Enhancing Energy Management in Standalone Microgrids Through Peak Shaving Techniques

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Abstract*— Standalone microgrids are becoming increasingly important in managing energy supply and demand, especially in remote or isolated areas. These systems operate independently from the main power grid, providing a reliable source of electricity to communities that do not have access to traditional energy infrastructure. One solution offered is the use of peak shaving techniques with Battery Energy Storage Systems (BESS), which store excess energy during low demand periods and release it during peak consumption times. This method helps to stabilize microgrid operations, reduce reliance on backup generators, save operational costs, and reduce greenhouse gas emissions. Simulations were conducted using MATLAB software to optimize energy usage. The simulation results show that the use of BESS can reduce peak load and increase the efficiency of renewable energy used in the microgrid system. The analysis data shows that the peak load before the use of BESS is 112.00 kW, and remains the same after the use of BESS. The total renewable energy used was 590.00 kWh, with the energy stored in the BESS amounting to 43.99 kWh.

***Keywords*— Standalone microgrid, peak shaving, Battery Energy Storage System (BESS), renewable energy, energy efficiency, peak load.**

I. Introduction

Standalone microgrids are becoming increasingly important in managing energy supply and demand, especially in remote or isolated areas [1, 2]. These systems operate independently from the main power grid, providing a reliable source of electricity to communities that do not have access to traditional energy infrastructure [3, 4]. The main challenges faced are the management of energy costs and the balance between energy generation and consumption [5].

Peak shaving using Battery Energy Storage Systems (BESS) offers a solution by storing excess energy during low demand periods and releasing it during peak consumption times [6, 7]. This helps to stabilize microgrid operations, reduce reliance on backup generators, save operational costs, and reduce greenhouse gas emissions [8].

The Peak Shaving method provides significant economic benefits, reduces the need for additional generation capacity, and improves the economic sustainability of standalone microgrids. This is important for communities with limited financial resources. Integration of renewable energy sources with BESS can further enhance energy independence and economic sustainability [9, 10].

Operationally, this method improves microgrid reliability and resilience by ensuring consistent energy supply, reducing the risk of blackouts, and increasing flexibility in adapting to changes in energy demand. As such, the Peak Shaving method is becoming increasingly important in optimizing the performance of standalone microgrids, making it a more efficient and environmentally friendly solution towards a more sustainable and reliable energy future [11].

II. Literature Review

A. Energy Storage Systems

Electrical energy is now becoming the backbone of every country as it directly helps to enhance economic growth through several applications in the national grid. The development of any industrial infrastructure is directly associated with the availability of electrical energy and due to this growing industrial infrastructure, the electricity demand is also increasing. As per the hike in demand for electrical energy, there is a need to enhance the generation, transmission, and distribution network capacity. Initially, the basic objective of the power system network was to generate electrical power in a remote area (due to natural resource availability and pollution issues), transmit this electrical power from a remote area to the load center by high voltage transmission lines and finally distribute the power as per customers' required voltage level [12].

The majority of the share of electrical energy comes from traditional/ conventional fossil fuel–based energy sources. These sources contribute to environmental pollution and greenhouse gases emission. Due to the depletion of fossil fuels, their non-availability in each country, and environmental concerns, an alternate source of energy is needed. So, nowadays, the focus on renewable energy resources/sources (RERs/RES) is more available across the globe. With the new policies, small power producers and renewable energy generation have been encouraged to meet the energy demand. In this case, the renewable generation can be much closer to the load and named as distributed generation. It saves the transmission resources, as well as losses, which are very less. Figure 1 shows the concept of distributed generation (DG) in modern power systems [13].

