List of References:

Main References for Part I


Main References for Part II


Control enhancement of power conditioning units for high quality PV systems

Ahmed Mohamed*, M. Elshaer, Osama Mohammed

Department of Electrical and Computer Engineering, Florida International University, Miami, FL 33174, USA

ARTICLE INFO

Article history:
Received 20 January 2012
Received in revised form 3 April 2012
Accepted 4 April 2012
Available online 3 May 2012

Keywords:
Adaptive controller
Maximum operating range
Optimal control
PV systems
PV system loadability

ABSTRACT

This paper presents an adaptive fuzzy-proportional integral derivative (PID) controller for DC–DC boost converters used as voltage regulators in PV systems. This proposed controller maximizes the stable operating range by tuning the PID parameters ultimately at various loading conditions. Then, a fuzzy logic approach is used to add a factor of intelligence to the controller such that it can move among different values of proportional gain ($K_p$), integral gain ($K_i$) and derivative gain ($K_d$) based on the system conditions. This controller allows optimal control of boost converters at any loading condition with no need to retune parameters or possibility of failure. Moreover, the paper presents a novel technique to move between the PI and PID configurations of the controller such that the minimum overshoot and ripple are obtained, which increases the controller applicability for utilization in PV systems supplying sensitive loads. A PV system with a capacity of 1 kW has been simulated and implemented in hardware to examine the proposed controller. Furthermore, this paper discusses the loading limitations in PV systems resulting from switching the power electronic interfaces and transients associated with large loads. These conditions derate the power generation capability of the PV system. We propose some methods to enhance the loadability of these systems under both steady state and dynamic operations. A PV system for home application purposes, with a rated power of 280 W was designed and built to investigate the loadability issue. The proposed enhancements were applied to the experimental setup and the obtained results verified the effectiveness of the proposed methods.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

Photovoltaic systems have become globally accepted as a practical and feasible tool for electric power generation. Researchers’ efforts for facilitating PV systems utilization and their integration to currently available systems have been always inspired by the national goal of having renewable and clean energy sources. These efforts successfully solved many of the problems that are attached to PV systems [1]. Generally, PV systems are of two types: grid-connected and stand-alone PV systems. Although grid-connected PV systems are designed to operate in parallel with the utility network, grid-connected PV systems may feed local loads independently from the utility grid in an islanded mode during outages. Moreover, they may involve battery storage or other generating sources in order to increase the overall reliability of the system. On the other hand, stand-alone PV systems are designed to supply power to certain loads independently from the utility grid. Therefore, system planning in terms of system sizing and capacity is crucial to satisfy the load demand. The loads can be in a DC form. In this case a DC–DC converter has to be used to regulate the output voltage of the PV panels. Moreover, these PV systems can supply AC loads but in this case an added DC–AC inversion has to be utilized. Generally, there are three types of stand-alone PV systems, PV-powered water pumping systems, Remote residential PV systems and PV-powered lighting systems. However, in this paper, the PV systems are divided into:

• PV systems supplying power in DC form

Such systems include PV systems integrating their output power into a common DC bus in a DC microgrid or a DC distribution system. In this case, a current controlled DC–DC converter is used as the only power conditioning unit interfacing the PV array to the DC bus. Moreover, this category also includes stand-alone PV systems supplying DC loads. In this case a voltage controlled DC–DC converter is used.

• PV systems supplying power in AC form

Such systems include grid-connected PV systems integrating their output power into utility grid in AC form or stand-alone PV systems supplying AC loads. The main purpose of this paper is to present some ideas to improve both the steady state and transient responses of different types of PV systems.
A Compact Digitally Controlled Fuel Cell/Battery Hybrid Power Source

Zhenhua Jiang, Member, IEEE, and Roger A. Dougal, Senior Member, IEEE

Abstract—A compact digitally controlled fuel cell/battery hybrid power source is presented in this paper. The hybrid power source composed of fuel cells and batteries provides a much higher peak power than each component alone while preserving high energy density, which is important and desirable for many modern electronic devices, through an appropriately controlled dc/dc power converter that handles the power flow shared by the fuel cell and the battery. Rather than being controlled to serve only as a voltage or current regulator, the power converter is regulated to balance the power flow to satisfy the load requirements while ensuring the various limitations of electrochemical components such as battery overcharge, fuel cell current limit (FCCL), etc. Digital technology is applied in the control of power electronics due to many advantages over analog technology such as programmability, less susceptibility to environmental variations, and low parts count. The user can set the FCCL, battery current limit, and battery voltage limit in the digital controller. A control algorithm that is suitable for regulating the multiple variables in the hybrid system is described by using a state-machine-based model; the issues about embedded control implementation are addressed; and the large-signal behavior of the hybrid system is analyzed on a voltage–current plane. The hybrid power source is then tested through simulation and validated on real hardware. This paper also discusses some important issues of the hybrid power source, such as operation under complex load profiles, power enhancement, and optimization of the hybrid system. The design presented here can not only be scaled to larger or smaller power capacities for a variety of applications but also be used for many other hybrid power sources.

