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Lifetime optimization framework for a hybrid renewable energy system based on receding horizon optimization

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ABSTRACT

In this work, a novel convex sequence framework for real-time receding horizon operation optimization of a hybrid renewable energy system integrated with optimal sizing is presented to increase the penetration rate of renewable energy in supplying the demand. The proposed framework optimizes the entire lifetime cost of a system consisting of two main steps which are 1) design & installation and 2) operation as two sequence modules. This framework is applied to a hybrid renewable energy system which includes PV, wind turbine, batteries and a diesel generator. In the operation optimization, receding horizon strategy is used to optimize the operation schedule. Mixed integer convex programming method is applied in order to achieve the optimal operation. The hybrid renewable energy system is installed to actualize the design optimization outputs and to measure the required data for real-time operation optimization. The results show the proposed framework can be applied to facilitate the reliable real-time operation using real optimal input data for taking better advantage of the renewable energy resources. The effect of length of the horizon on optimal scheduling is also investigated. The results indicate that increasing of prediction horizon length enhances the economic performance and increases the share of renewable energy in the hybrid renewable energy system (from 68.5% to 81.4%).

1. Introduction

Fossil fuel resources depletion and significant growth in worldwide energy demand are leading to more attention to alternative energy technologies. Also, the notable environmental concerns of using fossil fuel lead to requiring renewable resources to supply the rising energy demand [1]. The use of hybrid renewable energy systems (HRES) as the sustainable energy suppliers can decrease emission, transformation and transmission losses and moreover, increase the energy security. HRES including energy resources (such as solar, wind), energy conversion and energy storage technologies, have been widely considered in recent years owing to their capability in dealing with intermittent production and scarce supply of a single renewable energy resource [2].

However, there are challenges to increase the penetration of renewable energy to supply the incremental demand. One challenge is related to investment cost of HRES technologies as they are relatively expensive comparing the other non-renewable technologies. In this way, the design optimization plays an essential role to determine the HRES optimal capacity in order to improve the economic and reliability aspects of the system.

In the other hand, due to intermittency and uncertainty of renewable energy resources, operation management of HRES is considered as another challenge. Indeed, the real-time operation optimization can facilitate the control of renewable energy flows by capturing the variation of renewable generation in system operation time. In addition, the optimal design parameters which are calculated from design optimization, are considered as substantial input parameters to operation optimization of HRES. This leads to increase the ability of operation optimization to have the reliable control of system.

Consequently, the lifetime evaluation is necessary to cover the optimization of the entire lifetime of HRES from preliminary design to operation management. Lifetime cost can be used as an operative criterion to realize the economic justification of HRES by optimization cost of design and operation stages, sequentially [5]. Therefore, there is need to establish a comprehensive optimization framework as an infrastructure to facilitate the joint optimization of design and real-time operation from different time scales.

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Nomenclature

Parameter

A	area, (m^2)
G	solar irradiation (W/m^2)
T	Temperature (°C)
C^P	coefficient of wind turbine performance
V	wind speed (m/s)
V^C	cut-in wind speed (m/s)
V^r	Rated wind speed (m/s)
V^f	cut-off wind speed (m/s)
r	discount rate
D	demanded electricity load (W)
n	System lifetime (year)
N	Horizon number
M	relaxation constant parameter
NOCT	nominal operating cell temperature
SOC	state of charge
DOD	depth of discharge
CTF	cycles to failure
$\overline{g}$	vectors of constraint set
y	system capacity (W, Wh)
y^*	Optimal system capacity (W, Wh)
Φ	specific parameter

Variable

P	Power flow, (W)
Fuel	Fuel consumption (liter/hr)
E	Energy (Wh)
λ^L	estimated throughput (cycles Wh)
C	cost ($)
x	state variable
u	control variable
δ	integer variable

Subscript

t	time interval (hr)
i	time interval in each horizon (hr)

Superscript

T	thermal
r	rated
min	minimum
max	maximum
life	system life-time
PV	Photovoltaic
c	Cell
W	Wind turbine
Bat	Battery
ch	Charge status
dis	discharge status
Con	conversion system
Sto	storage system
w	wearing
amb	ambient
DG	Diesel generator
f	fuel
n	number of conversion system
m	number of storage system
Ope	Operation
D	design
i	system components
Opt	Optimized

Greek

η	efficiency
α	PV temperature coefficient
ρ	air density (kg/m^3)
α^{DG}	Coefficient of diesel fuel
β^{DG}	Coefficient of diesel fuel
τ	self-discharge of battery (/hr)

1.1. Design optimization

Design optimization for an HRES is an essential procedure which can increase the reliability of the system and prevent oversizing of system equipment. Designing is a complex problem which should consider different aspects of technical and economic issues. There are numerous optimization methodologies to design a HRES which are summarized at [3]. All of the sizing methodologies of HRES can be divided into two major approaches: 1) accumulated demand/supply approach which balances the accumulative generation with the total demand [4] and 2) energy flow based optimization approach which balances the generation/demand schedules in each time step (during the simulation time) [2]. Most of the sizing studies in the second approach have applied the heuristic technique which cannot guarantees that the resulted solutions are globally optimum.

1.2. Operation optimization

Operation optimization has been applied to manage the energy flows among all generation and storage systems in HRES operation time [10]. Proposed optimization techniques in operation approaches include heuristic methods, mathematical programming and priority rules [6]. Generally, the operation optimization of HRES can be divided into two main categories i) deterministic optimization and, ii) real-time optimization.

1.2.1. Deterministic optimization

In deterministic approach, all of the historical input data (availability of resources and demand profile) are provided before the optimizer try to find the optimal solutions [8]. Guinot et al. [7] developed an aging-based model to investigate the effect of system operation on degradation and wearing of system components. Garcia et al. [9] present a long-term operation optimization model based on three energy management systems (EMS): minimization the utilization cost of energy storage system (ESS), maximization the efficiency of ESS and maximization the lifetime of ESS which uses the heuristic optimization method. It should be noted that the long-term decision frameworks are proposed under deterministic conditions without considering the variability of input profiles (weather/demand).

1.2.2. Real time optimization

Receding Horizon Optimization (RHO) performs real-time optimization of control variables which are updated on an hourly/daily timescale and then optimizer returns results as state variables for further advance optimization in the next time step. RHO has been applied to determine the optimal scheduling in the process industries [11]. Also, RHO has the ability to better manage the uncertainties and intermittent behavior of renewable energy