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Optimal operation of a smart residential microgrid based on model predictive control by considering uncertainties and storage impacts

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Abstract

A model predictive control (MPC) based coordinated operation framework for a grid-connected residential microgrid with considering forecast errors is presented in this paper. This residential microgrid composes renewable energy resources (e.g., wind and solar), distributed generators (e.g., CHP), energy storages (e.g., battery bank and water tank), electrical vehicle, and smart loads (e.g. HVAC and washing machine). A novel mixed integer linear programming (MILP) problem is optimized at each decision time, on the basis of the short-term forecasts of renewable energy resources generation, load demand, and electricity price. This MILP problem is integrated into a MPC framework to reduce the negative impacts of forecast errors. Case study which considers forecast uncertainties is implemented for evaluating the performance of the proposed method and the traditional method is used. Besides, peak power price mechanism which is used to smooth the power exchanged with external grid is also considered. Moreover, a further sensitivity analysis is realized in order to discuss the impacts of energy storage units on the microgrid operation. Simulation results show that the proposed method is economic and flexible.

Keywords: Residential microgrid; Home energy management system (HEMS); Model predictive control (MPC); Mixed-integer linear programming (MILP); Demand response

1. Introduction

The emerging smart grid technologies have attracted increasing concerns since they can improve the power quality, incorporate high penetration level of renewable energy resources (RERs), and provide a two-way communication infrastructure (Ipakchi and Albuyeh, 2009). Meanwhile, the optimal energy management of house and building microgrids have also attracted more attentions, because the energy consumption of house and building occupies 30–40% of world's primary energy consumption (Lior, 2010; Ericson, 2011; Yohanis et al., 2008).

The lacking of knowledge among users about how to respond to the time-varying electricity price and inciting policies prevent the spread of residential microgrids (2012, http://www.powersmartpricing.org/how-it-works/; 2012, http://www.cntenergy.org/pricing/comed-rrtp/). However, the residential microgrids owners have the aspiration to save money by slightly changing their living habits. Home energy management system (HEMS), smart metering infrastructure and advanced communication