Index Terms—Battery, digital control, fuel cell, hybrid power source, microcontroller, power capacity.

I. INTRODUCTION

FUEL CELLS have shown promising potential for several areas of applications such as those in portable electronics, hybrid electric vehicles, remote communication facilities, remote-ground support stations, etc. [1]–[4]. However, many applications have a common characteristic in their load profiles, that is, they have a relatively low average power demand but a relatively high pulse power requirement. The typical pulse duration in these applications generally ranges from hundreds of milliseconds to minutes, with power levels depending on the applications. Fuel cell/battery hybrid power sources can meet these pulse power requirements with higher specific power and efficiency than the fuel cell alone while still preserving high energy density [5]–[11]. The simplest hybrid configuration, for example, passive hybrid, results from connecting both the fuel cell and the battery directly to the power bus [5]. However, this passive hybrid allows less flexibility in system design compared to the active hybrid that will be discussed below, because the nominal voltages of the fuel cell stack and the battery in the passive hybrid must be similar in order to not overcharge the battery, yet similar voltages then determine in a rather fixed way the amount of power that can be supplied from the fuel cell to the battery or to the load, as illustrated in Fig. 1.

As an alternative to the passive hybrid, a dc/dc power converter can be placed between the fuel cell and the battery so that they may have different voltage levels [6]–[11]. As shown in Fig. 1, the active hybrid can greatly augment the peak output power while not increasing the system weight and volume a lot, as will be discussed later. Active hybrid fuel cell power sources require a much more complex control scheme that must ensure efficient and robust power transfer from sources without risks of their rapidly degraded reliability due to prolonged overcurrent and/or undervoltage conditions. The power architecture and control scheme dedicated for hybrid fuel cell/battery sources must provide an uninterrupted power flow to the load. Therefore, rather than achieving a single voltage or current regulation goal at the output, the control system must regulate the power converter to balance the power flow of both sources so as to satisfy the load requirements while ensuring the various limitations of electrochemical components such as battery overcharge, fuel cell current limit (FCCL), etc.

Previous power controllers for hybrid power sources mostly employed complicated analog circuits [12]. Although analog...
Modified droop controller for paralleling of dc–dc converters in standalone dc system

S. Anand  B.G. Fernandes
Department Electrical Engineering, Indian Institute of Technology, Bombay, India
E-mail: sa@ee.iitb.ac.in; bgf@ee.iitb.ac.in

Abstract: Dc systems are gaining popularity because of its high efficiency, high reliability and easy interconnection of renewable sources as compared to ac systems. In standalone dc system, parallel dc–dc converters are used to interconnect storage element and loads. Use of master–slave controller for paralleling is limited because of its high cost, low reliability and complexity. Although conventional droop controllers overcome these limitations, they cannot simultaneously ensure equal current sharing (in per unit) and low-voltage regulation. This is due to the error in measurement of voltage feedback signal. To address this limitation, modified droop controller is proposed in this study. Circulating current between converters is used to modify nominal voltages such that error between them is reduced. This improves current sharing among converters. The advantage of the proposed method is that, equal current sharing is achieved along with low-voltage regulation. The effectiveness of the proposed scheme is verified through detailed simulation study. To confirm the viability of the scheme, experimental studies are carried out on a scaled-down laboratory prototype developed for the purpose and results are included in this study.

