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Optimal sizing of battery energy storage systems and reliability analysis under diverse regulatory frameworks in microgrids

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ABSTRACT

The integration of battery energy storage systems (BESS) with microgrids (MG) is crucial to improve the reliability and flexibility of renewable energy sources (RES) integration. However, the reliability and regulatory policies are critical factors that affect the optimal operation of MGs in the market. This study aims to enhance the reliability of MGs integrated with RES and BESS by evaluating their performance under different regulatory frameworks, namely feed-in tariff (FiT), net metering (NM), and energy storage incentive (ESI). Also, a dynamic FiT (D-FiT) framework is utilized to improve the reliability of the MG. An artificial bee colony optimization algorithm is utilized to optimize the size of BESS for each regulatory policy to minimize the total cost of the MG. Each policy is formulated based on its specific constraints in the problem. Subsequently, the reliability indices of Loss of Load Expectation (LOLE) and Expected Energy not Supplied (EENS) are calculated for each optimized solution. Moreover, we have integrated the dynamic thermal rating (DTR) system into our proposed model, focusing on the safe augmentation of system component ratings. The study finds that the D-FiT and standard FiT frameworks provide the best reliability level, whereas the reliability improvement under the ESI policy is not significant, as most of the MG's demand is supplied by the main grid. Furthermore, the study shows that the improvements in EENS are higher than LOLE, indicating that installing BESS reduces the loss of energy rather than the number of interruption hours. D-FiT framework has a significant positive impact on both reliability indices, unlike the other frameworks that have a greater effect on EENS. Furthermore, we have noticed a substantial improvement in reliability indices when the DTR system is taken into account, as compared to the static thermal rating (STR) system.

1. Introduction

Over the past few years, there has been a significant surge in the integration of renewable energy sources (RES) into the power grid. This shift is a crucial component of efforts to reduce greenhouse gas emissions, enhance energy independence, and promote sustainability. However, the inherently unpredictable nature of wind and solar RES has introduced complexities into power grid management, raising concerns about power quality and system stability, as demonstrated in prior studies [1,2]. To address these challenges effectively, the integration of battery energy storage systems (BESS) with microgrids (MGs) has emerged as a sustainable solution. One notable advantage of BESSs lies in their capacity to charge during periods of low-cost electricity and discharge during peak hours when electricity prices are typically high [3]. Moreover, BESSs exhibit rapid responsiveness to shifts in energy demand and serve as a dependable backup power source during emergencies or power outages, as underscored by previous research [4,5]. This approach holds significant promise for bolstering the reliability of power supply, promoting climate change mitigation, and lead to more stable grid operation [6].

Determining the optimal size of BESS has been a primary concern in the design of MGs. Optimizing the size and type of BESS is essential for enhancing the reliability of MGs and minimizing their overall cost. Several research studies have explored the optimal sizing of BESS in MGs using various methods such as mixed integer linear and nonlinear programming [7], dynamic programming [8], and meta-heuristic approach

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[9]. These methods seek to balance the investment cost of BESS with the performance, power quality, and reliability of the MG. To address uncertainties surrounding the optimal BESS size, probabilistic optimization models have also been employed, as indicated in prior research [10, 11].

Reliability considerations are crucial for ensuring the stability and reliability of MGs integrated with BESS. An undersized BESS may lead to compromised system stability, while an oversized BESS would increase investment costs without providing additional benefits [12]. In Ref. [13], the effect of utilizing optimal ESS capacity on different reliability indices of a grid-connected MG is investigated. The reliability of an islanded MG considering the effect of BESS is analyzed in Ref. [14]. Moreover, regulatory frameworks play a significant role in determining the operation and revenue streams of MGs integrated with RES and BESS. Ignoring the impact of regulatory frameworks can lead to inaccurate and overly optimistic results. Hence, incorporating both reliability and regulatory frameworks in the BESS optimization process can lead to more accurate and effective results. Previous studies on determining the optimal BESS size for MGs did not consider the influence of regulatory frameworks on the reliability of MGs with integrated BESS. This study aims to fill this gap by modeling and considering the effect of common regulatory frameworks, such as net metering (NM), feed-in tariffs (FiT), and energy storage incentives (ESI), on the reliability and economic feasibility of MGs with integrated RES and BESS.

NM is one of the common regulatory policies in which customers receive credit on their electricity bill for extra electricity exported to the grid. This policy applies to customers with RES. They can import electricity from the main grid when their own generation is less than the demand [15]. To implement this policy, the customer's meter to run forward and backward is required. When a customer is drawing power from the grid, the meter spins forward, recording their energy consumption. Conversely, when the customer is producing more energy than they are consuming and sending it back to the grid, the meter spins backward, recording the excess energy production. In their utility bill, the customers should pay for the net consumption, which is the difference between the electricity they consume and the electricity they export. the aim of NM framework is to lower the payback period and increase the economic beneficial of RES [16,17]. A comprehensive review of the NM mechanism for RES can be found in Ref. [16]. FiTs are a policy instrument that offers financial incentives to customers which use RES to supply part of their demand. They receive these benefits for the energy they supply to the grid. The main aim of FiTs is to encourage MG owners to increase the use of RES by making RESs more financially viable [18]. Under the FiT scheme, MG owners are given a fixed payment for energy they generated using RESs for a set period of time. This fixed payment is typically higher than the electricity price providing a strong economic incentive for producers to invest and operate their facilities. This scheme is a highly effective policy because it significantly reduces the investment risks associated with RESs, making them more economically beneficial and allowing the grid to expand rapidly and sustainably [19,20]. More details regarding FiT background, examples of FiT implementation in Denmark, Germany, Cyprus and Spain, and different payment plans including are provided in Ref. [18]. It should be noted that, NM, as explained earlier, involves a billing mechanism where customers receive credits for excess electricity exported to the grid. This policy is designed to lower the payback period and enhance the economic benefits of RES. Conversely, FiTs provide financial incentives to MG owners who generate energy using RES, typically through fixed payments that exceed prevailing electricity prices. FiTs aim to reduce investment risks and promote sustainable growth in RES integration. Energy storage system incentives (ESIs) are provided by governments to encourage the uptake and utilization of energy storage technology. These incentives can come in the form of tax credits, grants, rebates, or other financial rewards. The main aim of ESIs is to reduce the initial cost of energy storage systems, making them more affordable for businesses and consumers [21]. The specific details of these incentives may vary depending on the country, state, or utility company offering them. Many countries have implemented policies to promote the growth and adoption of energy storage technology. More examples of ESI policies in different countries can be found in Ref. [22]. In Ref. [23] an incentive Strategy for forecast accuracy in a PV power plant in South Korea along with an ESS optimization model is presented. Authors in Ref. [24] proposed a energy storage management system to optimize of ESS capacity for residential use, integrated with PV generation. They economic analysis results confirm the importance of incentive householders' investment. In Ref. [25] five different policy schemes are investigated in a PV system integrated with BESS in Greek case. Briefly, the role of FiT and ESI frameworks in the operation of MGs is pivotal. FiTs act as a financial catalyst, encouraging MG owners to integrate RES by offering a fixed payment for energy generated through RES. This payment typically exceeds prevailing electricity prices, providing a strong economic incentive for investment in and operation of RES facilities. FiTs effectively reduce investment risks, enabling rapid and sustainable expansion of renewable energy integration into MGs, ultimately enhancing their reliability and sustainability. On the other hand, ESIs complement these efforts by incentivizing the adoption of energy storage technology. Governments offer ESIs in various forms, such as tax credits, grants, or rebates, aiming to lower the initial cost barriers associated with energy storage systems. By making energy storage technology more affordable for businesses and consumers, ESIs promote its widespread use. The distinction between these policy instruments lies in their focus: FiTs primarily target RES integration, whereas ESIs concentrate on facilitating energy storage technology adoption.

Another possible framework for trading between MGs and the main grid is dynamic FiT (D-FiT), where the basic trading is based on the standard FiT policy, but the tariff rate is not fixed and varies based on the grid condition. In Ref. [26], a D-FiT suitable for residential rooftop photovoltaic systems was proposed, which considers the time of day, ambient temperature, value of energy at the MG location, and available hosting capacity as parameters controlling the tariff rate. A time-varying tariff rate based on peak load, intermediate load, and off-peak load hours was applied in this study. Choosing the tariff rate based on the time of day is advantageous because the main benefit of battery energy storage systems (BESS) is to charge during off-peak hours and discharge during peak hours.

In this study, the optimal size of a BESS for minimum total cost of MG is determined using a Artificial Bee Colony (ABC) algorithm [27]. The optimization problem is modeled based on the constraints of different frameworks. ABC is a population-based meta-heuristic algorithm that is highly efficient in solving non-linear optimization problems [28,29]. The reason for selecting ABC is that it exhibits a more aggressive search behavior and keeps a diverse set of solutions, which mitigates the risk of premature convergence and it is robust to noise and can handle noisy or incomplete data effectively. Also, ABC is a relatively simple algorithm to implement since it requires a few parameters to be set.