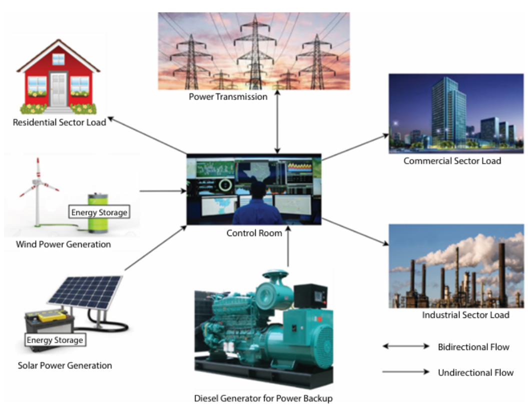

Figure 1. Distributed generation in power system

The application of energy storage systems (ESSs) has been identified as a possible solution to compensate for the challenges faced by the modern electric power system. ESSs are in urgent demand by the conventional power generation industry, DERs, and intermittent renewable energy supply systems as they can offer required ancillary support and flexibility to them. Energy storage does not mean just the energy sources but they also provide the added benefits of improving reliability, stability, and also the quality of the power supply [14]. They are suitable for large (GW), medium (MW), or micro (kW) scale applications of the electric power system, depending on the task and requirement. They can be utilized for power demand balance, energy arbitrage, and reserve at the generation side; for investment deferral and frequency regulation at transmission level; for grid capacity support and voltage control at the distribution side; and for cost management and for peak shaving, etc., at the customer-side [15].

In AC power systems, the electrical energy cannot be stored electrically. However, the AC energy can be stored by converting it into other energy forms such as kinetic, electromagnetic, electrochemical, or potential energy. Thus, a power conversion unit (PCU) is usually required by every energy storage technology to import electricity from the power grid and convert into a form that could be stored. The PCU converts it back to electricity during hours of peak demand 9or as when needed. Figure 2 demonstrates the main compo nents of the ESS [16].

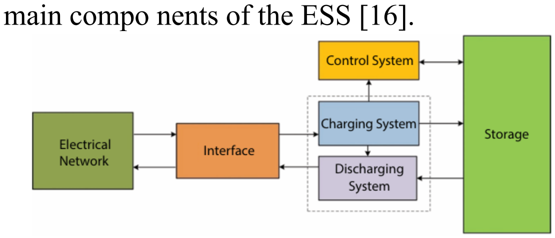

Figure 2. Main components of an ESS

A. Significance of Storage Technologies in Renewable Integration

The viability of commercial-scale storage systems increases with the drop in technological prices and incentives to renewable energies being fed to the electricity grid. Access, cost, and quality are issues in rural areas where agribusiness has major consumption and affect the economy of many countries [17].

The great economic relevance of agriculture is paramount in devel oping countries like Brazil, given the consequence of the wealth of natural resources, availability of area, and favorable climate. Assessing that in rural areas, access to the use of the electricity grid as an economic advantage is fundamental in terms of energy storage. The supply for buildings in urban areas has different patterns in contrast to the energy supply in rural areas [18].

In view of this, the agribusiness is extremely intense in energy, deciding a significant portion of its production costs. In addition to dealing with more distant regions, rural producers often suffer from a deficiency in the electrical structure such as poor quality or even a lack of energy. In general, a diesel generator is used to supply the need of power in rural areas, but they are expensive and harmful to the environment. Therefore, photovoltaic energy stands out as the best solution in this scenario [19].

This energy (solar photovoltaic energy) is "treated" by a device called an inverter, making it possible to use it to power any electrical equipment [20]. Analyzing solar energy more specifically, it is captured by means of solar cells that capture some wavelengths of solar radiation, that is, the solar rays when they reach the photovoltaic cells of a solar module and cause a reaction on an atomic scale, called photons (energy present in the sun's rays). When they collide with silicon electrons there is the generation of electricity and consequently an electric current [21].

Even in places with more moderate climates, or with most of the weather cloudy and covered by clouds, solar radiation can still be a source of energy. Solar electricity is one of the cleanest, most abundant, sustainable, and renewable sources in the world. Among the advantages of a solar- powered storage system, in addition to economy and sustainability, reliability is greater in the electrical system. Considering the possibility of its use in conjunction with other equipment, such as storage devices, gives greater stability to the electrical network, and can even supply part of the electrical consumption when there is a failure in the distribution network [22-24]. The electricity generated by solar energy does not cause noise pol lution and carbon emission [25].