1 Introduction

Depleting fossil fuels, increasing energy demand and concern over climate change because of CO₂ emission motivate the use of renewable sources. However, supplying electronic loads, variable speed drives and light emitting diode (LED) loads from renewable sources require multiple ac–dc and dc–ac conversions [1]. This causes substantial energy wastage before end use. To address this limitation, dc system is suggested, which offers high efficiency and reliability [1–4]. In this system, most of the loads, sources and storage elements operate on dc voltage. To interconnect these elements, dc–dc converters are used. For standalone applications, renewable sources and storage elements are used to provide uninterrupted power to loads, as shown in Fig. 1. Two category of converters are used (i) renewable side converter (RSC), interconnects renewable source to the storage elements and (ii) storage side converter (SSC), interconnects storage elements to the load bus. The RSC extracts maximum power from renewable sources and supply that to storage element, whereas control objective of SSC is to regulate the dc load bus voltage at its nominal value. At high powers and to increase the reliability of SSC, parallel combination of dc–dc converters is preferred over single dc–dc converter. Some advantages of paralleling are: (i) increased reliability because of \( N+1 \) formation of converters, (ii) easy expansion of power capacity by adding more parallel units and (iii) reduced manufacturing cost and design efforts because of standardisation of a single unit [5, 6]. The requirements for parallel operation of dc–dc converters operating as SSCs are: (i) load current should be shared equally (in per unit) by the converters operating in parallel and (ii) output voltage regulation should be within values acceptable to loads.

Modelling of parallel dc–dc converters and related stability criteria are given in [7–9]. Several control methods, for parallel dc–dc converters are reported in literature. Following are the two popular categories of controllers used:

- **Master–slave controller** [10–15]: One converter is operated in voltage controlled mode (master), regulating the output voltage equal to the nominal (set) value. Other converters operate in current controlled mode (slaves), regulating their output currents. Master controller computes the reference current value for slaves based on the total load current. These reference values are then communicated to the slave controllers. For sudden change in load, master regulates the output voltage and provides the difference between total current supplied by slave converters and that demanded by loads. This additional current gets distributed among slave converters only after the new reference values for currents are calculated, communicated and realised by slave controllers. Therefore high-speed communication link is required with minimum time delay for improved performance of the system. This increases the overall cost of the system. In case of analogue controllers, a bus (wire) replaces the communication link to carry the reference value of current. This method is prone to high noise injection in the system. Therefore it is used only for low-power applications. For medium/high power, dedicated digital communication schemes (such as controller area network, CAN) are used to realise master–slave control. This increases the cost of the system. Moreover, presence of single master controller reduces system reliability.
Abstract—This paper describes nonisolated high step-up DC-DC converters using zero voltage switching (ZVS) boost integration technique (BIT) and their light-load frequency modulation (LLFM) control. The proposed ZVS BIT integrates a bidirectional boost converter with a series output module as a parallel-input and series-output (PISO) configuration. It provides many advantages such as high device utilization, high step-up capability, power and thermal stress distribution, switch voltage stress clamping, and soft switching capability. As an example of ZVS BIT, a flyback converter with a voltage-doubler rectifier (VDR) as a series output module is presented and analyzed in detail. In addition, to overcome the efficiency degradation at a light load due to the load-dependent soft switching capability of the proposed ZVS BIT, a control method using a frequency modulation (FM) proportional to the load current is proposed. By means of ZVS BIT and LLFM control, the overall conversion efficiency is significantly improved. The experimental results are presented to clarify the proposed schemes.

Index Terms—Boost integration technique (BIT), frequency modulation (FM), step-up ratio, zero-voltage switching (ZVS).

I. INTRODUCTION

NONISOLATED DC-DC conversion applications such as electric vehicles (EV), photovoltaic (PV) grid-connected power systems, fuel cells, uninterruptible power supplies (UPS), and high-intensity-discharge (HID) lamps for automobile headlamps call for high-performance step-up techniques [1], [5], [13]. The general approach to these applications is a classical boost converter having simple structure, continuous input current, and clamped switch voltage stress to the output voltage. However, the limited step-up capability due to the parasitic resistances, the reverse recovery problem caused by a high voltage rating diode, and the large switching losses due to the hard switching are major obstacles not allowing the high step-up ratio and efficiency.

To handle these concerns, several converter topologies adopting the voltage conversion ability, i.e., a voltage-multiplier, a coupled-inductor, a transformer, and a stacked output capacitor, have been proposed [1]–[23].

In [2]–[6], it has been demonstrated that a voltage-multiplier using additional diodes and capacitors on the output stage in a classical boost converter contributes to extending a step-up ratio without the penalty of an extreme duty ratio. However, as the output voltage is increased, the number of stages is increased, demanding more capacitors and diodes. Moreover, the snubber circuits across the switches and diodes increase the cost, losses, and design complexity. Also, no soft switching capability still confines the efficiency to be low.