This study addresses a critical gap in the existing literature by simultaneously examining two key facets of MGs: the optimization of BESS and the influence of regulatory frameworks on MG performance, particularly in terms of reliability metrics such as LOLE and EENS. While previous research has delved into BESS sizing and regulatory policies in isolation, our work uniquely combines these elements into a comprehensive analysis. We extend the existing body of knowledge by comprehensively assessing the impact of different regulatory frameworks, including the dynamic Feed-in Tariff (D-FiT), on MG reliability. By doing so, we offer a holistic perspective on how to design and operate reliable MGs with integrated renewable energy sources and BESS while considering varying regulatory structures. This integrated approach recognizes the real-world challenges and variations that regulatory frameworks introduce, contributing to more accurate and effective results in the planning and implementation of resilient microgrid systems.

Moreover, many previous studies discussed in this context primarily relied on the conventional static thermal rating (STR) system, which assumes fixed component ratings. However, for a more accurate analysis of system reliability, adopting the dynamic thermal rating (DTR) system is advantageous. The integration of renewable RES into the grid can be limited by the capacity of the network, impacting its overall reliability [30,31]. The DTR system has gained prominence for enhancing transmission system capacity by dynamically assessing thermal limits based on environmental conditions, with recent advancements in sensor technology supporting its implementation [32]. An optimization-based framework for generation unit commitment and network switching, utilizing the DTR system and network topology optimization, is presented in Ref. [33]. The results demonstrate the effectiveness of both DTR and topology optimization in improving reliability. Furthermore, [34], focuses on mitigating network uncertainties through the design of an active distribution system model that combines DTR with AC/DC elements. The case study highlights the potential of this hybrid system to increase transmission capacity and address node overvoltage concerns. In this study, we also explore the impact of the DTR system on the reliability of MGs.

The rest of the paper is organized as follows: Section 2 explains the approach of the study and presents the mathematical formulation of the optimization problem, which includes the main objective of optimization problem, BESS modeling and problem constraints, modeling of regulatory frameworks, and reliability assessment formulations. Furthermore, the section explains and formulates the ABC algorithm. In

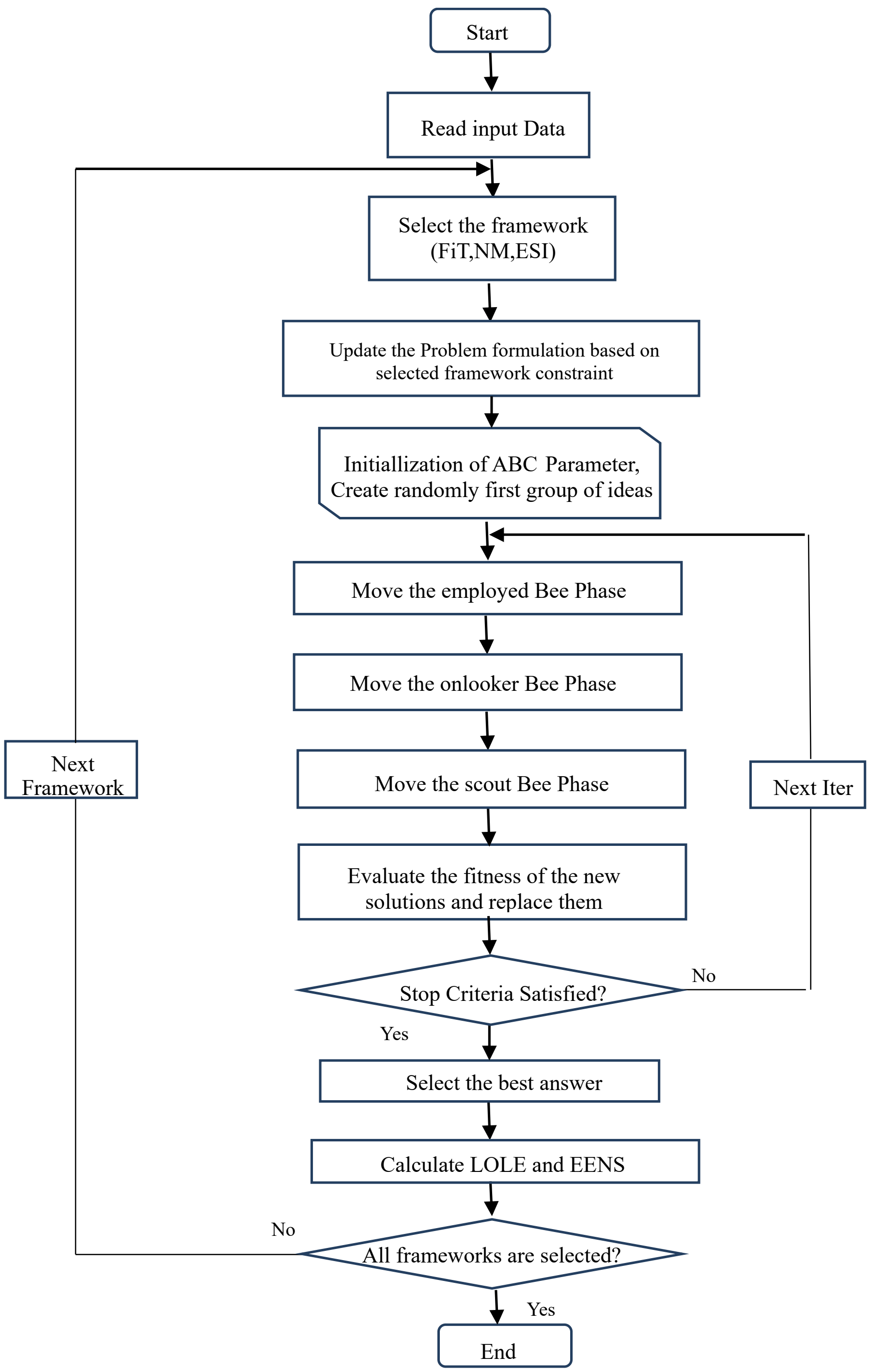

Fig. 1. Flowchart of the proposed approach.

Section 3, the case study details and the results of the effect of applying various regulatory frameworks on reliability indices are presented. Section 4 discusses the results obtained from the simulation, and Section 5 concludes the paper by summarizing the key findings and suggesting future research areas.

2. Proposed approach and mathematical model

In this section, we outline the approach and mathematical optimization formula employed in the study, and a flowchart depicting the method is provided in Fig. 1. As illustrated in the flowchart, the first step involves selecting a policy and updating the problem formulation based on the chosen framework. Subsequently, the optimal BESS size is determined to minimize the total cost, followed by the calculation of reliability indices for each case and policy. To accommodate different constraints, frameworks, and BESS configurations, they are formulated accordingly. The optimization problem is solved using the ABC algorithm, which is explained in detail in this section. Specifically, we elaborate on the objective function, the optimized BESS size, BESS and framework modeling, reliability assessment formulas, and the utilization of the ABC algorithm.

2.1. Reliability indices assessment

The BESS, renewable generations, and transmission system are modeled using a two-state reliability model. The availability and unavailability of the components are calculated based on their respective failure rate, λ_i, and repair rate, μ_i, formulated in Eq. (1) and Eq. (2) respectively.

$$A_i = \frac{\mu_i}{\lambda_i + \mu_i} \tag{1}$$

$$U_i = \frac{\lambda_i}{\lambda_i + \mu_i} \tag{2}$$

where A_i and U_i represents the availability and unavailability of element *i*. Also, the unavailability, A_{sys}, and availability, U_{sys}, of the whole system consists of n_c component are calculated based on Eq. (3) and Eq. (4) respectively.

$$U_{sys} = \prod_{i=1}^{nc} U_i \tag{3}$$

$$A_{sys} = 1 - U_{sys} \tag{4}$$

The reliability of the system is evaluated using two key indices, namely the loss of load expectation (LOLE) and expected energy not supplied (EENS) calculated using Eqs. (5)–(8) as follows:

$$LOLP(L_i) = \sum_{i=1}^{n_f} p_i \tag{5}$$

$$P_i = \prod_{j=1}^{nc} pc_j \tag{6}$$

where, n_f represents the number of system failure states in which the total generation capacity is insufficient to meet the load demand, while p_i denotes the probability of the i_{th} system state. The probability of component *j*, represented by pc_j, is calculated as the availability or unavailability of the component when its status is *ON* or *OFF*, respectively. *LOLE*, expressed in hours, is calculated as the sum of the loss of load probability for each load over the duration time (*T*).