Even in the midst of so many benefits, it is important to point out that wind and solar sources are not able to supply the needed energy in the necessary volumes or at the desired time always, requiring energy storage technologies. This makes it necessary to combine these efficient systems with other heat and electricity storage technologies, resulting in a significant increase in total energy storage compared to the separate implementation. Through an infrastructure connected to the electric grid the energy industry can overcome the interruption challenges [26, 27].

B. Battery Energy Storage System

Battery Energy Storage Systems (BESS) is a system consisting of a battery, a power conversion system, and a battery management system (BMS). The BESS has the fastest response time among all energy storage systems, making it essential in coping with power, voltage, and frequency variations. A BESS serves several purposes, such as meeting peak power demand, improving grid stability, power quality, and balancing, and mitigating the effects of erratic energy sources [28].

In a Battery Energy Storage System (BESS) system, the maximum and minimum energy stored refers to the highest and lowest State of Charge (SoC) achieved by the battery during operation or simulation. SoC (%) is an indicator of the remaining energy capacity in the battery relative to its total capacity. Capacity of a battery is affected by battery configuration, back-up period, temperature, battery lifetime, depth of discharge and renewable energy sources, etc. Detailed modeling of BESS is presented considering charge/ discharge limits, depth of discharge (DOD), efficiency and battery lifetime. Power charging/discharging of battery is expressed in equation.

$$E_{max} = SoC_{max} \times C_{BESS} \tag{1}$$

$$E_{min} = SoC_{min} \times C_{BESS} \tag{2}$$

Where:
E_{max}= Maximum energy stored (kWh)
SoC_{max}= Maximum State of Charge (% or decimal)
E_{min} = Minimum energy stored (kWh)
SoC_{min} = Minimum state of charge (% or decimal)
C_{BESS}= Battery total capacity (kWh)

C. Standalone Microgrid

Standalone microgrids enable independent operation without relying on the main power grid. The system integrates various distributed energy resources (DERs) such as solar panels, wind turbines, and energy storage systems, to provide reliable and efficient electricity, especially in remote areas or outside the traditional power grid.

Microgrids are small electrical systems that can operate either on-grid or off-grid in islanding mode. Microgrids improve energy reliability, operational efficiency, and enable the use of renewable energy such as solar PV, wind turbines, and storage batteries. These capabilities make microgrids versatile and able to adapt to varying energy demand and supply conditions.

The major benefits of micro-grids are increased power reliability, reduced utility costs and improved economic competitiveness, reduced greenhouse gas emissions, lowered transmission and distribution losses and capable of operating on renewable or non-renewable resources.

D. Applications and Benefits of Energy Storage Systems in the Microgrid System

The variability and intermittent nature of RES cause instability of the grid. The distribution generation offers additional opportunities for small-scale to large-scale energy storage systems. BESS is an effective tool to overcome the above problems; it enables optimal integration of renewable energy sources and ensures grid balancing and reliability. Moreover, significant economic benefits can also be obtained by incorporating BESS along with high-scale solar and wind farms. For small-scale systems like solar on a residential rooftop, substation and other buildings rooftop applications, using BESS electricity is stored during high PV production and dispatched to cater to load demand in an economic way during non-production time [29, 30].

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III. Research Methods

This research begins with data collection related to the daily load profile, power generated by the solar power plant, as well as BESS parameters such as storage capacity and SoC minimum limit. The data is analyzed to calculate Net Load, which is the difference between user load and available renewable power. Next, a Peak Shaving Operation simulation is performed to optimize energy usage as shown at Figure *3*. If there is a surplus of power from the solar plant, the energy will be stored in the BESS, while during peak load, the BESS will release power to stabilize the system.