A coupled-inductor employed in a boost converter is also a favorable step-up technique for its simple structure [1], [7]–[12]. Although it can achieve a high efficiency and protect the switch from the high peak voltage, an auxiliary circuit is required to suppress the switch voltage stress. The active-clamp cell in the coupled-inductor scheme can alleviate this problem [10]–[12]. Also, it can achieve the soft switching performance. However, the active-clamp cell in [10] and [11] is quite complex, requiring a pair of switches and diodes. Although the cell presented in [12] can reduce the number of active devices, the additional resonant inductor to guarantee the ZVS should be adopted. Besides, as the auxiliary turns of a coupled-inductor are increased to raise a step-up ratio further, an input current ripple becomes larger in return. Thus, more input filter is needed.

Another easy approach for a high step-up ratio is the current-fed type converters using a transformer [14]–[21]. A transformer leakage inductance causes a voltage spike across the switches so that a snubber circuit is required, resulting in an additional loss. The active-clamp approach similar to that applied on the coupled-inductor scheme releases these problems and reduces switching losses by using its soft switching capability [17]–[21].

Unfortunately, in view of the clamp capacitors in [10]–[12] and [17]–[21], they are connected to the input side so that it has no function of extending a step-up ratio.

Focused on the step-up ratio extension with the concept of the stacked output capacitors, the high step-up boost-flyback converter is proposed in [22] and improved with a secondary voltage-doubler rectifier in [23]. Despite their high step-up capability, the switch suffers from the hard switching losses.

Manuscript received April 18, 2011; revised June 17, 2011; accepted July 13, 2011. Date of current version February 7, 2012. Recommended for publication by Associate Editor J. A. Pomilio.

The authors are with the Department of Electrical Engineering, KAIST, 373-1, Guseong-dong, Yuseong-gu, Deajeon, Korea, 305-701 (e-mail: thisluv@powerlab.kaist.ac.kr).

This paper includes previously presented literatures titled as
1. “Zero-Voltage Switching Flyback-Boost Converter with Voltage-Doubler Rectifier for High Step-up Applications,” in ECCE 2010, Atlanta, USA.

Digital Object Identifier 10.1109/TPEL.2011.2162966
Real-Time Energy Management Algorithm for Mitigation of Pulse Loads in Hybrid Microgrids

Ahmed Mohamed, Student Member, IEEE, Vahid Salehi, Student Member, IEEE, and Osama Mohammed, Fellow, IEEE

Abstract—This paper presents a real-time energy management algorithm for hybrid ac/dc microgrids involving sustainable energy and hybrid energy storage. This hybrid storage system consists of super capacitors (SC) for ultra-fast load matching beside lithium-ion batteries for relatively long term load buffering. The energy management algorithm aims mainly at managing the energy within the system such that the effect of pulsed (short duration) loads on the power system stability is minimized. Moreover, an average annual saving of around 7% is achieved by shifting loads to off-peak hours. The expected energy needed during a future peak, the time of its occurrence and the current state of charge of both elements of the hybrid storage system are all examples of the inputs to the algorithm. A nonlinear regression technique is used to obtain mathematical models for the uncertain quantities including load and sustainable energy curves. The results show a significant improvement for the system in terms of voltage and power stability by applying the proposed algorithm.

Index Terms—Energy management, fuzzy controller, hybrid super capacitor/battery storage, nonlinear regression, pulsed load mitigation, state of charge.

I. INTRODUCTION

It is expected that the rapidly growing implementation of smart grids and microgrids will continue to change current systems in terms of design and operation. New designs may include much larger local generation, storage elements, hybrid ac/dc distribution systems and more extensive involvement of power electronic converters and pulsed loads [1]–[4]. An example would be a shipboard power system, which resembles the concept of a microgrid operating in a smart grid system where the system is capable of self-diagnosing, self-healing, and self-reconfiguring [5], [6]. In these systems, some particular loads draw very high short time current in an intermittent fashion such as electromagnetic rail weapon launch systems and free electron lasers. Henceforth, they will be referred to collectively as pulsed loads [7]. Such current behavior can potentially cause the system voltage and frequency to drop in the entire microgrid, momentarily. This disturbance can trip other sensitive control loads offline.

In the shipboard example, when a large magnitude, and prolonged voltage/frequency sag occurs, the propulsion system may shut down, or perhaps the fighting loads themselves may be thrown offline. Therefore, there is a great concern about how these loads can coexist in the same electrical environment and share the same energy storage systems while allowing a diverse range of operational scenarios [8], [9]. However, pulsed loads are not limited to shipboard power systems. For instance, a plug-in hybrid electric vehicle (PHEV), or a group of PHEVs during their charging process, or a big machine during its starting can be considered as pulsed load in residential and industrial applications, respectively.