EENS, expressed in kWh over a given time duration, is calculated using the amount of demand that was not supplied in each load, denoted by r_i.

$$LOLE = \sum_{i=1}^{T} LOLP(L_i) \tag{7}$$

$$EENS = \sum_{i=1}^{T} LOLP(L_i) \times r_i \tag{8}$$

2.2. Optimal size of BESS

The objective of the optimization problem is finding the optimal size of BESS and to minimize the total cost of the MG, as defined by Eq. (9).

$$\min TC = CR + C_{BESS} + C_{exchanged} + CRI - CRE \tag{9}$$

where, *TC* represents the total cost of the MG, which is a function of the costs associated with renewable energy *CR*, the battery energy storage system C_{BESS}, and the energy exchanged with the main grid $C_{exchanged}$. Additionally, *CRE* and *CRI* represent the revenue received from exporting energy to the grid and importing energy from the main grid, respectively. The formulation of C_{BESS} and $C_{exchanged}$ are presented in Eq. (10) [13] and Eq. (11) respectively.

$$C_{BESS} = PC_{BESS} \times P\_rated_{BESS} + EC_{BESS} \times E\_rated_{BESS} \tag{10}$$

$$C_{exchanged} = \sum_{t=1}^{NT} \rho_{i,t} \times EP_t \tag{11}$$

In Eq. (10), the power and energy costs of the BESS are denoted by PC_{BESS} and EC_{BESS}, respectively. Additionally, P_rated_{BESS} and E_rated_{BESS} represent the rated power and energy of the BESS. In Eq. (11), EP_t represents the power exchanged with the main grid at time t, and $\rho_{i,t}$ is the price of per KWh energy exchanged with the main grid at time *t* of the day. We denote the energy exported and imported in time period t as $E_{\exp ort,t}$ and $E_{import,t}$, respectively.

The revenues from exchanged power with the main grid, *CRE* and *CRI*, in time period t are calculated using Eq. (12) and Eq. (13), respectively, where $R_{\exp ort}$ and R_{import} represent the export and import tariff rates.

$$CRE = \sum_{t=1}^{NT} E_{\exp ort,t} \times R_{\exp ort} \tag{12}$$

$$CRI = \sum_{t=1}^{NT} E_{import,t} \times R_{import} \tag{13}$$

The BESS is modeled based on its constraints. The energy stored in the BESS at time t is calculated using Eq. (14), where the charging and discharging power of the BESS are represented by P^c_{BESS} and P^d_{BESS}, respectively.

$$E_{BESS,T} = E_{BESS,T-1} + \left(P^c_{BESS} \times \eta_c - \frac{P^d_{BESS}}{\eta_d}\right) \times \Delta t \swarrow\!\!\nearrow \forall t \in NT \tag{14}$$

where, the efficiency of charging and discharging of the BESS is denoted by η_c and η_d, respectively. The maximum and minimum rated values of the BESS are presented in Eq. (15) and Eq. (16) as constraints, respectively.

$$-P^R_{BESS} \le P_{BESS,t} \le P^R_{BESS} \swarrow\!\!\nearrow \forall t \in NT \tag{15}$$

$$0 \le E_{BESS,t} \le E^R_{BESS} \swarrow\!\!\nearrow \forall t \in NT \tag{16}$$

Finally, Eq. (17) expresses the constraint on the power exchanged between the main grid and the MG, which is limited by the maximum capacity of the transmission lines that connect them ($P^{\max}_{exchanged}$).

$$0 \le P_t \le P^{\max}_{exchanged} \swarrow\!\!\nearrow \forall t \in NT \tag{17}$$

$$P^{Max}_{exchanged} = \begin{cases} pl^{DTR}_{Max} \\ pl^{STR}_{Max} \end{cases} \tag{18}$$

where, the maximum possible exchanged power is represented by $P^{\max}_{t}$. Moreover, the optimal DC load flow formula (Eq. (18)) considers the maximum transmission capacity, which is defined by either the rating established by the DTR system or the STR system.

2.3. Modeling of regulatory frameworks

The regulatory frameworks are modeled using their associated constraints applied to the problem. For the NM policy, the revenue from exporting is calculated based on the net energy exported to the grid (Eq. (19)). Similarly, the revenue from importing is determined based on the net energy imported from the grid (Eq. (20)). The net energy exported or imported is calculated as the difference between the total energy exported to the grid and the total energy imported from the grid (Eq. (21) and (22)).

The constraints of regulatory frameworks are incorporated into the problem formulation. For the NM policy, the revenue from exporting and importing energy are determined by Eq. (19) and Eq. (20) respectively. The net energy exported, $N\_E_{\exp ort,t}$, or imported, $N\_E_{import,t}$, are the difference between the total energy exported to the grid, and the total energy imported from the grid, which are given by Eq. (21) and Eq. (22) respectively.

$$CRE_{Net-metering} = \sum_{t=1}^{NT} N\_E_{\exp ort,t} \times R_{\exp ort} \tag{19}$$

$$CRI_{Net-metering} = \sum_{t=1}^{NT} N\_E_{import,t} \times R_{import} \tag{20}$$

$$N\_E_{import} = \sum_{t=1}^{NT} E_{import,t} - E_{\exp ort,t} \tag{21}$$

$$N\_E_{\exp ort,t} = \sum_{t=1}^{NT} E_{\exp ort,t} - E_{import,t} \tag{22}$$

In the case of the FiT framework, the main grid purchases the electricity generated by the MG at a predetermined fixed rate, which is usually higher than the retail rate of electricity. The revenue from exporting energy under the FiT framework is calculated by updating the parameter $\boldsymbol{FiT_{rate}}$ in Eq. (23) as the fixed rate.

$$CRE_{FiT} = \sum_{t=1}^{NT} E_{\exp ort,t} \times R_{\exp ort} \times FiT_{rate} \tag{23}$$

In D-FiT framework, the revenue from exporting energy is calculated by the same formula; however, the tariff rate is vary based on the hours of a day (Eq. (24)).

$$FiT_{rate} = \begin{Bmatrix} FiT\_Peak_{rate} \swarrow \nearrow \forall t \in Peak\_hours \\ FiT\_\text{intermediate}_{rate} \swarrow \nearrow \forall t \in \text{intermediate}\_hours \\ FiT\_off\_peak_{rate} \swarrow \nearrow \forall t \in \text{int}off\_peak\_hours \end{Bmatrix} \tag{24}$$

In the case of an ESI based policy, the constraints may be similar to those of other frameworks, as the main difference lies in the revenue calculation. The incentive rate can be considered as either a discount in the unit price of imported electricity from the main grid, as shown in Eq. (25), or as a fixed amount per unit of BESS capacity installed, as shown in Eq. (26).

$$CRI_{Net-metering} = \sum_{t=1}^{NT} N\_E_{import,t} \times R_{import} \times ESI_{discount-rate} \tag{25}$$

$$C_{BESS-ESI} = PC_{BESS} \times P\_rated_{BESS} \times ESI_{Fixed\_rate} + EC_{BESS} \times E\_rated_{BESS} \tag{26}$$

where, The variable $\boldsymbol{ESI_{discount-rate}}$ represents the discount applied to the unit price of electricity imported from the main grid under the ESI framework, while $\boldsymbol{ESI_{Fixed\_rate}}$ represents the fixed amount of BESS capacity installed as part of the revenue calculation under the same framework.

2.4. Artificial bee colony algorithm

The ABC algorithm is a swarm-based optimization algorithm inspired by the foraging behavior of honey bees. The algorithm consists of three types of bees: employed bees, onlooker bees, and scout bees. Employed bees explore the search space by exploiting the best food sources they have found, while onlooker bees choose the best food sources to exploit based on the information shared by the employed bees. Scout bees are responsible for exploring new food sources by randomly searching the search space [28]. The ABC algorithm iteratively improves the population of solutions by generating new solutions based on the employed and onlooker bees, and by replacing inferior solutions with new solutions generated by the scout bees. The algorithm maintains a set of candidate solutions, called food sources, and assigns a fitness value to each solution based on its quality. The fitness value is determined by the objective function that needs to be optimized. The process of finding the best solution by ABC can be described by the following steps:

- Set the input parameters (including population size NP, the number of iterations Iter_max, and the limit L to abandon a food source).
- Randomly generate an initial population of solutions (food sources).
- Move the employed Bee Phase:
  - For each employed bee x_i, generate a new solution v_i by exploiting the position of a randomly selected employed bee x_j using Eq. (27).

$$v_i = x_i + rand \times (x_i - x_j) \tag{27}$$

  - Evaluate the fitness of the new solution.
  - If the fitness of v_i is better than the fitness of the current solution x_i, replace x_i with v_i.