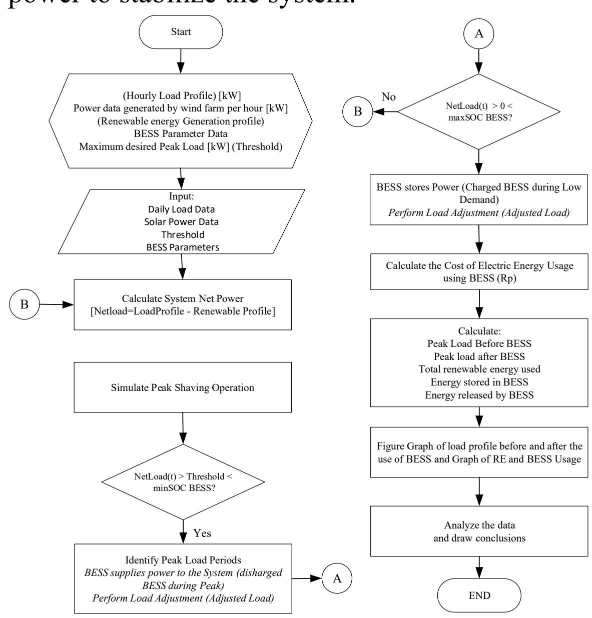

Figure 3. Flowchart of Research Procedures

Afterwards, the system calculates the cost of energy consumption and evaluates the load changes before and after BESS integration. The simulation results are visualized in the form of graphs to show the effectiveness of BESS in reducing peak load and increasing renewable energy efficiency. Finally, data analysis is performed to evaluate the overall system performance and determine the optimal energy management strategy.

IV. Result and Discussion

On the basis of the information that is presented in Tables 1 and 2, we are able to determine the connection that exists between the maximum daily load and the maximum amount of energy that is produced by the solar power plant. Data on the amount of electricity produced by the photovoltaic plant is presented in Table 1, while the daily load profile is presented in Table 2. Day V saw the highest daily load recorded at 1014 kW, while day III saw the highest energy generated by the PV system at 1558 kW. Both of these figures were reported on day V.

Table 1. Data On Energy Generated By PV PLTS

Day	Energy Generated by PV [kW]																								Ave.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
I	0	0	0	0	0	0	5	10	15	45	80	100	110	95	80	60	35	0	0	0	0	0	0	0	635
II	0	0	0	0	0	0	6	12	32	42	80	150	105	85	56	34	23	0	0	0	0	0	0	0	625
III	0	0	0	0	0	0	7	28	42	56	195	250	210	86	65	43	32	0	0	0	0	0	0	0	1014
IV	0	0	0	0	0	0	8	16	34	45	140	155	145	67	56	42	32	0	0	0	0	0	0	0	740
V	0	0	0	0	0	0	9	18	43	55	185	220	195	88	55	43	22	0	0	0	0	0	0	0	933
VI	0	0	0	0	0	0	4	13	34	43	155	195	145	76	54	44	21	0	0	0	0	0	0	0	784
VII	0	0	0	0	0	0	5	15	23	33	110	135	120	65	56	34	21	0	0	0	0	0	0	0	617

Table 2. Data Loadprofile

Day	Hourly Load Profile [kW]																								Ave.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
I	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	75	70	65	60	55	45	40	1175
II	6	12	18	24	30	36	42	48	52	60	66	72	78	84	90	96	106	96	90	84	78	72	66	60	1466
III	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	95	48	45	42	39	36	33	30	776
IV	7	14	21	28	35	42	48	49	56	63	70	77	84	91	98	105	112	105	98	91	84	77	70	63	1588
V	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	64	60	56	52	48	44	40	976
VI	2	6	10	14	18	22	26	40	44	48	52	56	60	64	68	72	76	72	68	64	60	56	52	48	1098
VII	8	12	16	20	24	26	30	34	38	42	46	50	54	58	62	66	70	66	62	58	54	50	46	42	1034

The author employs the maximum column in Tables 1 and 2 as the data source for the analysis. The author employs the maximum column in Tables 1 and 2 as the data source for the analysis. Maximum value is the energy value throughout a single cycle of operation of the solar power plant. The peak shaving value of the system will be determined by simulating this maximum value.

This data is used to perform simulations in MATLAB to obtain the value of Peak Load Before and After BESS, Total Renewable Energy Used, Energy Stored in BESS, and Energy Wasted from BESS. From the simulation results, the value is obtained Peak Load Before BESS was 112.00 kW, Peak Load After BESS was 112.00 kW. Total Renewable Energy Used was 590.00 kWh, Energy Stored in BESS was 43.99 kWh, and Energy Discharged from BESS was -0.00 kWh.

