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(Research Article)

Energy management of greenhouses in micro grids: A case study

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Abstract

The nexus of population growth, constrained access to agricultural land, and enhanced living standards has necessitated the expansion of commercial greenhouses. These controlled environments are vital for shielding produce from unpredictable weather patterns and ensuring the availability of high-quality fresh produce throughout the year. Greenhouses maintain precise control over key parameters such as indoor temperature, humidity, CO2 concentration, and lighting, which are pivotal for optimal plant growth and product quality. However, the stringent control of these variables often results in substantial energy consumption, posing significant environmental and economic challenges. This research explores optimizing the internal environment of greenhouses while curbing energy usage, thereby mitigating potential environmental impacts. By focusing on grid-connected modes of operation, this study addresses the unique challenges posed by limited access to local energy resources. It explores the integration of microgrids, renewable energy sources, and combined heat and power systems to maintain operational efficacy and sustainability.

Keywords: Greenhouses; Energy Management; Microgrids; Sustainability; Renewable Energy

1. Introduction

The nexus of population growth, constrained access to agricultural land, and enhanced living standards has necessitated the expansion of commercial greenhouses. These controlled environments are vital not only for shielding produce from unpredictable weather patterns but also for ensuring the availability of high-quality, fresh produce throughout the year. Greenhouses, by design, maintain precise control over key parameters such as indoor temperature, humidity, CO2 concentration, and lighting, which are pivotal for optimal plant growth and product quality. However, the stringent control of these variables often results in substantial energy consumption, posing significant environmental and economic challenges. This has spurred extensive research aimed at optimizing the internal environment of greenhouses while curbing energy usage, thereby mitigating potential environmental impacts.

Contemporary studies have highlighted the application of advanced control strategies to manage these environmental parameters effectively. For instance, the use of fuzzy logic controllers has been explored to emulate expert knowledge in atmospheric regulation within greenhouses, as seen in [1]. Hierarchical analytical approaches and adaptive control mechanisms employing neural networks have also been proposed to address the complexities and dynamic nature of greenhouse environments [2, 3]. These innovations reflect an ongoing shift towards more sophisticated, automated systems capable of fine-tuning greenhouse climates in response to both internal and external variability.

Despite these advancements, significant challenges remain, particularly in scenarios where greenhouses operate off-grid. The isolation from traditional power networks necessitates innovative solutions to sustain control over environmental conditions without compromising plant health or energy efficiency. This research builds upon the foundation laid in [9] and extends its analysis to encompass grid-connected modes of operation. By focusing on the latter, this study addresses the unique challenges posed by limited access to local energy resources, exploring the

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integration of microgrids, renewable energy sources, and combined heat and power systems to maintain operational efficacy and sustainability. This paper aims to present an optimal energy management plan that not only considers the operational flexibility offered by microgrids but also emphasizes the need for robust control systems capable of minimizing the recurrence of environmental parameter deviations. Through this approach, we strive to enhance the resilience and sustainability of greenhouse operations, ensuring that they can continue to meet the demands of a growing population in an environmentally conscious manner.

2. Energy system analysis

One method of analyzing energy systems involves applying Heisenberg's uncertainty principle, as detailed in [10]. When an individual uses the energy hub as the main energy supplier, they can choose to participate in either the electricity market or the gas market based on the types of energy carriers, through a contractual agreement for electricity supply. This uncertainty principle is significant and can be crucial in clarifying specific cases and uncertainties, especially in technical and economic contexts. The specifications of our proposed model are outlined in Table 1.

Table 1 The specification of studied model.

Transformer	
Efficiency	88%
Capacity	450 kW
CHP	
Electrical Efficiency	39%
Thermal Efficiency	28%
Capacity	850 kW
Furnace	
Efficiency	79%
Capacity	500kW
Storage	
Efficiency	43%
Capacity	600m^3

The fuel costs for each season are as follows: $4 for spring, $3.9 for summer, $5 for fall, and $5.6 for winter. The electric load profile consumption has been detailed in Table 2.

Table 2 The load profile for studied model.