- Move the onlooker Bee Phase [27]:

  - Calculate the probabilities of the food sources based on their fitness values using Eq. (28) and (29).

$$fit_i = \begin{Bmatrix} \dfrac{1}{1+f_i} \swarrow \nearrow \forall f_i > 0 \\ 1 + abs(f_i) \swarrow \nearrow \forall f_i < 0 \end{Bmatrix} \tag{28}$$

$$p_i = \frac{fit_i}{\sum_{j=1}^{N} fit_j} \tag{29}$$

where f_i represents the objection function related to the food source, and fit_i is the fitness value.

  - Generate a new solution v_i by exploiting the position of the selected food source j
  - Evaluate the fitness of the new solution v_i.
  - If the fitness of v_i is better than the fitness of the current solution x_i, replace x_i with v_i.

- Move the scout Bee Phase:

- For each food source i that has been abandoned L times, generate a new solution v_i by randomly searching the search space.
- Evaluate the fitness of the new solution v_i
- Replace the food source i with v_i if the fitness of v_i is better than the fitness of i

- Termination:

If the termination criterion is met (e.g., the maximum number of iterations is reached), return the best solution found so far, otherwise, go to the Employed Bee Phase.

In the utilization of the ABC algorithm for optimizing the BESS size while taking into account the regulatory frameworks, the process unfolds as follows: After inputting the relevant data and selecting each policy (e.g., NM, FiT, or ESI), the ABC algorithm is set in motion. In this context, each conceivable solution to the problem, encompassing the rated power of the BESS, assumes the role of an 'artificial bee' within the ABC algorithm. Over a series of iterations, as outlined earlier, the ABC algorithm actively seeks the optimal BESS size that minimizes the total cost of the MG. Subsequently, the best solution discovered during this optimization process is used to calculate reliability indices, specifically tailored to the selected regulatory framework. This approach allows us to determine the reliability performance of the MG under each policy.

3. Case study and results

The selected MG [35], consists of photovoltaic (PV) and wind turbine (WT). We reasonably excluded the diesel generator and micro turbine installed in the case study since the aim of the study is to investigate the effect of utilizing BESS on reliability under different frameworks. Fig. 2 shows the load demand profile, as well as the power outputs of PV, WT, and imported power from the grid over 24 h, in the absence of BESS.

Table 1 presents a comprehensive overview of the input data employed in our study. This includes electricity pricing data for power generated by the PV and WT systems, as well as electricity prices for grid imports, delineated across various time periods throughout the day. Technical specifications for the BESS are also detailed in this table. Additionally, the parameters utilized in the ABC algorithm are specified. The colony size is set at 50, with optimization conducted over 1000 iterations. The input parameters, denoted as L (limit of abandoning a food source) and r (exploration rate), are assigned values of 25 and 0.1, respectively. Moreover, Table 2 furnishes data concerning failure rates and repair rates associated with renewable energy sources, BESS, and the primary grid. These rates play a critical role in the calculation of component availability and unavailability within the study.

In the context of the DTR system's reliability, it's important to note that this system includes both sensors and communication-related equipment. Within our model, we consider the communication devices to be completely dependable. However, we treat the sensors as a unified entity and employ a two-state reliability model for them. Specifically, we assume that these sensors experience a failure rate of 3/year and a repair rate of 364/year. Table 3 offers a comprehensive analysis of how different regulatory frameworks influence key aspects of the MG performance. It presents data on the total cost of the MG, energy supplied by BESS, and energy imports and exports from the main grid. The regulatory frameworks under comparison encompass NM, FiT with fixed rates set at 1.25 and 1.75, (D-FiT featuring varying tariff rates (1.75 for intermediate, 2 for peak, and 1.5 for off-peak hours), and ESI with intensive rates of 20 % and 10 %.

The MG without BESS has a total cost of $ 683.90 with 1866 and 125 KWh imported and exported energy respectively. In this study, we initially assumed a rated power of 200 kW for the BESS, denoted as P^R_{BESS}. The results of Table 3 show that the D-FiT regulatory framework has the lowest total cost of $ 387.08 with an optimal BESS size of 150 kW and BESS energy of 2250 kWh. The second lowest total cost is achieved by applying FiT framework with fixed rate of 1.75. Under NM, the total cost is reduced to 602.90 USD, with 1350 kWh of BESS energy. The ESI regulatory framework can be more effective in reducing the total cost of the MG compared to the NM framework. For ESI with an intensive rate of 20 %, the total cost decreases to 555.37 USD, with a smaller BESS size of 135 kW, with 405 kWh of BESS energy, which is the minimum energy supplied by BESS among all frameworks.

The analysis revealed that the optimal BESS size varies significantly across different regulatory frameworks. As illustrated in the results, this optimal size can differ considerably, demonstrating the dynamic nature

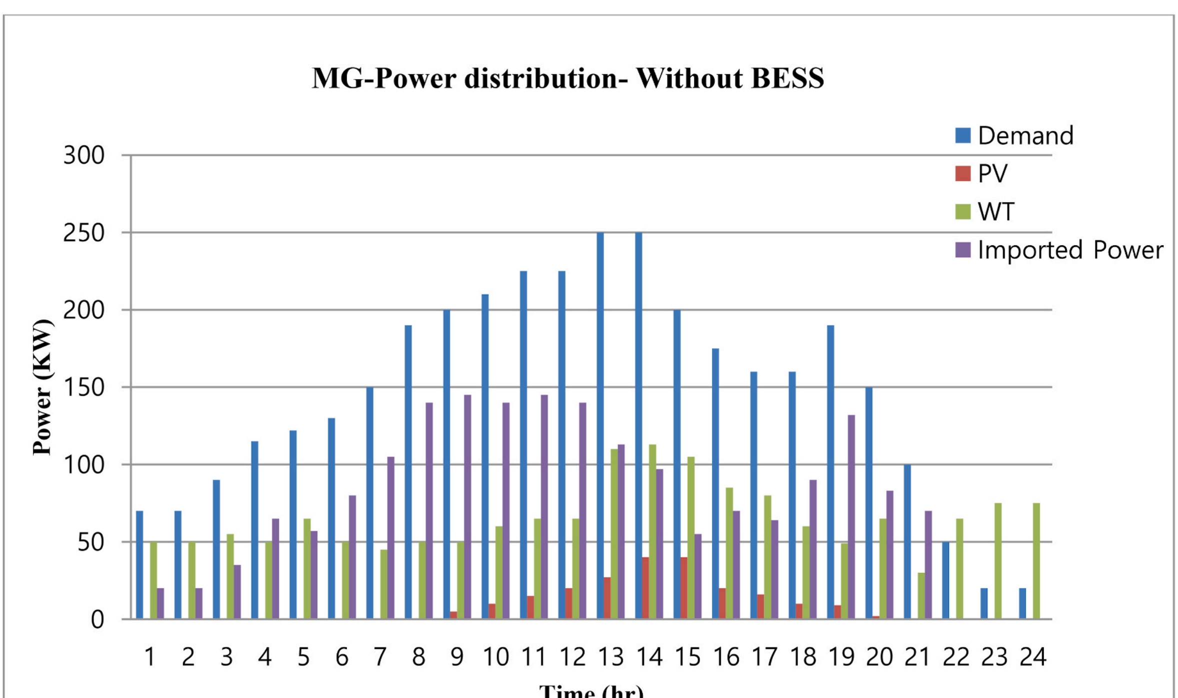

Fig. 2. Load demand, WT,PV, and imported energy from grid without BESS for a MG in 24 h [29].

Table 1
Input Data: Electricity prices and BESS technical data [35,36].

RES – Main grid					
Parameter	cost of energy-**PV** ($/kWh)	cost of energy-**WT** ($/kWh)	cost of exchanged energy-peak demand ($/kWh)	cost of exchanged energy-intermediate demand ($/kWh)	cost of exchanged energy-off-peak demand ($/kWh)
	0.048	0.033	0.43	0.3	0.12
BESS					
Parameter	**Technology**	**Max. Power rate**	**power cost ($/KW)**	**Cost of electricity ($/KWh)**	**Efficiency (%)**
	Lead-acid	150	300	0.37	80–90

Table 2
Failure rate and repair rate for system components [37].

System Component	Main grid	PV	WT	BESS
Failure Rate (Failure/year)	0.25	0.5	0.769	0.172
Repair Time (h)	48	40	279	7.8

Table 3
Total cost of MG for different regulatory frameworks - BESS, imported and exported energy.