A. Load Profile before and after BESS integration

The energy generated by the PLTS Perumda Mappatuwo is detailed in **Error! Reference source not found.**, while the load data handled by the PLTS system is presented in Table 2. The total energy generated by the system to supply energy in accordance with the load requirements stated in Table 2 is reported in **Error! Reference source not found.**. Consequently, this research does not employ two distinct types of load profiles in a single system.

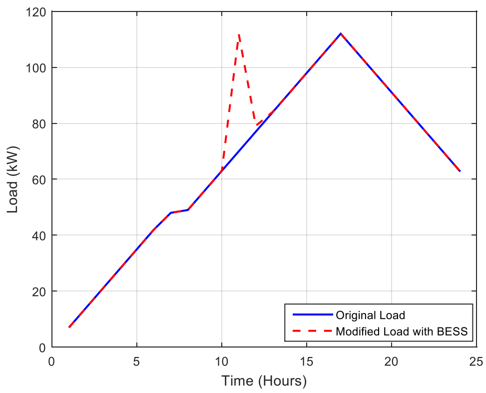

Figure 4. Curve Load profile before and after BESS integration

The variation in electrical load over time is indicated in Figure 4, which uses a comparison between the initial load, which is represented by the blue line, and the modified load (depicted by the red dashed line). The peak shaving strategy is a strategy that aims to reduce peak electricity demand during high-load periods in order to improve the efficiency of the power system and optimize energy consumption. The graph illustrates the implementation of the peak shaving strategy, which is a strategy that aims to reduce peak electricity demand. Within the framework of energy management, this technique is currently being put into operation.

The graph indicates that the electrical load gradually increases until it reaches a peak around the 10th to 12th hour. In the absence of intervention (the red curve), a significant surge in load occurs during this period. However, after applying the peak shaving strategy (red curve), the peak load is reduced or leveled by shifting part of the energy consumption to periods with lower demand. There are a number of different approaches that can be taken in order to achieve this reduction. Some of these approaches include the utilization of energy storage systems (for instance, batteries or capacitors), the management of the operational schedules of high-power equipment, or the incorporation of distributed energy resources such as solar power or backup generators.

B. Renewable Energy and BESS Usage

Figure 5 illustrates the relationship between renewable energy generation and the operation of a battery energy storage system (BESS) in the context of energy management and peak shaving strategies. The green curve represents power generation from renewable sources, such as solar or wind energy, which increases significantly around the 10th hour, reaches its peak, and then gradually declines. Meanwhile, the dashed purple curve represents BESS operation, indicating a charging process when renewable generation reaches its peak. This is observed through the negative values on the curve around the 10th hour, signifying that the storage system is absorbing excess energy. After this period, the curve returns to zero, indicating no further charging or discharging activity.

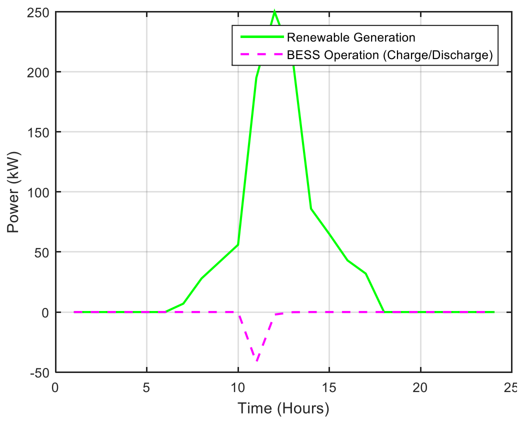

Figure 5. Curve Renewable Energy and BESS Usage

In the context of peak shaving, this graph demonstrates how energy storage systems can effectively manage power surges caused by the variability of renewable energy generation. By absorbing surplus power during periods of high renewable energy production, the BESS prevents power imbalances within the electrical grid. The stored energy can later be discharged when electricity demand rises or when renewable generation decreases. This strategy contributes to grid stability, optimizes the utilization of renewable energy, and reduces peak loads, ultimately helping to lower operational costs and decrease reliance on conventional energy sources. Overall, the integration of energy storage systems with renewable generation plays a crucial role in enhancing the efficiency and sustainability of power systems while supporting the effective implementation of peak shaving strategies.