Season	**Min kW**	**Average (kW)**	**Peak (kW)**
Spring	210	240	270
Summer	210	260	300
Fall	200	220	290
Winter	90	200	240

The research computes energy expenses for each interval by utilizing data from Tables 1 and 2, alongside fuel prices and the efficiency coefficients of equipment. Given the dynamic nature of the electricity market, it is crucial to incorporate uncertainties in the calculations to ensure reliability. The study highlights the significance of equipment efficiency and diverse energy carriers as key computational indicators. The assessment approach relies on models and uncertainties, striving to identify the optimal configuration and structural setup within the energy hub to reduce energy losses and minimize costs.

2.1. Microgrid Perspectives on Greenhouses

Mohammadzadeh et al. [11] achieved nearly net-zero energy status in a building through effective energy exchange with the grid, optimizing and reducing energy use and losses. By installing advanced energy systems for lighting, heating, cooling, air conditioning, and managing windows and curtains, they observed a 40.7% improvement in energy efficiency and a 12% increase in exergy efficiency. Their research involved a standard greenhouse equipped with electric loads, heating, cooling, and local products. As per Figure 1, renewable energy sources, combined heat and power units (CHP), controllable distributed generating units (CDG), and storage systems were used to maintain greenhouse stability and enhance energy efficiency [12]. The greenhouse is capable of interacting with the utility network in a grid-connected mode, effectively functioning as a microgrid.

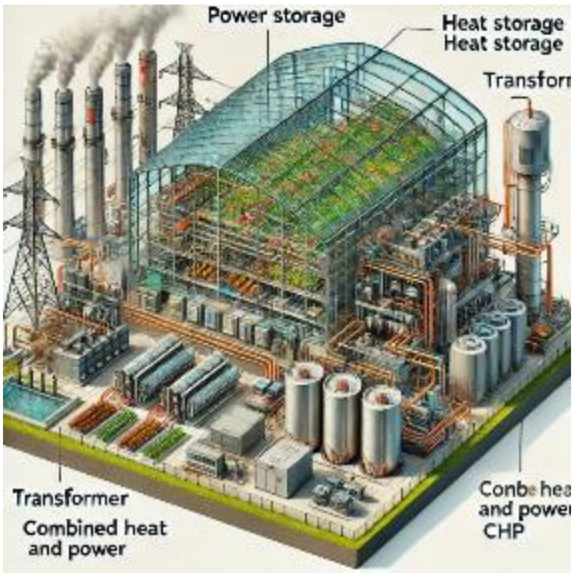

Figure 1 A model of an energy hub for greenhouse.

2.2. Control Parameters for Greenhouse Management

Optimal product growth is achieved by regulating internal temperatures to accelerate chemical reactions. Elevating the concentration of carbon dioxide (CO2) enhances plant photosynthesis, serving as an alternative to extra lighting. It is critical to maintain ideal humidity levels to foster a conducive environment for plant growth and to avert crop diseases. Keeping humidity within optimal ranges is vital to avoid restricting respiration and decelerating growth. Additionally, adequate lighting, both natural sunlight and artificial, plays a crucial role in supporting optimal plant growth, as discussed in [9] and [12].

2.3. Optimum Greenhouse Operations

The Energy Management System (EMS) plays a pivotal role in the efficient operation of greenhouses, collecting data from various sensors and analyzing operational needs. Geri et al., in [13], conducted studies on monitoring and controlling energy systems using sensors, a methodology that can also be applied to greenhouses.

The EMS orchestrates resource allocation to reduce operational costs in greenhouses while adhering to limitations on control parameters. It regulates four key parameters: indoor temperature, relative humidity, CO2 levels, and indoor lighting [14-17]. The system manages both electrical and thermal loads, utilizing combined heat and power units (CHP), controllable distributed generating units (CDG), battery energy storage systems (BESS), and renewable energy sources to calculate electric demand. Thermal demand is assessed using a CHP, a heat-only boiler (HOB), an electric heating pump (EHP), and a thermal energy storage tank (TESS). Additionally, cooling needs are addressed using the EHP and a chiller. The EMS coordinates the scheduling for each component, ensuring compliance with its directives [18-24].

2.4. Greenhouse Performance Modes

The proposed greenhouse model is designed to function in both grid-connected modes, effectively optimizing operational costs by exchanging power with the utility grid and utilizing a Battery Energy Storage System (BESS). The Energy Management System (EMS) oversees connectivity and automatically shifts to island mode during power disruptions. To manage limited local resources, a priority work method along with a penalty mechanism is implemented, ensuring optimal conditions for research plant growth. A priority matrix, focusing on factors like temperature, humidity, and light intensity, was established, with temperature given the highest importance for tomato cultivation. CO2 levels were also given separate prioritization. This model has been adapted for various plant species to enhance greenhouse management efficiency [25-27].