Regulatory Framework	Total Cost (USD)	Optimal BESS (kW)	BESS Energy (kWh)	Imported Energy (KWh)	Exported Energy (KWh)
MG – Without BESS	683.90	0	0	1866	125
Net Metering	602.90	150	1350	821	430
Feed in Tariff (Fixed rate = 1.25)	585.22	135	1215	856	330
Feed in Tariff (Fixed rate = 1.75)	421.37	150	2100	624	983
Energy Storage Intensive (Intensive rate = 10 %)	594.4	130	1170	881	310
Energy Storage Intensive (Intensive rate = 20 %)	555.37	135	405	1644	308
Dynamic-FiT	**387.08**	**150**	**2250**	**544**	**1053**

of BESS requirements under varying conditions. Notably, the D-FiT framework consistently resulted in the selection of the highest capacity BESS among all regulatory structures. Also, the lowest and highest energy imported from and exported to the grid is achieved in D-FiT policy. In addition, the highest imported energy is in case of ESI with an intensive rate of 20 %.

Figs. 3–8 provide an insightful visual representation of the power distribution within the MG, encompassing various elements such as the load profile, renewable energy outputs, energy imports from the grid, energy exports to the grid, and the operation of the BESS. As depicted in Fig. 2, in the absence of BESS, the MG primarily relies on grid-imported energy to meet its demand during off-peak hours. Fig. 3 delves into the power distribution within the NM framework, where the BESS comes into play during peak hours to support the MG's operation. Figs. 4 and 5 provide a detailed overview of the power distribution under the FiT framework, with fixed rates of 1.25 and 1.75, respectively. These figures shed light on how these FiT policies influence the MG's power dynamics. Moving forward, Figs. 6 and 7 present the power distribution within the ESI framework, with intensive rates of 10 % and 20 %, respectively. Notably, both scenarios within the ESI framework highlight increased energy imports from the grid, distinguishing them from other frameworks. Finally, Fig. 8 showcases the results associated with the D-FiT framework. These figures underscore the significant impact of both D-FiT and the standard FiT framework, particularly the one with a fixed rate of 1.75, on the utilization of BESS and the export of surplus energy to the grid. These visual representations offer valuable insights into how various regulatory policies shape the energy flow and utilization within the MG.

Furthermore, the results of the economic analysis by comparison between the total costs, cost of BESS, cost of imported energy from the grid, and exported energy to the grid under different regulatory frameworks is shown by a bar chart in Fig. 8. It can be observed that the use of the all policies results in a significant reduction in the total cost of the MG, while the D-FiT policy results in the lowest total cost, where the highest cost of investment for BESS is needed. The ESI policies result in a relatively small amount of BESS investment and earning from exporting

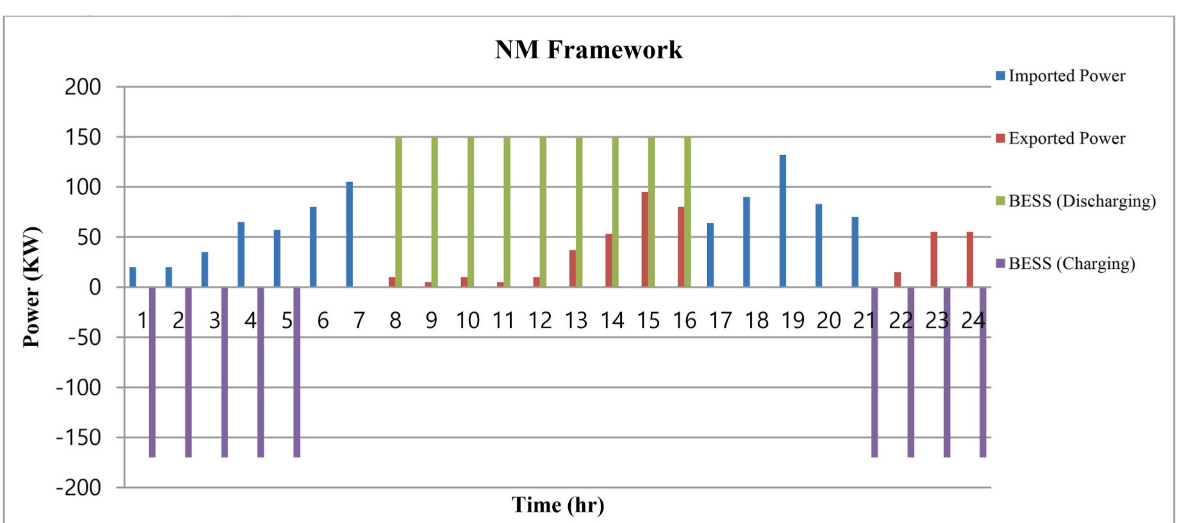

Fig. 3. Power distribution – NM Framework.

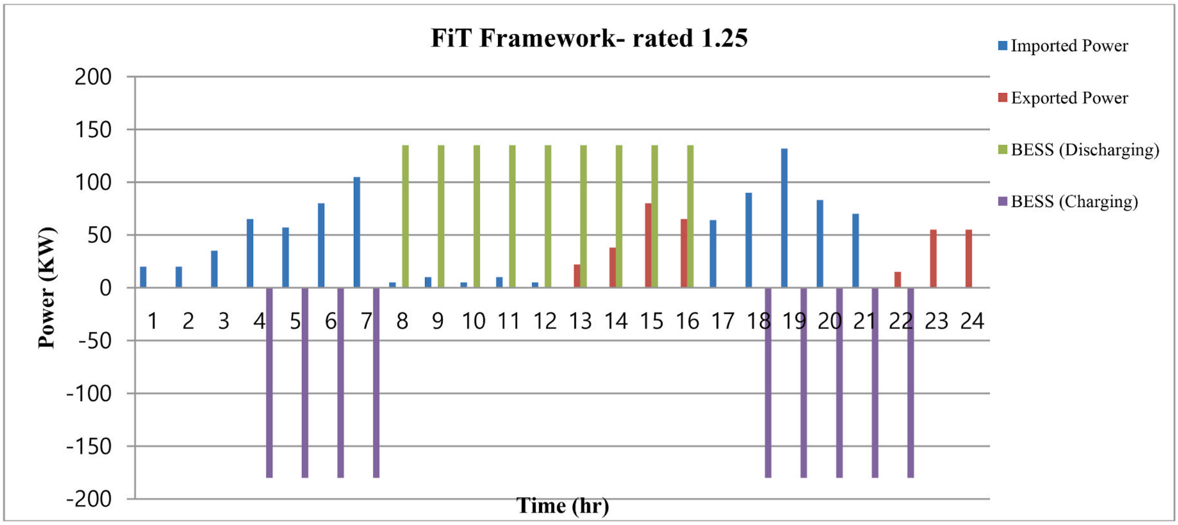

Fig. 4. Power distribution – FiT Framework – FiT rate: 1.25.

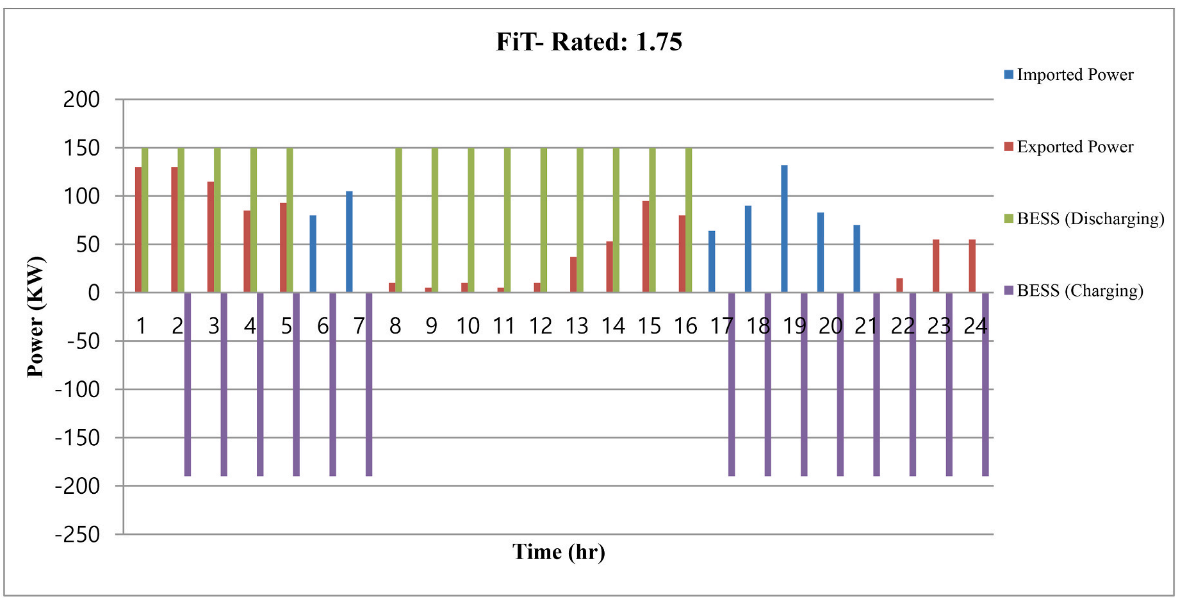

Fig. 5. Power distribution – FiT Framework – FiT rate: 1.75.

energy to the grid, while leading to the highest cost of energy imported from the grid.