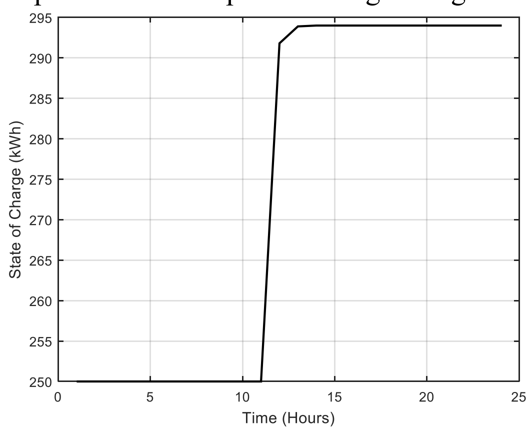

Figure 6. Curve Battery State Of Charge (SoC)

Error! Reference source not found. shows the energy data generated by the PV plant, while Table 2 shows the load profile data. Figure 6 depicts the battery State of Charge (SoC) curve of the PV system. By combining the information from **Error! Reference source not found.** dan Table 2, we can understand how the energy generated by the PV plant relates to the load profile and how this affects the battery SoC.

A preliminary analysis of **Error! Reference source not found.** reveals daily fluctuations in energy production by the PV plant, which depends on weather conditions and sunlight intensity. This data is important for understanding the capacity and efficiency of the PV plant in meeting energy demand. Meanwhile, Table 2 provides insight into the time-based energy consumption patterns. This profile shows the energy demand at various hours of the day, which can be compared with the energy production recorded in Table 1.

Figure 6, which displays the battery SoC curve, serves to illustrate how the energy produced by the PV plant is used and stored throughout the day. When energy production by the solar PV plant is greater than energy consumption, the excess energy is stored in the battery, which is reflected in an increase in SoC in Figure 6. Conversely, when energy consumption is greater than production, the SoC of the battery will decrease, indicating the use of previously stored energy.

The correlation between **Error! Reference source not found.** dan Table 2 with Figure 6 can be further understood by analyzing the pattern of changes in battery SoC throughout the day. By comparing the data from both tables with the curves in the figure, we can determine the periods during which the solar farm produces excess energy and charges the battery, as well as the periods during which the energy stored in the battery is used to meet energy demand. This helps in planning and optimizing the use of energy from the solar farm to ensure stable and efficient energy availability.

The battery capacity at that time was sufficient to deliver energy to the load, as evidenced by the curve in Figure 6, which has remained in a charging state.

V. Conclusion

This study shows that the Peak Shaving technique using Battery Energy Storage Systems (BESS) is effective in reducing peak load and increasing renewable energy efficiency in a standalone microgrid. The simulations conducted reveal that the use of BESS can reduce peak load and increase renewable energy usage significantly. By integrating BESS, excess energy generated by solar power plants can be stored during low demand periods and released during peak demand. This not only helps stabilize microgrid operations, but also reduces reliance on backup generators, saves operational costs, and reduces greenhouse gas emissions.

The implementation of the Peak Shaving technique resulted in a peak load before and after BESS that remained at 112 kW, with a total renewable energy used of 590 kWh and energy stored in BESS of 43.99 kWh. These results confirm that the use of BESS in a standalone microgrid not only provides significant economic benefits but also increases energy independence and contributes to environmental sustainability.

References

R. Ghasemi, M. Wosnik, D. L. Foster, and W. Mo, "Multi-Objective Decision-Making for an Island Microgrid in the Gulf of Maine," *Sustainability,* vol. 15, no. 18, p. 13900, 2023, doi: 10.3390/su151813900.