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Nomenclature

t time interval index
i delay flexible task index
θ delay flexible appliance's operation period (h)
$P_{i\theta}^{ele}$ power of appliance i at the θ_i operation period (kW)
DT_i processing time of appliance i, $\theta_i \in DT_i$ (h)
T_i^F, T_i^S latest finishing, earliest starting time of appliance i (h)
M number of delay flexible appliances
α_{CHP} CHP heat-to-electricity ratio (%)
P_{WDmax} wind generator capacity (kW)
P_{PVmax} PV generator capacity (kW)
E_{TESmin}^{ther}, E_{TESmax}^{ther} minimum, maximum capacity level of TES (kW h)
$E_{TES}^{ther}(t)$ energy level of TES at time t (kW h)
E_{TESint}^{ther} initial energy level of TES (kW h)
$P_{TEScmin}^{ther}$, $P_{TEScmax}^{ther}$ minimum, maximum charge rate of TES (kW)
$P_{TESdmin}^{ther}$, $P_{TESdmax}^{ther}$ minimum, maximum discharge rate of TES (kW)
η_{TESd}^{ther}, η_{TESc}^{ther} discharge, charge efficiency of TES (%)
c_{TES}^{ther} operation and maintenance cost of TES (Ect/kW h)
ε_{TES}^{ther} self-discharge energy loss of TES (kW)
E_{EVmin}^{ele}, E_{EVmax}^{ele} minimum, maximum energy level of EV (kW h)
$E_{EV}^{ele}(t)$ energy level of EV at time t (kW h)
E_{EVint}^{ele} initial energy level of EV (kW h)
P_{EVcmin}^{ele}, P_{EVcmax}^{ele} minimum, maximum charge rate of EV (kW)
P_{EVdmin}^{ele}, P_{EVdmax}^{ele} minimum, maximum discharge rate of EV (kW)
η_{EVd}^{ele}, η_{EVc}^{ele} discharge, charge efficiency of EV (%)
c_{EV}^{ele} operation and maintenance cost of EV (Ect/kW h)
c_{CHPup}, $c_{CHPdown}$ start-up, shut-down cost of CHP generator (Ect)
P_{CHPmin}, P_{CHPmax} minimum, maximum power rate of CHP generator (kW)
ΔU_{CHP} maximum ramp rate of CHP generator (kW)
η_{CHP} CHP generator's electrical efficiency (%)
$P_{boilmax}^{ther}$, $P_{boilmin}^{ther}$ maximum, minimum boiler power rate (kW)
c_{boilup}, $c_{boildown}$ start-up, shut-down cost of boiler (Ect)
P_{Gmax}^{ele} maximum power can be exchanged with the external grid (kW)
η_{boiler}^{ther} boiler's efficiency (%)
E_{EESmin}^{ele}, E_{EESmax}^{ele} minimum, maximum energy level of EES (kW h)
ε_{EES}^{ele} self-discharge energy loss of EES (kW)
c_{gas} price of natural gas (Ect/kW h)
β_{max}^{ther} maximum allowed curtailment ratio of thermal loads (%)
ρ_{cur} penalty efficiency on power curtailment
$\varphi_{wind}(t)$, $\varphi_{PV}(t)$ forecast error of wind, solar at time t (kW)
$\varphi_{load}(t)$ forecast error of load demand at time t (kW)
$\varphi_{pr}(t)$ forecast error of electricity price at time t (Ect/kW h)
$P_{PV}(t)$ forecasted solar generation at time t (kW)
$P_{wind}(t)$ forecasted wind generation at time t (kW)
$P_{load}(t)$ forecasted power required at time t (kW)
$c^P(t)$, $c^S(t)$ purchasing, selling electricity price at time t (Ect/kW h)
$P_{wind}^{real}(t)$, $P_{PV}^{real}(t)$ actual wind, solar production at time t (kW)
$P_{load}^{real}(t)$ actual load demand at time t (kW)
$Pr^{real}(t)$ actual basic electricity price at time t (Ect/kW h)
$P_{TESc}^{ther}(t)$, $P_{TESd}^{ther}(t)$ charge, discharge rate of TES at time t (kW)
$P_{EVc}^{ele}(t)$, $P_{EVd}^{ele}(t)$ charge, discharge rate of EV at time t (kW)
$P_{EESc}^{ele}(t)$, $P_{EESd}^{ele}(t)$ charge, discharge rate of EES at time t (kW)
$P_{GI}^{ele}(t)$, $P_{GO}^{ele}(t)$ power imported from, exported to the external grid at time t (kW)
$P_{CHP}(t)$ electric power generation of CHP at time t (kW)
$P_{boiler}(t)$ heat output of boiler at time t (kW)
$\beta^{ther}(t)$ curtailed power percentage of thermal loads at time t (%)
$\delta_i(t)$ operation status of appliance i at time t (binary)
$\delta_{TESc}^{ther}(t)$, $\delta_{TESd}^{ther}(t)$ charge, discharge status of TES at time t (binary)
$\delta_{EVc}^{ele}(t)$, $\delta_{EVd}^{ele}(t)$ charge, discharge status of EV at time t (binary)
$\delta_{EESc}^{ele}(t)$, $\delta_{EESd}^{ele}(t)$ charge, discharge status of EES at time t (binary)
$\delta_{CHP}(t)$ power generation of CHP at time t (binary)
$\delta_{boiler}(t)$ heat output of boiler at time t (binary)
$\delta_{GI}^{ele}(t)$, $\delta_{GO}^{ele}(t)$ electricity purchasing, selling status at time t (binary)
t_{EVe}^{ele}, t_{EVd}^{ele} the earliest starting time, deadline for the EV connected to the residential microgrid (h)