Loads based on hourly average variations can be considered as low-frequency variations, whereas power transients that sustain for minutes, seconds, or milliseconds come under the high-frequency segment. To buffer out the low-frequency oscillations and to compensate for the intermittency of the renewable energy sources, energy storage elements with high energy density is required. To provide the high-frequency component of power and also to supply or absorb the high-power transients, energy storage with high power density is required [10]. Recently, high-power capability of super capacitors and high energy capability of batteries or fuel cells are exploited in pulse operating modes for portable power systems, electric vehicle and digital telecommunication systems [11]–[13]. Advanced storage technologies now allow extraordinary energy densities where the load draws large power impulses. This deficiency can be solved by using more batteries in parallel. Technically, hybrid power sources that utilize batteries with advanced charge/discharge strategies in parallel with super capacitors can overcome the power deficiency problems and increase the operating time [14], [15].

Real time or dynamic energy management in smart grids whether directed towards microgrids or electric vehicle applications was investigated in several publications [10], [15]–[18]. These papers generally aim at handling renewable energy and its uncertainty, managing the demand side in an intelligent way in order to enhance the performance of the microgrid as well as the main grid, and/or achieving an optimal economic operation of the system. However, all these energy management algorithms do not take into consideration the occurrence of pulsed loads. In this paper, an energy management algorithm that aims at handling the energy in a system involving renewable energy sources such that pulsed loads are mitigated is developed. Furthermore, this developed algorithm assures economic operation of the microgrid.

The paper is organized as follows, in Section II: the nonlinear regression modeling technique used to obtain mathemat-
Demand Side Management in Smart Grid Using Heuristic Optimization

Thillainathan Logenthiran, Student Member, IEEE, Dipti Srinivasan, Senior Member, IEEE, and Tan Zong Shun

Abstract—Demand side management (DSM) is one of the important functions in a smart grid that allows customers to make informed decisions regarding their energy consumption, and helps the energy providers reduce the peak load demand and reshape the load profile. This results in increased sustainability of the smart grid, as well as reduced overall operational cost and carbon emission levels. Most of the existing demand side management strategies used in traditional energy management systems employ system specific techniques and algorithms. In addition, the existing strategies handle only a limited number of controllable loads of limited types. This paper presents a demand side management strategy based on load shifting technique for demand side management of future smart grids with a large number of devices of several types. The day-ahead load shifting technique proposed in this paper is mathematically formulated as a minimization problem. A heuristic-based Evolutionary Algorithm (EA) that easily adapts heuristics in the problem was developed for solving this minimization problem. Simulations were carried out on a smart grid which contains a variety of loads in three service areas, one with residential customers, another with commercial customers, and the third one with industrial customers. The simulation results show that the proposed demand side management strategy achieves substantial savings, while reducing the peak load demand of the smart grid.

Index Terms—Demand side management, distributed energy resource, evolutionary algorithm, generation scheduling, load shifting, smart grid.

I. INTRODUCTION

SMART GRID [1], [2] represents a vision of the future power systems integrating advanced sensing technologies, control methodologies and communication technologies at transmission and distribution levels in order to supply electricity in a smart and user friendly way. According to the U.S. Department of Energy’s modern grid initiative report, the main characteristics [2] of a smart grid are consumer friendliness, hack proof self-healing, resistance for attack, ability to accommodate all types of generation and storage options, electricity market based efficient operation, high power quality, and optimal assets. This modern grid is prompted by several economical, political, environmental, social, and technical factors.

Demand side management [3], [4] is an important function in energy management of the future smart grid, which provides support towards smart grid functionalities in various areas such as electricity market control and management, infrastructure construction, and management of decentralized energy resources and electric vehicles. Controlling and influencing energy demand can reduce the overall peak load demand, reshape the demand profile, and increase the grid sustainability by reducing the overall cost and carbon emission levels. Efficient demand side management can potentially avoid the construction of an under-utilized electrical infrastructure in terms of generation capacity, transmission lines and distribution networks.

Smart pricing [5], [6] is a unique characteristic of smart grid made possible by usage of smart metering devices in the automatic metering infrastructure. It could lead to cost-reflective pricing based on the entire supply chain of delivering electricity at a certain location, quantity and period. When smart pricing is used with demand side management, control of the customer’s energy usage will be influenced by real-time penalty and incentive schemes at all levels of the supply chain. However, the rationale behind the implementation of demand side management within the context of the smart grid is to promote the overall system efficiency, security and sustainability by maximizing the capacity of the existing infrastructure while facilitating the integration of low carbon technology into the system.

