[*OPTIMAL DESIGN AND SCHEDULING OF A GRID-CONNECTED PV/CHP HYBRID SYSTEM WITH INCENTIVE-BASED DEMAND RESPONSE AND ELECTRIC VEHICLES: A CASE STUDY OFA MULTI-RESIDENTIAL COMPLEX BUILDING*]

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Overview

The global overpopulation, fast urbanization, and large use of fossil fuels-based centralized power plants are the main sources of carbon emissions and temperature rise in cities [1]. Due to the rising demand for energy services in residential buildings for lighting, appliances, cooking, and heating, it share 17% of the global energy-related CO_2 emissions by sector in 2020 [2]. Besides, the global transport sector was responsible for 23% of CO_2 emissions in the same year. This alarming situation urged utilities and policymakers, to establish alternative solutions for climate change mitigation through the employment of renewable generation sources, energy efficiency measures, and electric vehicles [3],[4]. This is to enforce environmental preservation and eradicate the people's concerns about the energy crisis. Today, integrated hybrid energy systems (iHESs) have gained traction as a viable solution for mixing renewable (e.g., solar photovoltaic (PV) and wind turbine (WT)), and non-renewable (e.g., diesel generator, combined heat and power (CHP) microturbine) distributed generation sources [5]. iHESs could offer a path for affordable and sustainable energy as well as fulfill the desire for a reliable and resilient supply of the building sector [6]. On the other side, the ongoing technological innovations and the growing adoption of information, and communication infrastructures have rapidly increased the active participation of energy customers under demand response program (DRP) [14]. DRP, as one of the approaches to implement demand-side management, allows for a better interaction mechanism and balances supply and demand by incentivizing and benefiting customers to shift or curtail their consumption during on-peak hours according to contractual obligations with the grid operator [15]. This can stretch the capacity and reliability of the grid during most stressed periods and manage the intermittency of renewable resources, reduce the electricity cost and emission rate [16]. Different studies have been presented in the literature on the modeling of DRP techniques and objectives including time-based DRP, and incentive-based DRP in the context of the hybrid energy system as recently reviewed in detail by Imani et al.[17] and Ibrahim et al.[18].

Methods

This paper proposes a methodology for optimal design and scheduling of a hybrid grid-connected iHES comprising roof-top PV, CHP microturbine, boiler and inverter considering private/shared EV charging stations, incentive-based DR program, and net metering mechanism (NEM). Different alternatives for system configuration are optimized and analyzed in terms of cost, emission, and resiliency metrics. A representative case study of a multi-residential complex building with electrical and thermal loads, located in Al-Mostakbal city, New Cairo (Egypt) is applied to validate the established methodology. The research method framework has two main stages. The first stage includes walkthrough data analysis to assess the site solar resource, fuel availability, electricity and heat consumption profiles of the building, specification and charging pattern of EVs, cost and technical data of PV and CHP, and grid parameters. The second stage involves the methodology approach adopted for the design optimization of the proposed iHES. The second stage is accomplished with the aid of HelioScope and HOMER GRID tools. Using HelioScope, the 3D model of building geometry including orientation, height, roof dimensions, slope, parapet walls, and other structural/ services obstacles is created and then the number and arrangements of PV modules as well as the inter-row distance are optimized. After that HOMER GRID is used as a reliable platform for modeling and optimization of the proposed iHES. In this stage, models of the system’s elements including PV, CHP, EV, grid, boiler, inverter, and DRP are established. Then, the peak demand limits and the component sizes are optimized, to find the least-cost system under the so-called peak shaving approach. Furthermore, under the adopted incentive-DRPs for summer and winter seasons, in which customers voluntarily curtail their consumption during specific conservation periods (DRP events) in response to a financial signal from the grid operator, the algorithm optimizes demand reduction bid during each DRP event to maximize the revenue. The adopted dispatch strategy features the ability two days look-ahead to know the electric demand, PV production, and grid tariff for each time step in the future to avoid any capacity shortage whenever possible. Once all feasible systems are investigated, the system with the least net present cost (NPC) and levelized cost of energy (LCOE) is nominated as the winning design.

Results

In this paper, the results are analyzed and discussed from the perspective of three scenarios, including (i) Scenario 1 (base): iHES with Grid/Boiler only, in which the grid is responsible for maintaining the electricity demand of the building apartments and EV charging demand, while the boiler is the source of the thermal power for water and space heating of the building apartments, (ii) Scenario 2: iHES with Grid/PV/CHP/Inverter/Boiler without DRP, (iii) Scenario 3: iHES with Grid/PV/CHP/Inverter/Boiler with DRP. Fig.1 shows the demand profiles for the different load types of the complex building under study. Based on the findings of the HelioScope, the maximum allowable capacity of the roof-top PV array is found 86.9 kW and consists of 161 fixed tilt modules of JKM540M-72HL4-TV type, with each having a rated power of 530W and efficiency of 20.94%. Fig. 2 shows the mounting and arrangement of the PV modules for the complex building under study. For design optimization of the proposed iHES, Table 1 summarizes the component sizes, cost, emission, and technical performance results for the three studied scenarios. The results show that the full utilization of the building roof with maximum PV capacity and adoption of the DRP incentives for both summer and winter seasons reduces the electricity import from the grid and encouraged the use of the on-site generation CHP microturbine. The optimal design with 86.9 kW PV, 100 CHP, and 100 kW inverter is of superior performance with the least NPC (476,878 $) and LCOE ($0.0513 $/kWh), and considerable bill savings (28,248 $/yr) when compared to the other two scenarios as shown in Table1. The winning alternative also comes with a significant reduction in CO_2 emission of 312092 kg/yr (21% less than the base scenario) and zero unmet electrical, thermal, and charging demands despite the grid outages.