Table 4 provides valuable insights into the reliability indices of the MG operating under diverse regulatory frameworks, showcasing key metrics such as LOLE and EENS. Overall, the integration of BESS into the MG demonstrates a positive impact on the reliability indices. Among the various regulatory frameworks, the ESI policy, characterized by a higher discount rate, exhibits the least improvement in terms of reliability indices. Conversely, the D-FiT policy stands out as the framework with the most significant enhancements, boasting a remarkable 27.76 % reduction in LOLE and a substantial 45.03 % reduction in EENS. Additionally, when compared to the MG without BESS, the NM policy demonstrates a modest but notable improvement in both LOLE (3.8 %) and EENS (23.74 %). Notably, the ESI policy, characterized by its higher discount rate, presents the least significant improvements in terms of reliability indices.

Moreover, the effect of BESS failure rate on the LOLE and EENS of the MG under different regulatory frameworks are given in Table 5. The failure rates of BESS are improved by 1,5, and 10% respectively for a sensitivity analyzes of reliability indices in BESS availability.

The results of Table 5 show that failure rate of BESS has a remarkable effect on reliability indices of MG. Obviously, indices are enhanced considering lower failure rates of BESS in all cases, however, the improvement is more significant in case of applying D-FiT and standatd FiT (with fixed rate 1.75)policy. LOLE and EENS can be decreased to 0.4095 and 18.59, by 10% lower failure rate of BESS in D-FiT framework, respectively. Also, the results reveal that reliability enhancement is more significant in case of NM framework compared to ESI policy.

Furthermore, Table 6 demonstrates the impact of incorporating the DTR system on reliability indices across various regulatory frameworks. The most substantial effect of utilizing the DTR system is observed in the MG-Without BESS case, with a significant improvement in both LOLE (27.2 %) and EENS (31.4 %). Among the regulatory frameworks, the ESI framework with a discount rate of 20 % exhibits the most pronounced enhancement in reliability, recording a 14.83 % reduction in LOLE and a 15.26 % decrease in EENS. In contrast, the D-FTI framework shows the least impact, with a 9.74 % reduction in LOLE and a 10.05 % decrease in EENS.

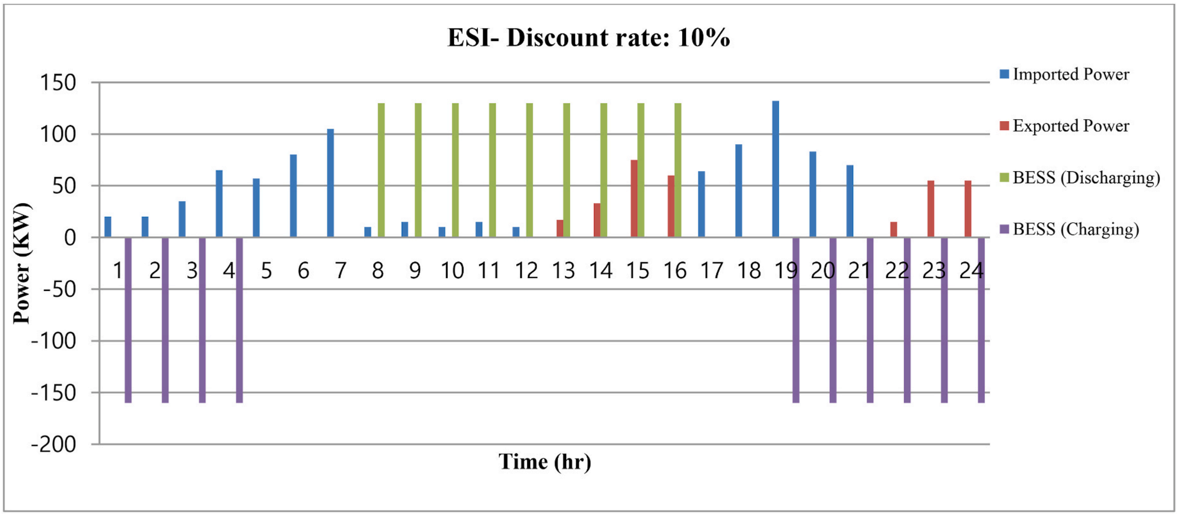

Fig. 6. Power distribution – ESI Framework – ESI Discount rate: 10 %.

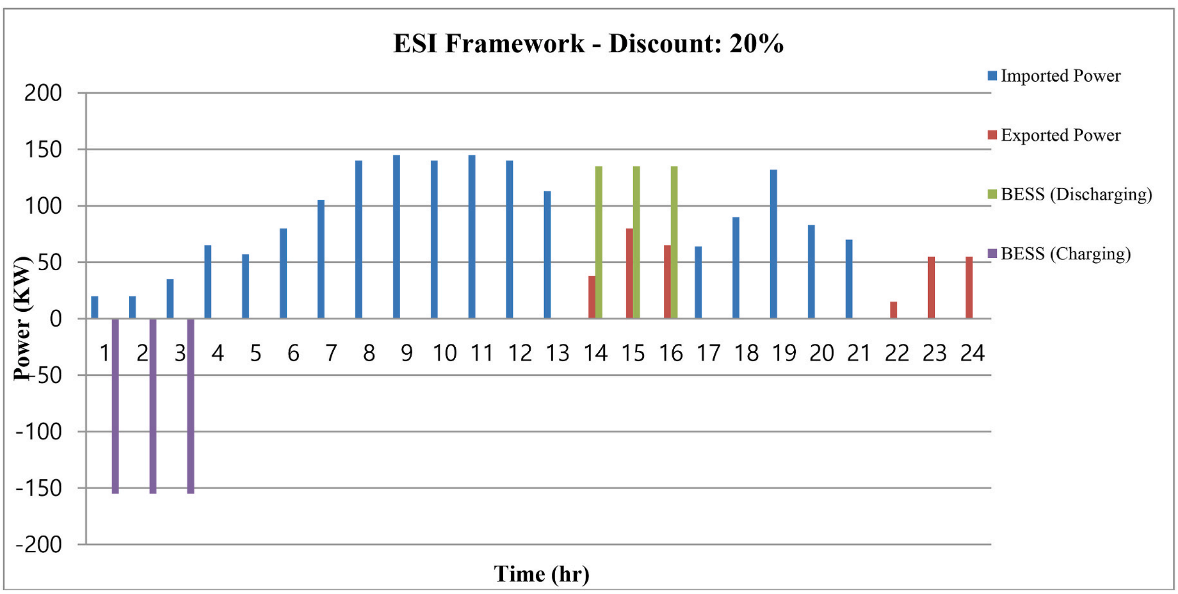

Fig. 7. Power distribution – ESI Framework – ESI Discount rate: 20 %.

4. Discussion

In this section, we explore the impact of various regulatory frameworks on the reliability indices of a MG. This study focuses on evaluating the effectiveness of different frameworks, such as NM, FiT, ESI, nd D-FiT, in enhancing MG reliability while integrating BESS. We also explore the nuanced effects of BESS failure rates on reliability. This discussion sheds light on the crucial factors influencing MG performance and offers insights into the choice of regulatory frameworks for optimal reliability outcomes. Also, ABC algorithm is utilized to find the optimal size of BESS in this study. Various aspects of analyzing the achieved results are discussed as follows:

- Overall, the calculated reliability indices demonstrate that the reliability of the MG falls below acceptable levels. This emphasizes the need for enhancements in MG reliability, especially given the growing emphasis on reliability in addition to cost-efficiency. While our study intentionally excluded the use of a diesel generator or microturbine, which are commonly employed for backup power generation, the achieved values for LOLE and EENS indicate that even with renewable energies and BESS, the MG's reliability remains a challenge. In light of these results, it is worth considering the inclusion of a diesel generator or microturbine to bolster MG reliability.
- Generally, regulatory frameworks have significant impact on reliability of a MG. The most improvements in reliability of a MG (up to 27.76 % and 45.03 % for LOLE and EENS respectively) can be achieved by applying the D-FiT framework. Also, with decreasing the failure rates of BESS by 10 %, or installing the BESS types with lower failure rate, the LOLE and EENS can be decreased up to 40.95 % and 50.42 % respectively. The reason is that the BESS is used to supply the demand in more hours of a day compared to other frameworks.
- A comparison between NM and ESI frameworks shows that NM is more effective framework than ESI policy. Although the total cost of MG is lower in ESI, but the NM has a better impact on reliability indices. Utilizing NM framework leads to improve LOLE and EENS by 3.8 % and 23.74 %, while, the reliability enhancement is not remarkable in case of ESI framework (up to 1.33 % and 15.62 % for LOLE and EENS respectively). The reason is that due to intensive rated in ESI, MG owners will tend to import energy from the main