Demand side management also plays a significant role in electricity markets [7], [8]. Demand side management system will inform cluster’s central controller about new load schedule and available load reduction capabilities for each time step of next day. Then, the central controller can place bids in the market such that some loads from the peak demand will be shifted. Profits made through this load demand side management will be reimbursed to customers of the cluster.

There are several demand side management techniques and algorithms used in the literature [4]–[6], [9]–[13]. Most of them are system specific [4]–[6], [10], [13] strategies, and some of which are not applicable to practical systems that have a wide variety of independent devices. Most of the techniques were developed using dynamic programming [13] and linear programming [5], [10]. These programming techniques cannot handle a large number of controllable devices from several types of devices which have several computation patterns and heuristics. The primary objective of the demand side management techniques presented in the literature is reduction of system peak load demand and operational cost. Although the utilities are capable of offering different incentives to respective customers for direct control [12]–[15] over selected loads by grouping the customers’ loads, most of the methodologies used in the literature do not consider the criteria and objectives independently. Thus, it is difficult to employ these methods for demand side management of future smart grids which aim to provide the customers with greater control over their energy consumption. In a smart grid, the demand side management strategies need to handle a large number of controllable loads of several types. Furthermore, loads have characteristics which spread over a few hours. Therefore, the strategies should be able to deal with all possible control durations of a variety of controllable loads.

Manuscript received July 22, 2011; revised November 08, 2011; accepted April 11, 2012. Date of publication June 08, 2012; date of current version August 20, 2012. This work was supported by National Research Foundation programme grant, NRF-2007EWT-CERP01-0954 (R-263-000-522-272). Paper no. TSG-00260-2011.

The authors are with the Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117576 (e-mail: logenthiran@nus.edu.sg; dipti@nus.edu.sg; u0705831@nus.edu.sg).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TSG.2012.2195686
BEVs/PHEVs as Dispersed Energy Storage for V2B Uses in the Smart Grid

C. Pang, Student Member, IEEE, P. Dutta, Student Member, IEEE, and M. Kezunovic, Fellow, IEEE

Abstract—Numerous recent studies have assessed the feasibility of vehicle-to-grid (V2G) mode of discharging, which provides an option to use the energy stored in a battery in electric vehicles to support the power grid. This paper aims at demonstrating the potential benefits of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) as dynamically configurable dispersed energy storage acting in a vehicle-to-building (V2B) operating mode. V2B is a concept that is practically viable today being far simpler than V2G, and it may be implemented on a 3–5 year time horizon while V2G may take 10–15 years to gain wider acceptance. Based on the battery characteristics, the benefits of using BEVs/PHEVs as energy storage for demand side management (DSM) and outage management (OM) are discussed in detail. This paper is also focused on the implementation issues of DSM and OM in the smart distribution grid. A strategy for adopting BEVs/PHEVs in the V2B mode under the peak load and during outage condition is proposed and demonstrated with test cases and numerical results.

Index Terms—Battery electric vehicle, demand side management, outage management, plug-in hybrid electric vehicle, smart grid, vehicle-to-building, vehicle-to-grid.

I. INTRODUCTION

POWER SYSTEM security and reliability are becoming more challenging to meet due to the increasing complexity of power system operation. Smart grid deployment has been aggressively pursued with sponsorship and involvement from government, businesses, utilities, and other stakeholders to bring additional knowledge combined with advanced information technology to power grid, which will make the grid more secure and reliable [1]. Currently, utilities in North America are adopting far reaching steps applying the new equipment and advanced technologies trying to meet the emerging requirements of the smart grid. Similar trends may be observed across the world.

With the development of renewable energy coming from such resources as sun and wind, the number of distributed generations increased dramatically. Due to the variability and unpredictability of these renewable energy sources, especially wind energy, high penetration of energy storage systems is highly desirable to make such resources dispatchable. With the distributed generation and energy storage system being connected to the power grid, power network structure becomes more complex. The stressed power system becomes more difficult to control. Maintaining the operational security, reliability and stability while expanding and developing the grid to meet the growing demand remains challenge in future electricity grids.