Additionally, the Environmental Management System (EMS) for greenhouses includes four integrated components: structure, service, management, and communication. Industrial sensors and relays facilitate precise monitoring, while a standardized management algorithm promotes thorough oversight, particularly in greenhouse settings [28]. A hierarchical, systematic approach underpinned by a mathematical model of the comprehensive energy cycle is essential for developing an EMS tailored for greenhouses. Various stages of testing and evaluation help fine-tune critical parameters within the greenhouse to maximize efficiency and effectiveness [29].

To manage the energy system effectively, it's crucial to focus on optimizing energy use, implementing precise control measures, and integrating energy storage solutions. This strategy is designed to reduce costs, improve control efficiency, and lower CO2 emissions. Figure 2 depicts a control and monitoring system for a greenhouse, highlighting the array of physical equipment employed, such as heaters, energy generators, meters, and systems for controlling light and CO2 levels. Ventilation and heat exchange play vital roles in energy management, with CO2 concentration being one of the critical parameters to monitor and control. The system utilizes various controllers, notably PID controllers, to maintain both external and internal temperatures within predetermined norms, ensuring optimal growing conditions and energy efficiency [30].

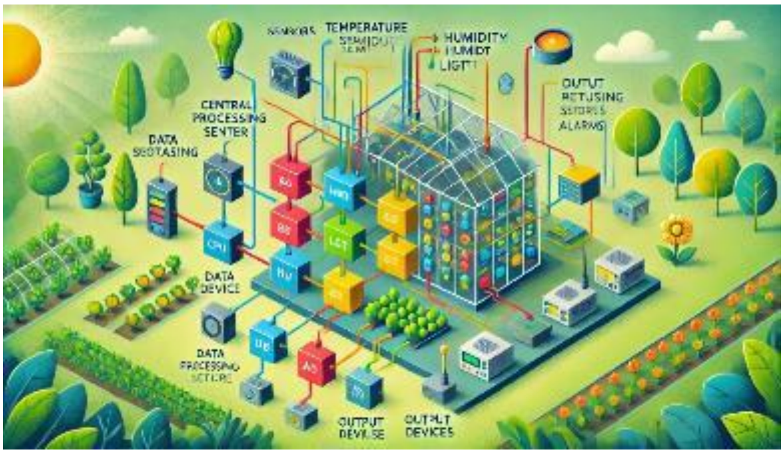

Figure 2 Greenhouse control and monitoring system design.

3. Simulation Results

This section introduces a system, introduces an optimization algorithm for a greenhouse energy hub using MATLAB software, explains each step, and analyzes the results.

3.1. Input Parameters

This study investigates the parameters of BESS (Battery Energy Storage Systems) and TESS (Thermal Energy Storage Systems), focusing on load input and discharge losses for BESS and time-dependent losses for TESS. BESS units, which are generally linked to the power grid via substation converters, experience a 4% loss. The losses for TESS depend on both time and the materials used, corresponding to the thermal energy provided by TESS [22]. Table 3 outlines the hourly losses for TESS, which are calculated to be 2%.

Table 3 Parameters of BESS and TESS.

BESS Parameters				**TESS Parameters**		
Capacity (kWh)	Charging Loss (%)	Discharging Loss (%)	Initial (kWh)	Capacity (kWh)	Loss (%)	Initial (kWh)
2800	4	4	460	23000	2	2400

Table 4 lists the acceptable ranges for all four control parameters along with their respective priority values. 'U' represents the upper limit, and 'L' represents the lower limit. A higher priority value indicates a more favorable control variable. The 'U' and 'L' values for the four control parameters are sourced from [9], while the priority values are derived from [23] and adjusted accordingly. Similar to the approach in [23], temperature is given the highest priority, followed by CO2, light, and humidity.