[2] K. Gholami and S. Jazebi, "Energy Demand and Quality Management of Standalone Diesel/ <scp>PV</Scp> /Battery Microgrid Using Reconfiguration," *International Transactions on Electrical Energy Systems,* vol. 30, no. 10, 2020, doi: 10.1002/2050-7038.12550.

[3] E. Yusubov and L. Bekirova, "A Standalone Dc Microgrid Energy Management Strategy Using the Battery State of Charge," *Informatyka Automatyka Pomiary W Gospodarce I Ochronie Środowiska,* vol. 13, no. 3, pp. 75-78, 2023, doi: 10.35784/iapgos.5320.

[4] B. Zhou *et al.*, "Multi-Microgrid Energy Management Systems: Architecture, Communication, and Scheduling Strategies," *Journal of Modern Power Systems and Clean Energy,* vol. 9, no. 3, pp. 463-476, 2021, doi: 10.35833/mpce.2019.000237.

[5] A. Elmouatamid, M. A. Chowdhury, M. Netto, and P. W. T. Pong, "Economic Feasibility Study of Standalone Community Microgrid in 37 Cities of the USA," *Hkie Transactions,* vol. 31, no. 1, pp. 1-17, 2024, doi: 10.33430/v31n1thie-2022-0027.

[6] S. Abid, T. A. Alghamdi, A. Haseeb, Z. Wadud, A. Ahmed, and N. Javaid, "An Economical Energy Management Strategy for Viable Microgrid Modes," *Electronics,* vol. 8, no. 12, p. 1442, 2019, doi: 10.3390/electronics8121442.

[7] O. Izquierdo-Monge, P. Peña-Carro, A. Hernández-Jiménez, A. Zorita-Lamadrid, and L. Hernández-Callejo, "Methodology for Energy Management in a Smart Microgrid Based on the Efficiency of Dispatchable Renewable Generation Sources and Distributed Storage Systems," *Applied Sciences,* vol. 14, no. 5, p. 1946, 2024, doi: 10.3390/app14051946.

[8] P. Yu, Y. Sun, and R. Gu, "Distributed Control of Energy Storages for Multi-Time-Step Peak Load Shaving in a Microgrid," *Journal of Physics Conference Series,* vol. 2703, no. 1, p. 012022, 2024, doi: 10.1088/1742-6596/2703/1/012022.

[9] Y. Achour, A. Ouammi, and D. Zejli, "Model Predictive Control Based Demand Response Scheme for Peak Demand Reduction in a Smart Campus Integrated Microgrid," *Ieee Access,* vol. 9, pp. 162765-162778, 2021, doi: 10.1109/access.2021.3132895.

[10] M. Rana, M. Atef, M. R. Sarkar, M. Uddin, and G. M. Shafiullah, "A Review on Peak Load Shaving in Microgrid—Potential Benefits, Challenges, and Future Trend," *Energies,* vol. 15, no. 6, p. 2278, 2022, doi: 10.3390/en15062278.

[11] M. Rana, "Peak Load Shaving in Isolated Microgrid by Using Hybrid PV-BESS System," *International Journal of Emerging Trends in Engineering Research,* vol. 8, no. 1.1, pp. 7-14, 2020, doi: 10.30534/ijeter/2020/0281.12020.

[12] T. Strasser *et al.*, "A review of architectures and concepts for intelligence in future electric energy systems," *IEEE Transactions on Industrial Electronics,* vol. 62, no. 4, pp. 2424-2438, 2014.

[13] O. Krishan and S. Suhag, "An updated review of energy storage systems: Classification and applications in distributed generation power systems incorporating renewable energy resources," *International Journal of Energy Research,* vol. 43, no. 12, pp. 6171-6210, 2019.

[14] A. Shahmohammadi, R. Sioshansi, A. J. Conejo, and S. Afsharnia, "The role of energy storage in mitigating ramping inefficiencies caused by variable renewable generation," *Energy Conversion and Management,* vol. 162, pp. 307-320, 2018.

[15] K. Dragoon, "Energy Storage Opportunities and Challenges," *West Coast Perspect. White Pap,* p. 61, 2014.