With the threat of global climate change increasingly acknowledged and the growing concern about energy security, new technologies that will reduce the CO₂ emissions and current dependency on carbon-based fuels have been investigating for some years. The interest in battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) has increased due to their impact on redistribution of the pollution from tail pipe to smog stuck, low-cost charging, and reduced petroleum usages. Compared with traditional hybrid electric vehicles (HEVs), BEVs/PHEVs have an enlarged battery pack and an intelligent converter. Using a plug, BEVs/PHEVs can charge the battery using electricity from an electric power grid, also referred to as “grid-to-vehicle” (G2V) operation, or discharge it to an electric power grid during the parking hours, also referred to as “vehicle-to-grid” (V2G) operation.

Many researchers have investigated the various potential benefits and implementation issues of V2G [2]–[10] concept. Kempton and Tomić studied the fundamentals of using BEVs/PHEVs for load leveling, regulation, reserve, and other purposes [2], [3]. Hadley and Tsvetkova analyzed the potential impacts of BEVs/PHEVs on electricity demand, supply, generation, infrastructure, prices, and associated emission levels in 2020 and 2030 in 13 regions specified by the North American Electric Reliability Corporation (NERC) [4]. Meliopoulos et al. considered the impacts of BEVs/PHEVs on electric power network components [5]. Han et al. proposed the optimal V2G aggregator for frequency regulation by applying the dynamic programming algorithm to compute the optimal charging control for each vehicle [6]. Shimizu et al. [7] and Ota et al. [8] also discussed power system frequency control by using V2G system. Anderson, et al. performed the case studies of plug-in hybrid electric vehicles if used by regulating power providers in Sweden and Germany [9]. Pillai and Bak-Jensen modeled the aggregated BEV-based battery storage for the use in long-term dynamic power system simulation when integrating V2G in the western Danish power system [10].

However, recent research on the feasibility of V2G is based on the assumption of large-scale penetration of BEVs/PHEVs, which is envisioned on a 10–15 year time horizon in the most optimistic scenarios. As a more near-term application of V2G, vehicle-to-building (V2B) operation is proposed in this paper,
Exploitation of Electric-Drive Vehicles in Electricity Markets

Miloš Pantoš, Member, IEEE

Abstract—The paper presents the optimization algorithm which may eventually be used by electric energy suppliers to coordinate charging and discharging of electric-drive vehicles (EDVs) exploited in electricity markets. The research is focused on a day-ahead market and a provision of system regulation in an ancillary-service market. The proposed optimization minimizes the charging costs that can be partly compensated with profits obtained from participation in the energy markets. Due to the stochastic nature of transportation patterns, the Monte Carlo simulation is applied to model uncertainties presented by numerous scenarios. To reduce the problem complexity, the simulated driving patterns are not individually considered in the optimization but clustered into fleets using the GAMS/SCENRED tool. Uncertainties of energy requirements in the market and energy prices are presented by statistical central moments that are further considered in Hong’s 2-point + 1 estimation method in order to define points considered in the optimization. Finally, each energy supplier has to offer competitive energy prices to EDV users for transportation. Due to uncertainties, the final prices cannot be deterministically calculated; thus, the paper proposes the risk-based approach applying value at risk. Case studies illustrate the application of the proposed optimization in achieving competitive prices for EDV users.

Index Terms—Electric-drive vehicles, linear programming, optimization, risk management.

NOMENCLATURE

Indices:

\( b \) Subscript index for purchase energy price.
\( c \) Subscript index for charging efficiency.
\( d \) Subscript index for V2G efficiency.
\( e \) Subscript index for regulating energy price.
\( g \) Subscript index for concentration.
\( k \) Subscript index for scenario.
\( m \) Subscript index for output variables \( Y_m \).
\( n \) Subscript index for input variable \( X_n \).
\( p, h, i, j \) Subscript indices for hour.
\( r \) Subscript index for capacity payment price.

Variables and functions:

\( b_y(.)\) Energy used from the battery.
\( w(.)\) Charged energy for system regulation.
\( X(.)\) Input data variable.
\( x(.)\) Charged energy for transportation.
\( y(.)\) Output data variable.
\( z(.)\) Charged energy for electric energy market.

