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OPTIMAL TRANSACTIVE ENERGY MANAGEMENT IN MICROGRIDS

by

Rama Kishore Bonthu

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Certificate of Authorship/Originality

I, Rama Kishore Bonthu, declare that this thesis, is submitted in fulfilment of the requirements for the award of Master of Engineering (Research), in the Faculty of Engineering & Information Technology (FEIT) at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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ABSTRACT

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The combination of renewable energy generation systems and battery energy storage system (BESS) in a microgrid is a promising solution for the rapid increase in electricity demand and the decline of fossil fuel sources. To gain competency in the present market, microgrids are actively connected to the grid and optimally controlled in order to avoid unnecessary usage fees due to the variability of renewable energy generation. Here, the challenge rests with the imbalance of dynamic power demand and renewable power generation with consideration of variable energy pricing conditions. This research work focuses on the modeling and design of an optimal transactive energy management system (EMS) to minimize the electricity bill of a commercial building supplied with a microgrid. Following a comprehensive literature survey on relevant topics, the first phase of this work refines the models of a real-world building microgrid equipped with power electronic converters. Incorporating different kWh pricing and feed-in tariff values, the building energy cost is cast as a multiobjective optimization problem subject to variable constraints. In the second phase of this work, effective control and optimization schemes are developed for optimal transactive energy management of the microgrid and dealing with nonlinearities associated with energy conversion losses. Here, a particle swarm optimization (PSO) and a model predictive control (MPC) approach based on the mixed integer linear programming (MILP) are utilized in an optimal EMS for minimizing the electricity bill of the building's on-grid system. As compared with other meta-heuristic algorithms, the PSO method, on one hand, provides an effective solution, particularly in handling multi-objective, dynamic and constraints. On the other hand, PSO suffers

from high computational time and local optima. As MILP is mostly based on the branch-and-bound algorithm, which more likely reaches a global optimum solution, the combined MILP-MPC strategy is used in this work to achieve optimal EMS in the microgrid. In this regard, the proposed strategy is formulated as a MILP-MPC problem subject to time-varying constraints. The constraints are then linearized at each sampling time so that the receding horizon principle can be used to determine the control input applied to the plant and update the system model. In this work, the efficiency of power converters is considered time-varying and evaluated for each time interval persistently for the prediction time horizon. Performance of the proposed EMS using both PSO and MILP-MPC is verified through the extensive simulation results of the microgrid in consideration.

Dedication

To my mother *Seethalakshmi*, wife *Amrin Begum*, and son *Aaron Ammuram*.

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List of Publications

Conference Papers

C-1. **R. K. Bonthu**, H. Pham, R. P. Aguilera, and Q. P. Ha, "Minimization of building energy cost by optimally managing pv and battery energy storage systems," in *Proc. 2017 20th International Conference on Electrical Machines and Systems (ICEMS)*, Aug 2017, pp. 1-6, doi:10.1109/ICEMS.2017.8056442.

C-2. **R. K. Bonthu**, R. P. Aguilera, H. Pham, M. D. Phung, and Q. P. Ha, "Energy cost optimization in microgrids using model predictive control and mixed integer linear programming," in *Proc. The 20th IEEE International Conference on Industrial Technology (ICIT)*, Feb 2019, pp. 1113-1118.

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Nomenclature

Acronyms

BESS	battery energy storage system
CF	cost function
EIF	education investment fund
EMS	energy management system
HESS	hydrogen energy storage system
MILP	mixed integer linear programming
MPC	model predictive control
ORC	organic Rankine cycle
PV	photovoltaic
RBC	rule-based control
RES	renewable energy sources
SLB	storage level based
SoC	state of charge
ToU	time-of-use
UTS	university of technology sydney
VAWT	vertical axis wind turbine

Constants

C_b	BESS capital cost [AUD/kWh]
C_e	electrolyser capital cost [AUD/kW]

C_{fc}	fuel cell capital cost [AUD/kW]
$C_{OM,b}$	BESS operation and maintenance cost [AUD/hr]
$C_{OM,e}$	electrolyser operation and maintenance cost [AUD/hr]
$C_{OM,fc}$	fuel cell operation and maintenance cost [AUD/hr]
LoH_{max}	upper limit of hydrogen storage level [kWh]
LoH_{min}	lower limit of hydrogen storage level [kWh]
N	number of discrete time intervals
N_p	prediction horizon
N_{cycles}	number of BESS life cycles
$N_{hours,e}$	number of electrolyser life hours
$N_{hours,fc}$	number of fuel cell life hours
P_{max}^{buy}	maximum allowable buying power from grid [kW]
P_{min}^{buy}	minimum allowable buying power from grid [kW]
P_{max}^{ch}	maximum allowable charging power [kW]
P_{min}^{ch}	minimum allowable charging power [kW]
P_{max}^{dis}	maximum allowable discharging power [kW]
P_{min}^{dis}	minimum allowable discharging power [kW]
P_{max}^{e}	maximum allowable power to electrolyser [kW]
P_{min}^{e}	maximum allowable power to electrolyser [kW]
P_{max}^{fc}	maximum allowable discharging power from fuel cell [kW]
P_{min}^{fc}	maximum allowable selling power from fuel cell [kW]
P_{max}^{sell}	maximum allowable selling power to grid [kW]

P_{min}^{sell} minimum allowable selling power to grid [kW]

SoC_{max} upper limit of state-of-charge [kWh]

SoC_{min} lower limit of state-of-charge [kWh]

T_s discrete time interval duration

Decision variables

δ^b binary variable for charging/discharging power from/to BESS

δ^f binary variable for discharging/electrolisation of HESS

δ^g binary variable for buying/selling power from/to the grid

P^{buy} power bought from the grid [kW]

P^{ch} power exchanged with BESS during charging [kW]

P^{dis} power exchanged with BESS during discharging [kW]

P^e power to electrolyser [kW]

P^{fc} power discharged from the fuel cell [kW]

P^{sell} power sold to the grid [kW]

Indices

$\hat{x}$ predicted value of x

j prediction horizon intervals

k discrete time intervals

Parameters

$\boldsymbol{u}^{opt}$ optimal input sequence

η^{ch} efficiency of BESS connected converter during charging

η^{dis} efficiency of BESS connected converter during discharging

η^{ely}	efficiency of electrolyser
η^{e}	efficiency of electrolyser connected converter
η^{fcs}	efficiency of fuel cell stack
η^{fc}	efficiency of fuel cell connected converter
η^{ORC}	efficiency of ORC turbine connected converter
η^{pv}	efficiency of PV system connected converter
η^{r}	efficiency of AC/DC bus connected converter
η^{w}	efficiency of VAWT connected converter
C^{f}	feed-in tariff [AUD/kWh]
C^{tou}	time-of-use energy price [AUD/kWh]
H^{cv}	higher heating (calorific) value of hydrogen [kWh/Nm^3]
H^{c}	rate of hydrogen consumption [Nm^3/h]
H^{p}	rate of hydrogen production [Nm^3/h]
H^{vol}	volume of hydrogen storage [Nm^3]
LoH	level of hydrogen storage [kWh]
P^{l}	load power demand [kW]
P^{ORC}	ORC power generation [kW]
P^{pv}	power generation from PV system [kW]
P^{w}	wind power generation [kW]
SoC	state-of-charge of BESS [kWh]