[16] D. O. Akinyele and R. K. Rayudu, "Review of energy storage technologies for sustainable power networks," *Sustainable energy technologies and assessments,* vol. 8, pp. 74-91, 2014.

[17] M. Rostami and S. Lotfifard, "Scalable coordinated control of energy storage systems for enhancing power system angle stability," *IEEE Transactions on Sustainable Energy,* vol. 9, no. 2, pp. 763-770, 2017.

[18] O. M. Babatunde, J. L. Munda, and Y. Hamam, "Power system flexibility: A review," *Energy Reports,* vol. 6, pp. 101-106, 2020.

[19] P. Colbertaldo, S. B. Agustin, S. Campanari, and J. Brouwer, "Impact of hydrogen energy storage on California electric power system: Towards 100% renewable electricity," *International Journal of Hydrogen Energy,* vol. 44, no. 19, pp. 9558-9576, 2019.

[20] H. Kim and T. Y. Jung, "Independent solar photovoltaic with Energy Storage Systems (ESS) for rural electrification in Myanmar," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 1187-1194, 2018.

[21] J. Liu, W. Yao, J. Fang, J. Wen, and S. Cheng, "Stability analysis and energy storage-based solution of wind farm during low voltage ride through," *International Journal of Electrical Power & Energy Systems,* vol. 101, pp. 75-84, 2018.

[22] M. Ahmadi, M. E. Lotfy, M. S. S. Danish, S. Ryuto, A. Yona, and T. Senjyu, "Optimal multi-configuration and allocation of SVR, capacitor, centralised wind farm, and energy storage system: a multi-objective approach in a real distribution network," *IET Renewable Power Generation,* vol. 13, no. 5, pp. 762-773, 2019.

[23] H. Akbari *et al.*, "Efficient energy storage technologies for photovoltaic systems," *Solar Energy,* vol. 192, pp. 144-168, 2019.

[24] M. Basu, "Multi-region dynamic economic dispatch of solar–wind–hydro–thermal power system incorporating pumped hydro energy storage," *Engineering Applications of Artificial Intelligence,* vol. 86, pp. 182-196, 2019.

[25] L. Han, R. Zhang, and K. Chen, "A coordinated dispatch method for energy storage power system considering wind power ramp event," *Applied Soft Computing,* vol. 84, p. 105732, 2019.

[26] D. H. S. Tan, A. Banerjee, Z. Chen, and Y. S. Meng, "From nanoscale interface characterization to sustainable energy storage using all-solid-state batteries," *Nature nanotechnology,* vol. 15, no. 3, pp. 170-180, 2020.

[27] M. A. Zelinsky, J. M. Koch, and K.-H. Young, "Performance comparison of rechargeable batteries for stationary applications (Ni/MH vs. Ni–Cd and VRLA)," *Batteries,* vol. 4, no. 1, p. 1, 2017.

[28] I. B. N. Anwar, M. N. M. Hussain, S. Z. M. Noor, N. Y. Dahalan, M. S. Onn, and A. Tumian, "Micro-Grid of Batteray Energy Storage System (BESS) Design for Malaysia's Net Energy Metering (NEM)," 2024, vol. 473: EDP Sciences, p. 02001.

[29] J. A. P. Lopes, C. L. Moreira, and A. G. Madureira, "Defining control strategies for microgrids islanded operation," *IEEE Transactions on power systems,* vol. 21, no. 2, pp. 916-924, 2006.

[30] I. Alsaidan, A. Khodaei, and W. Gao, "A comprehensive battery energy storage optimal sizing model for microgrid applications," *IEEE Transactions on Power Systems,* vol. 33, no. 4, pp. 3968-3980, 2017.

[31] M. Machado *et al.*, "Recent Research and Development of Microgrids in Parana," *Brazilian Archives of Biology and Technology,* vol. 64, no. spe, p. e21210177, 2021.

[32] D. Swain *et al.*, "P2P Coordinated Control between SPV and STATCOM in a Microgrid for Power Quality Compensation Using LSTM–Genetic Algorithm," *Sustainability*, vol. 15, no. 14, doi: 10.3390/su151410913.