Parameters and Constants:

\( a \) Number of input data variables.
\( b \) Number of input data states.
\( c \) Energy price for transportation of EDVs.
\( C(.)\) Battery capacity.
\( D(.)\) Energy requirement of fleet for transportation.
\( d(.)\) Energy requirement of EDV for transportation.
\( E \) Stored energy in batteries in initial stage.
\( E'(.)\) Expectation operator.
\( F \) Number of output data variables.
\( f \) Number of EDVs in a fleet.
\( G \) Number of concentrations.
\( H \) Number of hours.
\( J \) Objective function.
\( l(.)\) Driving distance.
\( L(.)\) Charging ramp-rate limit.
\( M(.)\) Energy requirement in electric energy market.
\( MP \) Profit in electric energy market.
\( o \) Parameter in central moment calculation.
A Flexible Control Strategy for Grid-Connected and Islanded Microgrids With Enhanced Stability Using Nonlinear Microgrid Stabilizer

Seyed Mahdi Ashabani and Yasser Abdel-Rady I. Mohamed, Senior Member, IEEE

Abstract—The energy sector is moving into the era of distributed generation (DG) and microgrids (MGs). The stability and operation aspects of converter-dominated DG MGs, however, are faced by many challenges. Important among these are: 1) the absence of physical inertia; 2) comparable size of power converters; 3) mutual interactions among generators; 4) islanding detection delays; and 5) large sudden disturbances associated with transition to islanded mode, grid restoration, and load power changes. To overcome these difficulties, this paper presents a new large-signal-based control topology for DG power converters that is suitable for both grid-connected and islanding modes of operation without any need to reconfigure the control system and without islanding detection. To improve MG stability, the proposed control structure is realized via two steps. First, an emulated inertia and damping functions are adopted. Second, to guarantee stability and high performance of the MG system during sudden harsh transients such as islanding, grid reconnection, and large load power changes, a nonlinear MG stabilizer is proposed. An augmented converter model is developed and used to design the MG stabilizer via the adaptive backstepping (AB) technique to guarantee large-angle stability and robustness against unmodeled dynamics. Theoretical analysis and evaluation results are presented to show the effectiveness of the proposed control scheme in achieving stable and smooth operation of a MG system in grid-connected, islanding, and transition modes.

Index Terms—Grid-connected, islanded microgrid, microgrid, power stability, supplementary control.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_v$</td>
<td>Voltage frequency.</td>
</tr>
<tr>
<td>$\psi_f$</td>
<td>Virtual rotor flux.</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Voltage angle.</td>
</tr>
<tr>
<td>$\omega_i$</td>
<td>Current frequency.</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Power angle.</td>
</tr>
<tr>
<td>$T_v$</td>
<td>Virtual electrical torque.</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Current angle.</td>
</tr>
<tr>
<td>$J$</td>
<td>Virtual rotor momentum of inertia.</td>
</tr>
</tbody>
</table>

$\dot{m}$ Friction factor (droop coefficient).
$T_v$ Virtual electrical torque.
$P_e$ Electrical power.
$Q_e$ Electrical reactive power.
$\eta$ Voltage droop constant.
$i$ Amplitude of phase current.

I. INTRODUCTION

Due to fast development of renewable energy resources, the concept of distributed generation (DG) is gaining an important role in future smart power grids [1]–[3]. DG has many advantages such as closeness to customers, increased efficiency and reduced transmission loss, better reliability, and improved energy management [4]–[8]. The majority of DG resources are interfaced to grid/loads via power electronic converters. A cluster of DG units connected to the grid via power electronic interfaces form a microgrid (MG). Fig. 1 shows a typical MG. MGs form an important portion of future smart grids and therefore, their roles are vital in power system operation. A microgrid system has two states of operation; namely, they are grid-connected and islanding modes. The islanding is a situation in which the MG is disconnected from the main grid when a fault is occurred in the grid. Because of power reliability and power quality issues, it is necessary that microgrids continue their operation in autonomous mode when grid is not available.

The main goal of a grid-connected MG is to supply real and reactive powers under high power quality injection constraints. In the islanded mode, DG units are required to supply “regulated power” under controllable voltage and frequency while maintaining accurate power sharing among different DG units [2], [5]. Driven by these requirements two main control strategies—namely communication based centralized [9]–[13], and decentralized [5], [14]–[27]—have been proposed in the literature. Between these two methods, due to reliability issues, the droop-based decentralized controller has been widely adopted for power sharing and control of MGs.

The dominant control method for a DG interface is based on a current-controlled voltage source converter (CC-VSC), to inject the required real and reactive powers via current control [10], [28]. However, when the MG works in the islanding mode, the absence of a stiff grid to regulate the voltage may lead to voltage and frequency distortion [10], [28] or even instability with this control method. Therefore, DG needs to switch to voltage controlled mode and therefore, an islanding detection technique is required. Furthermore, this transition to islanding mode may result in very severe transients in power, frequency, and angle,