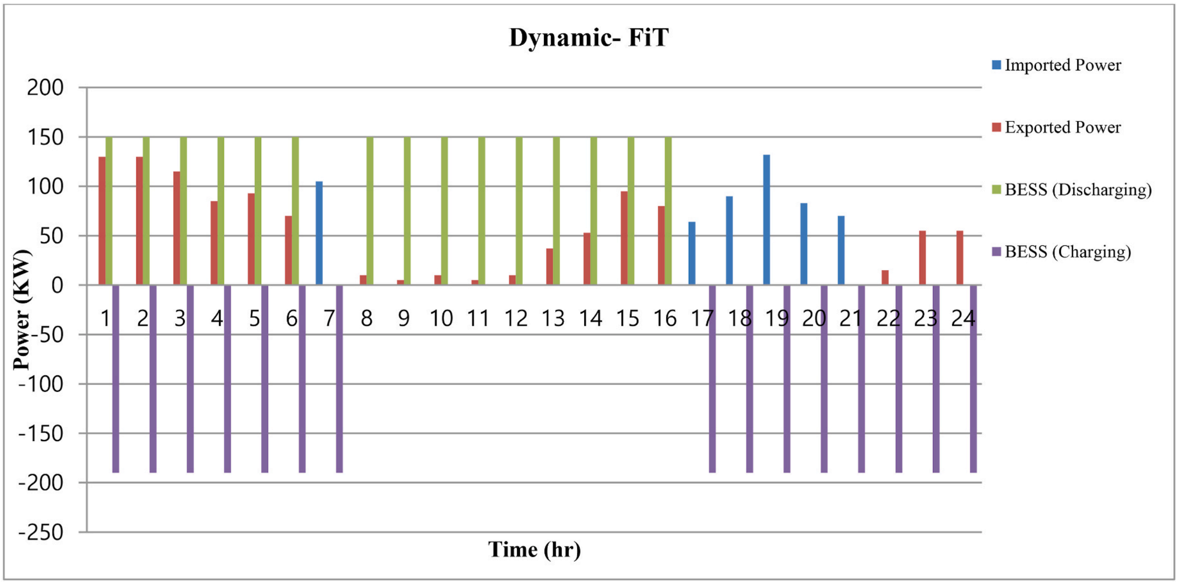

Fig. 8. Power distribution – Dynamic FiT Framework.

Table 4
Reliability indices of MG under different frameworks.

Regulatory Framework	LOLE	Changes %	EENS	Changes %
MG – Without BESS	0.6284	…	37.5135	…
Net Metering	0.6045	3.80	28.6045	23.74
Feed in Tariff (rated = 1.25)	0.6200	1.33	31.1196	17.04
Feed in Tariff (rated = 1.75)	0.4790	23.7747	21.9114	41.5906
Energy Storage Intensive (Discount = 10 %)	0.6200	1.33	31.6502	15.62
Energy Storage Intensive (Discount = 20 %)	0.6204	1.27	32.6517	12.96
Dynamic Feed in Tariff	**0.4539**	**27.7689**	**20.6190**	**45.0358**

Table 5
Effect of BESS failure rate improvement on reliability indices of MG under different frameworks.

Regulatory Framework	BESS Failure Rate Improvement	LOLE	Changes %	EENS	Changes %
Net Metering	No Improvement	0.6045	3.80	28.6045	23.7488
	1 %	0.5986	4.9783	28.3248	24.4944
	5 %	0.5749	8.9375	27.2048	27.4800
	10 %	0.5453	13.8824	25.8020	31.2194
Feed in Tariff (rated = 1.75)	No Improvement	0.4790	23.7747	21.9114	41.5906
	1 %	0.4743	24.5226	21.6971	42.1619
	5 %	0.4556	27.4984	20.8390	44.4493
	10 %	0.4321	31.2381	19.76	47.3256
Energy Storage Intensive (Discount = 20 %)	No Improvement	0.6204	1.27	32.6517	12.96
	1 %	0.6144	2.2786	32.3322	16.0252
	5 %	0.5901	6.2337	31.0532	19.9810
	10 %	0.5598	11.1654	29.4512	24.9358
Dynamic Feed in Tariff	No Improvement	0.4539	27.7689	20.6190	45.0358
	1 %	0.4495	28.4691	20.4174	45.5732
	5 %	0.4317	31.3017	19.6099	47.7258
	10 %	**0.4095**	**34.8345**	**18.5984**	**50.4221**

Table 6
Reliability indices for different frameworks considering the effect of DTR system.

Regulatory Framework	LOLE	Changes %	EENS	Changes %
MG – Without BESS	0.6284	27.2	37.5135	31.4
Net Metering	0.6045	11.94	28.6045	12.06
Feed in Tariff (rated = 1.75)	0.4790	13.78	21.9114	14.42
Energy Storage Intensive (Discount = 20 %)	0.6204	14.83	32.6517	15.26
Dynamic Feed in Tariff	0.4539	9.74	20.6190	10.05

grid rather than invest on utilizing BESS, while the main goal of these frameworks is to encourage MG owners to use BESS.

- Both LOLE and EENS are important factors for customers in a MG, especially for residential MGs. LOLE represent the hours of interruptions and EENS indicates the amount of energy not supplied. The results of this study reveal that the frameworks improve the EENS more than LOLE. The D-FiT and standard FiT frameworks have supreme over the other two frameworks from this point of view that enhance both indices. Also, proposing a framework which is able to decrease the interruption hours along with decreasing the amount of lost energy and total cost is necessary.
- In this study, we calculated the optimized values for the BESS rating, including its kWh rating, for each of the different regulatory frameworks, as presented in the Results section. Specifically, the optimal BESS size and energy capacity for the D-FiT, FiT, NM, and ESI regulatory frameworks were determined. As mentioned in the Results section, the optimal BESS size and energy capacity vary based on the specific framework, ranging from 135 kW with 405 kWh for ESI to 150 kW with 2250 kWh for D-FiT.
- The DTR system has been utilized into the analysis of MG reliability under various regulatory frameworks. The results displayed in Table VI illustrate the significant improvements in reliability indices achieved through the integration of the DTR system. Notably, the most substantial impact is observed in the MG-Without BESS scenario, with a remarkable 27.2 % reduction in LOLE and a 31.4 % decrease in EENS. This outcome underscores the critical role of the DTR system in enhancing the reliability of MGs that lack BESS. Furthermore, a discernible pattern emerges when we consider the relationship between the percentage of improvement induced by the

DTR system and the amount of imported energy in different regulatory frameworks. Specifically, in cases where a substantial amount of energy is imported from the main grid, such as in the MG-Without BESS scenario, the DTR system exhibits its most pronounced effects. Conversely, the D-FTI framework, characterized by the least imported energy from the main grid, demonstrates the smallest improvements. This correlation highlights the significance of the DTR system in bolstering the reliability of MGs, particularly those heavily reliant on energy imports from the grid.

- While our study primarily focuses on MG reliability and the impact of regulatory frameworks, it is essential to acknowledge the growing importance of addressing stability issues, especially as MGs integrate a higher share of RES and power electronics. Several studies, such as [38–40], have delved into the challenges posed by harmonic and voltage problems in MGs. These issues can be mitigated through innovative deployment of power converters and inverters. For future research, it is advisable to extend our analysis to consider the impact of these stability concerns and propose strategies for addressing them within the context of MG operation.
- As the limitation of this study, it should be notice that the results can be vary for a MGs in different geographic region, load profile pattern, and cost variables. The achieved total cost of MG is highly depended on the electricity prices in hours of a day and type and price of utilized BESS. Also, more accurate failure and repair rates of all components lead to more accurate evaluation of reliability of MG. Another limitation of our study against scenarios of investigating the effect of high RES penetration on stability and harmonic problems is lack of involving intricate power electronics configurations and innovative power-sharing strategies.