Table 4 Parameters of BESS and TESS

Parameter	**Temperature (ºC)**		**Humidity (%)**		**Lighting (W/m^2)**		**CO_2 (ppm)**	
Bound	U	L	U	L	U	L	U	L
	20	17	95	75	900	300	1600	900
Precedence	12		3		5		7	

This study examined the production capacities of different generators, including a Stirling engine and an absorption chiller. The Stirling engine exhibited a heat-to-power ratio of 3.23 [24], while the absorption chiller had a coefficient of performance (COP) of 0.9 [25]. Economical energy options like electric heat pumps (EHPs) were deemed suitable for generating both cooling and heating energies [26]. Typically, EHPs have a heating and cooling COP ranging from 2 to 5 [26]. In this research, the chosen EHP had a heating COP of 3.0 and a cooling COP of 3.5. The lower heat-to-combined heat and power (CHP) ratio observed in this study is attributed to Korea's unique electricity pricing system, which offers lower rates for the agricultural sector compared to residential and industrial sectors.

Table 5 The capacity of different generators

CHP	**CDG**	**EHP**	**HOB**	**Chiller**	**Dehumidifier**	**CO_2 Generator**
2300	3000	6000	2000	6000	200	400

The forecasted output power from renewable energy sources, such as photovoltaic panels and wind turbines, is used as input data and illustrated in Figure 3.a. Figure 3.b presents the Controlled Dispatchable Generation (CDG). The uncertainty margin for renewable energy output was set at ±20%, while the electric load, heating, and cooling were adjusted within a ±10% uncertainty range.

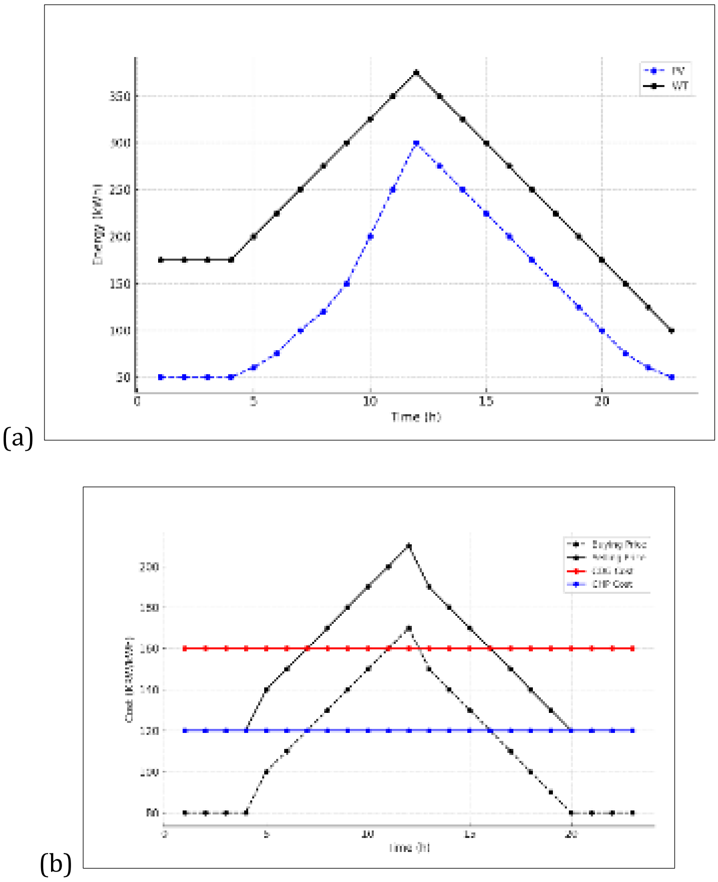

Figure 3 (a) Output power of resources, (b) Signal of Price and cost of generation.

3.2. Grid Connected Mode

In this scenario, the greenhouse can trade power with the utility network to reduce its operational costs. Figure 4 shows that more electricity is purchased from the utility network during the morning and night hours. This electricity is used to operate artificial lights or charge BESS. It can either meet the load demand during peak hours or be sold back to the utility network during peak price hours.