Table 1 Results of optimized configurations with the studied iHES scenarios

iHES	Optimal size				EV results Peak demand (missed session)	Grid results						NPC	LCOE	Unmet demand	CO_2 emission
	PV	CHP	Inverter	Boiler production		Energy purchased	Energy sold	Peak load	Energy charge	DRP revenue	bill saving				
	kW	kW	kW	kWh/yr	kW (session/day)	kWh/yr	-	kW	$/yr	$/yr	$/yr	$	$/kWh	kWh/yr	Kg/yr
#1	-	-	-	134,320	83.2 (0.2)	573,242		181	39,662	-	-	610,005	0.0692	299	393,346
#2	86.9	-	100	134,320	83.2 (0.2)	443,098	19,657	181	29,522	-	10,140	540,988	0.0590	236	311,095
#3	86.9	100	100	110,744	0.2	277,719	19,668	169	$18,079	$6,665	28,248	474,172	0.0513	0	310,092

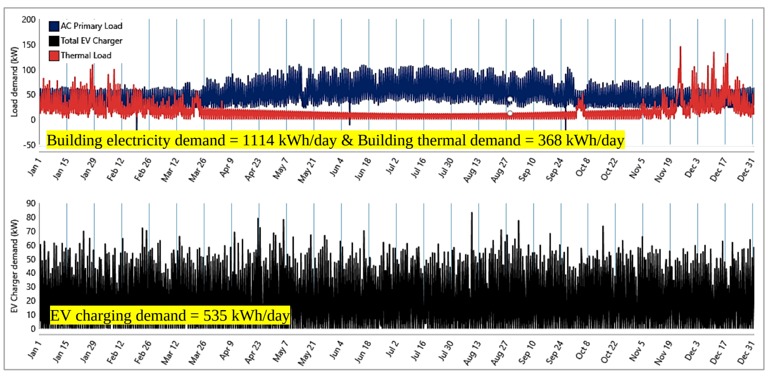

Fig. 1 Annual load profile for electrical, thermal, and EV demands

Fig. 2 The designed roof-top PV system

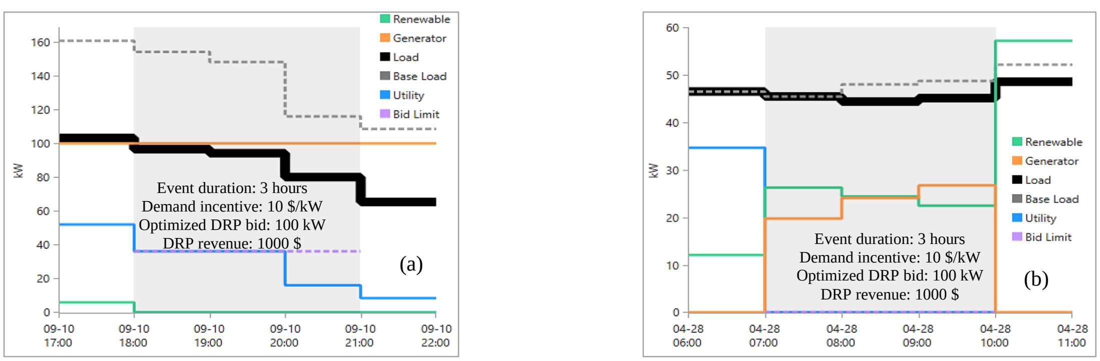

Fig. 3. Illustration of energy scheduling under incentive DRP in case of optimal design (scenario#3) (a) Sumer event on 10th September (b) Winter event on 28th April

Conclusions

The proposed method for design and scheduling of iHES shows that hybrid utilization of roof-top solar PV and CHP showed evidence of being promising contributors to cost savings and decarbonized energy supply for complex buildings equipped with electrical, thermal, and EV charging demands. The implementation of incentive-based DRP, as well as NMM, allows for exploit of demand flexibility and on-site generation sources to minimize the grid bill and supply resiliency despite the intermittent nature of solar resources. The optimized iHES based on PV/CHP/grid has reduced the system NPC, LCOE, and CO_2 by around 22%, 26%, and 27% compared to the base scenario with grid/boiler and by 14%, 15%, and 0.3% compared to the second scenario with PV/grid/boiler, respectively. Also, the winning system can boost customer satisfaction and provide redundancy of reliable, even power during power outages.