershoot, a long settling time and a large steady state error under disturbances. To overcome these deficiencies, a sliding mode controller is employed to replace the PI controller in MPC. A model predictive sliding mode control (MPSMC) scheme is proposed to achieve better stability and dynamic performances. Since the control law and the controller are based on the system model, the proposed scheme can reduce the effects of unexpected disturbances, such as the output voltage demand and the resistive load variations. Numerical simulation and experimental test results are obtained via the proposed MPSMC method and compared with the results form the traditional MPC scheme.

For convenient integration into the power grid, the topology of an electric car park can be based on either AC bus or DC bus. The EV chargers can be controlled to achieve four-quadrant operation, delivering active and reactive power from or to the main grid. The system performance obtained from simulation tests with these two topologies are compared and discussed, including the cost, reliability, size, active and reactive power ripples, and current distortion, etc.