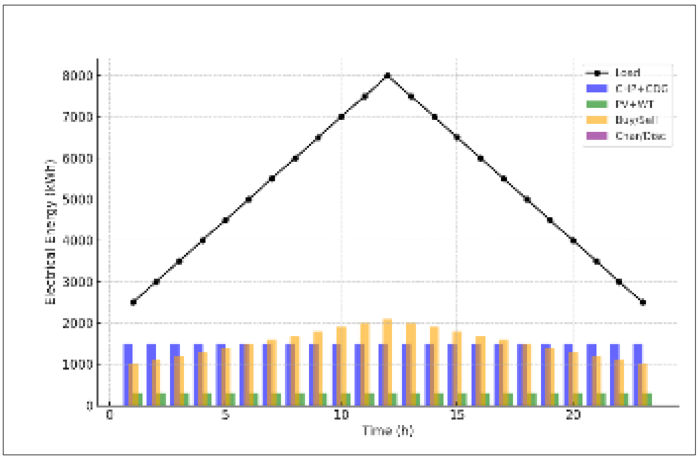

Figure 4 Balance of electrical energy in grid-connected mode

According to Figure 5.a, during noon hours, sunlight reduces the electric load, thereby avoiding the high production costs associated with Controlled Dispatchable Generation (CDG) when connected to the grid. Instead, the Combined Heat and Power (CHP) system, which utilizes heat, operates at full capacity. A significant amount of heat charge remains constant at all times, making CHP the primary heating source during morning and night hours. The highly efficient Electric Heat Pump (EHP) is used to address any remaining heating deficiencies.

In Figure 5.b, the Thermal Energy Storage System (TESS) optimizes thermal energy use by charging during periods of low load and discharging during periods of higher load. The thermal energy generated at night powers the chiller, which is initially used to meet cooling demands. In cases of higher demand, the EHP is activated in cooling mode.

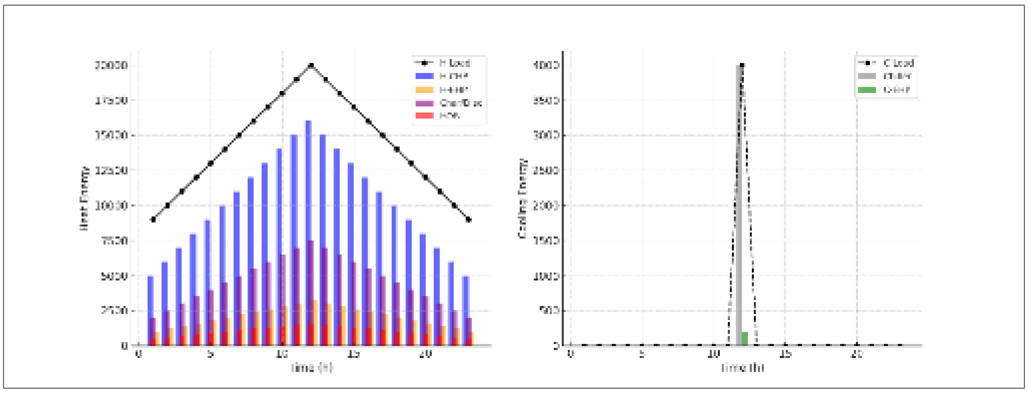

Figure 5 Energy balance (kWh) in normal mode (a) heating, (b) cooling

The operating range of all four control variables is monitored for each time interval within the scheduling horizon and is displayed in Figure 6. These ranges fall within the acceptable limits defined in Table 4.

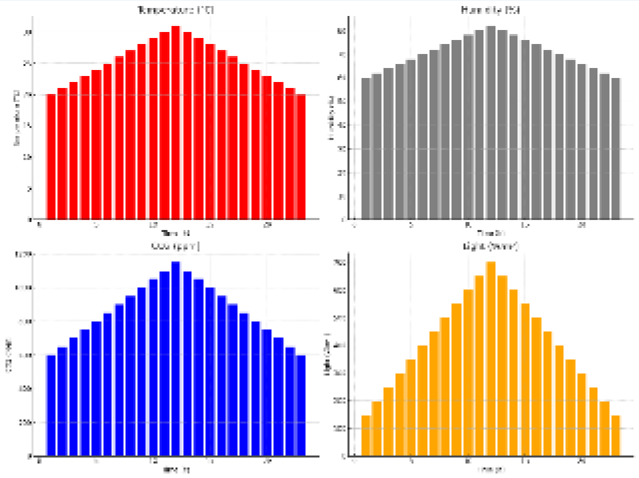

Figure 6 The operating range of all four control variables for each time interval of the scheduling horizon

4. Conclusion

The proposed greenhouse model is designed to operate in grid-connected modes, optimizing operational costs by exchanging power with the utility grid and utilizing a Battery Energy Storage System (BESS). The Energy Management System (EMS) manages connectivity and automatically switches to island mode during power outages. To effectively manage limited local resources, a priority-based method along with a penalty mechanism is employed to ensure optimal conditions for plant growth. A priority matrix, focusing on factors like temperature, humidity, and light intensity, was established, with temperature given the highest importance for tomato cultivation. CO2 levels were prioritized separately. This model has been adapted for various plant species to enhance greenhouse management efficiency. Effective management of the energy system requires optimizing energy use, implementing precise control measures, and integrating energy storage solutions. This strategy aims to reduce costs, improve control efficiency, and lower CO2 emissions.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this document.

References

[1] Samadian A, Marangalu MG, Talebian I, Hadifar N, Hosseini SH, Sabahi M, Vahedi H. Analysis of High Step-up Quasi Z-Source Based Converter with Low Input Current Ripple. IEEE Open Journal of the Industrial Electronics Society. 2024 May 8.

[2] Khalili M, Aliasghari TP, Najmi ES, Abdelaziz AY, Abu-Siada A, Nowdeh SA. Optimal allocation of distributed thyristor controlled series compensators in power system considering overload, voltage, and losses with reliability effect. Energies. 2022 Oct 11;15(20):7478

[3] Shahir FM, Aliasghari TP, Babaei E. Analysis of Self-Lift Luo Converter in DCM and Critical Inductance Calculation. In2021 International Symposium on Devices, Circuits and Systems (ISDCS) 2021 Mar 3 (pp. 1-4). IEEE.

[4] Zahraoui Y, Korõtko T, Rosin A, Zidane TE, Agabus H, Mekhilef S. A Competitive Framework for The Participation Of Multi-Microgrids in The Community Energy Trading Market: A Case Study. IEEE Access. 2024 May 8.

[5] Zaman MR, Halim MA, Khan MY, Ibrahim S, Haque A. Integrating Micro and Smart Grid-Based Renewable Energy Sources with the National Grid in Bangladesh-A Case Study. Control Systems and Optimization Letters. 2024 Feb 20;2(1):75-81.

[6] Navas SJ, González GC, Pino A, Pino FJ. Integration of microgrids in chemical industries with hydrogen as a byproduct: Styrene production Case Study. International Journal of Hydrogen Energy. 2024 Mar 15;59:947-57.

[7] Fresia M, Bordo L, Delfino F, Bracco S. Optimal day-ahead active and reactive power management for microgrids with high penetration of renewables. Energy Conversion and Management: X. 2024 Jul 1;23:100598.

[8] Kanakadhurga D, Prabaharan N. Smart home energy management using demand response with uncertainty analysis of electric vehicle in the presence of renewable energy sources. Applied Energy. 2024 Jun 15;364:123062.

[9] Eyimaya SE, Altin N. Review of Energy Management Systems in Microgrids. Applied Sciences. 2024 Feb 2;14(3):1249.

[10] Kyeremeh F, Fang Z, Liu F, Peprah F. Techno-economic analysis of reactive power management in a solar PV microgrid: A case study of Sunyani to Becheam MV feeder, Ghana. Energy Reports. 2024 Jun 1;11:83-96.

[11] Mohammadzadeh M, Hadifar N, Mohammadzadeh B. A sustainable PV-powered energy retrofit modelling to achieve net ZEB in churches: a simulation study for San Marcello Al Corso. International Journal of Exergy. 2021;36(2-4):191-207.

[12] Hadifar N, Ayanlou A. A Comparative Feasibility Study of Stand-Alone and Grid-Connected PV System for Residential Load: A Case Study in Iran. InE3S Web of Conferences 2021 (Vol. 239, p. 00008). EDP Sciences.

[13] Geri A, Gatta FM, Maccioni M, Dell'Olmo J, Carere F, Bucarelli MA, Poursoltan P, Hadifar N, Paulucci M. Distributed generation monitoring: a cost-effective Raspberry Pi-based device. In2022 2nd International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET) 2022 Mar 3 (pp. 1-6). IEEE.

[14] Geri A, Gatta FM, Maccioni M, Dell'Olmo J, Carere F, Bucarelli MA, Poursoltan P, Hadifar N, Paulucci M. A Low-Cost Smart Monitoring Device for Demand-Side Response Campaigns. InProceedings of Seventh International Congress on Information and Communication Technology: ICICT 2022, London, Volume 2 2022 Jul 27 (pp. 593-603). Singapore: Springer Nature Singapore.

[15] Akarne Y, Essadki A, Nasser T, El Bhiri B. Experimental Analysis of Efficient Dual-Layer Energy Management and Power Control in an AC Microgrid System. IEEE Access. 2024 Feb 26;12:30577-92.

[16] Sady H, Rashidi S, Rafee R. Towards a net-zero-energy building with smart control of Trombe walls, underground air ducts, and optimal microgrid composed of renewable energy systems. Energy. 2024 Feb 16:130703.

[17] Chakraborty A, Ray S. Multi-objective operational cost management with minimum net emission of a smart microgrid. Electric power components and systems. 2024 Jun 14;52(10):1870-91.

[18] Machele IL, Onumanyi AJ, Abu-Mahfouz AM, Kurien AM. Interconnected Smart Transactive Microgrids—A Survey on Trading, Energy Management Systems, and Optimisation Approaches. Journal of Sensor and Actuator Networks. 2024 Mar 1;13(2):20.

[19] Hong W, Tao ZH, Yang B. Investigating the Impact of Demand Management on the Microgrid with the Presence of Renewable Resources Uncertainty and Reliability. Process Integration and Optimization for Sustainability. 2024 Mar 14:1-5.

[20] Sawhney A, Delfino F, Bonvini B, Bracco S. EMS for Active and Reactive Power Management in a Polygeneration Microgrid Feeding a PED. Energies. 2024 Jan 26;17(3):610.

[21] Tan B, Chen S, Liang Z, Zheng X, Zhu Y, Chen H. An iteration-free hierarchical method for the energy management of multiple-microgrid systems with renewable energy sources and electric vehicles. Applied Energy. 2024 Feb 15;356:122380.

[22] Nemouchi W, Amrane Y, Nemouchi H, Boucetta NL. Energy management for optimal design of PV/wind/diesel system for water pumping irrigation in semi-arid climate. Energy Conversion and Management. 2024 Mar 15;304:118216.

[23] Chauhan RK, Chauhan K, Badar AQ. Optimization of electrical energy waste in house using smart appliances management System-A case study. Journal of Building Engineering. 2022 Apr 1;46:103595.

[24] Arcos-Aviles D, Pascual J, Guinjoan F, Marroyo L, Garcia-Gutierrez G, Gordillo-Orquera R, Llanos-Proaño J, Sanchis P, Motoasca TE. An energy management system design using fuzzy logic control: Smoothing the grid power profile of a residential electro-thermal microgrid. IEEE access. 2021 Feb 2;9:25172-88.

[25] Ferahtia S, Djeroui A, Rezk H, Houari A, Zeghlache S, Machmoum M. Optimal control and implementation of energy management strategy for a DC microgrid. Energy. 2022 Jan 1;238:121777.

[26] Hossain MA, Chakrabortty RK, Ryan MJ, Pota HR. Energy management of community energy storage in grid-connected microgrid under uncertain real-time prices. Sustainable Cities and Society. 2021 Mar 1;66:102658.

[27] Barja-Martinez S, Rücker F, Aragüés-Peñalba M, Villafafila-Robles R, Munné-Collado Í, Lloret-Gallego P. A novel hybrid home energy management system considering electricity cost and greenhouse gas emissions minimization. IEEE Transactions on Industry Applications. 2021 Feb 3;57(3):2782-90.

[28] Khalili M, Aliasghari TP, Najmi ES, Abdelaziz AY, Abu-Siada A, Nowdeh SA. Using Improved Equilibrium Optimization Algorithm for Optimal Allocation of Distributed Thyristor Controlled Series Compensators in Power System Considering Overload, Voltage, and Losses with Reliability Effect. Energies 2022, 15, 7478.

[29] Raya-Armenta JM, Bazmohammadi N, Avina-Cervantes JG, Sáez D, Vasquez JC, Guerrero JM. Energy management system optimization in islanded microgrids: An overview and future trends. Renewable and Sustainable Energy Reviews. 2021 Oct 1;149:111327.

[30] Shahir FM, Aliasghari TP, Aberoumandazar M. Switching Correction of Direct Torque Control Method in order to Improve the Electrical Vehicle Performance Quality. In2021 International Symposium on Devices, Circuits and Systems (ISDCS) 2021 Mar 3 (pp. 1-4). IEEE.