5. Conclusion

This study conducted a comprehensive evaluation of the influence of standard regulatory frameworks, including FiT, NM, and ESI, as well as the proposed D-FiT framework, on the reliability of MG integrated with BESS. The research process involved determining the optimal BESS size to minimize the total cost, followed by the calculation of reliability indices for each regulatory framework. To accommodate diverse constraints, the formulations for the frameworks and BESS were tailored accordingly. The optimization task was tackled using an ABC optimization algorithm, and various aspects such as the objective function, BESS and framework modeling, reliability assessment formula, and the specifics of the ABC algorithm were elaborated. The findings of this study highlight the superiority of the D-FiT framework in terms of achieving the highest reliability levels, boasting a remarkable 27.76 % improvement in LOLE and a substantial 45.03 % reduction in EENS. In contrast, the NM policy demonstrates its effectiveness when compared to the ESI framework, as the latter showed limited improvements in reliability indices (up to 1.33 % for LOLE and 15.62 % for EENS). The results underscore the significance of considering reliability alongside cost optimization, as many studies predominantly concentrate on minimizing the total cost of the MG. Furthermore, the study underscores the critical role of BESS in reducing energy loss, with a particular emphasis on the higher improvements observed in EENS compared to LOLE. This research contributes valuable insights into enhancing the reliability of MGs integrated with BESS under varying regulatory structures. The findings of this study highlight the superiority of the D-FiT framework in terms of achieving the highest reliability levels, boasting a remarkable 27.76 % improvement in Loss of Load Expectation (LOLE) and a substantial 45.03 % reduction in Expected Energy Not Supplied (EENS). In contrast, the Net Metering (NM) policy demonstrates its effectiveness when compared to the Energy Storage Intensive (ESI) framework, as the latter showed limited improvements in reliability indices (up to 1.33 % for LOLE and 15.62 % for EENS). The results underscore the significance of considering reliability alongside cost optimization, as many studies predominantly concentrate on minimizing the total cost of the MG. Furthermore, the results reveal the critical role of BESS in reducing energy loss, with a particular emphasis on the higher improvements observed in EENS compared to LOLE. Also, this study has contributed to the understanding of MG reliability by incorporating the DTR system into the analysis, demonstrating its significant impact on enhancing reliability indices. In addition, the study underscores the need for the development of innovative regulatory frameworks that prioritize the reduction of interruption hours while simultaneously minimizing energy losses and total costs. Moreover, our findings underscore the remarkable impact of the DTR system, particularly in MGs scenarios characterized by high levels of energy importation from the main grid.

Credit author statement

Mohammadreza Gholami: Methodology, First draft preparation, Data collection, Revised manuscript- Response to reviewers comments, Conceptualization, **S.M Muyeen**: Supervision: Conceptualization, Data collection, Revised manuscript- Response to reviewers comments; **Soad Abokhamis Mousavi**: First draft preparation: Conceptualization, Revised manuscript- Response to reviewers comments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

[1] M. Shafiul Alam, F.S. Al-Ismail, A. Salem, M.A. Abido, High-level penetration of renewable energy sources into grid utility: challenges and solutions, IEEE Access 8 (2020) 190277–190299, https://doi.org/10.1109/ACCESS.2020.3031481.
[2] S. Impram, S. Varbak Nese, B. Oral, Challenges of renewable energy penetration on power system flexibility: a survey, Energy Strategy Rev. 31 (August) (2020), 100539, https://doi.org/10.1016/j.esr.2020.100539.
[3] E. Telaretti, L. Dusonchet, Battery storage systems for peak load shaving applications: Part 2: economic feasibility and sensitivity analysis, in: EEEIC 2016 - Int. Conf. Environ. Electr. Eng, 2016, https://doi.org/10.1109/EEEIC.2016.7555795.
[4] Y.O. Shaker, D. Yousri, A. Osama, A. Al-Gindy, E. Tag-Eldin, D. Allam, Optimal charging/discharging decision of energy storage community in grid-connected microgrid using multi-objective hunger game search optimizer, IEEE Access 9 (2021) 120774–120794, https://doi.org/10.1109/ACCESS.2021.3101839.
[5] M.G. Al-Mufti, R.A. Ghani, Control of battery energy storage system for peak shaving using enhanced time of use scheme, in: PECon 2020 - 2020 IEEE Int. Conf. Power Energy, 2020, pp. 224–228, https://doi.org/10.1109/PECon48942.2020.9314416.
[6] S. Bahramirad, W. Reder, A. Khodaei, Reliability-constrained optimal sizing of energy storage system in a microgrid, IEEE Trans. Smart Grid 3 (4) (2012) 2056–2062, https://doi.org/10.1109/TSG.2012.2217991.
[7] P.P. Gupta, P. Jain, S. Sharma, R. Bhakar, Reliability-security constrained unit commitment based on benders decomposition and mixed integer non-linear programming, in: 2017 Int. Conf. Comput. Commun. Electron. COMPTELIX, vol. 2017, 2017, pp. 328–333, https://doi.org/10.1109/COMPTELIX.2017.8003988.
[8] T.A. Nguyen, M.L. Crow, A.C. Elmore, Optimal sizing of a vanadium redox battery system for microgrid systems, IEEE Trans. Sustain. Energy 6 (3) (2015) 729–737, https://doi.org/10.1109/TSTE.2015.2404780.
[9] N.T. Mbungu, R. Naidoo, R.C. Bansal, M. Bipath, Optimisation of grid connected hybrid photovoltaic-wind-battery system using model predictive control design, IET Renew. Power Gener. 11 (14) (2017) 1760–1768, https://doi.org/10.1049/iet-rpg.2017.0381.
[10] P. Xiong, P. Jirutitijaroen, C. Singh, A distributionally robust optimization model for unit commitment considering uncertain wind power generation, IEEE Trans. Power Syst. 32 (1) (2017) 39–49, https://doi.org/10.1109/TPWRS.2016.2544795.

[11] N. Nikmehr, S. Najafi-Ravadanegh, Optimal operation of distributed generations in micro-grids under uncertainties in load and renewable power generation using heuristic algorithm, IET Renew. Power Gener. 9 (8) (2015) 982–990, https://doi.org/10.1049/iet-rpg.2014.0357.
[12] S. Bahramirad, E. Camm, Practical modeling of Smart Grid SMS^{TM} storage management system in a microgrid, in: Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf, 2012, pp. 1–7, https://doi.org/10.1109/TDC.2012.6281697.
[13] M.A. Abdulgalil, M. Khalid, Enhancing the reliability of a microgrid through optimal size of battery ESS, IET Gener. Transm. Distrib. 13 (9) (2019) 1499–1508, https://doi.org/10.1049/iet-gtd.2018.5335.
[14] I. Alsaidan, A. Khodaei, W. Gao, A comprehensive battery energy storage optimal sizing model for microgrid applications, IEEE Trans. Power Syst. 33 (4) (2018) 3968–3980, https://doi.org/10.1109/TPWRS.2017.2769639.
[15] C.G. Marcelino, G.M.C. Leite, E.F. Wanner, S. Jiménez-Fernández, S. Salcedo-Sanz, Evaluating the use of a Net-Metering mechanism in microgrids to reduce power generation costs with a swarm-intelligent algorithm, Energy 266 (December 2022) (2023), 126317, https://doi.org/10.1016/j.energy.2022.126317.
[16] I.H. Andreas Poullikkas, Kourtis George, A review of net metering mechanism for electricity renewable energy sources, Int. J. Energy Environ. 4 (6) (2013) 975–1002 [Online]. Available: https://www.osti.gov/etdeweb/biblio/22188315.
[17] Y. Zhao, Solar energy sharing in net metered community microgrids: can the social goals be achieved?, in: 2018 52nd Annu. Conf. Inf. Sci. Syst. CISS, vol. 2018, 2018, pp. 1–6, https://doi.org/10.1109/CISS.2018.8362287.
[18] A. Pyrgou, A. Kylili, P.A. Fokaides, The future of the Feed-in Tariff (FiT) scheme in Europe: the case of photovoltaics, Energy Pol. 95 (2016) 94–102, https://doi.org/10.1016/j.enpol.2016.04.048.
[19] A.A. Bayod-Rújula, A. Burgio, Z. Leonowicz, D. Menniti, A. Pinnarelli, N. Sorrentino, Recent developments of photovoltaics integrated with battery storage systems and related feed-in tariff policies: a review, Int. J. Photoenergy 2017 (2017), https://doi.org/10.1155/2017/8256139.
[20] N.K. Meena, J. Yang, E. Zacharis, Optimal planning and operational management of open-market community microgrids, Energy Proc. 159 (2019) 533–538, https://doi.org/10.1016/j.egypro.2018.12.002.
[21] S.B. Sani, et al., Energy storage system policies: way forward and opportunities for emerging economies, J. Energy Storage 32 (2020), https://doi.org/10.1016/j.est.2020.101902.
[22] S. Cai, Y. Li, Incentive policy for battery energy storage systems based on economic evaluation considering flexibility and reliability benefits, Front. Energy Res. 9 (March) (2021) 1–12, https://doi.org/10.3389/fenrg.2021.634912.
[23] W. Ko, M.K. Kim, Operation strategy for maximizing revenue of an energy storage system with a photovoltaic power plant considering the incentive for forecast accuracy in South Korea, IEEE Access 9 (2021) 71184–71193, https://doi.org/10.1109/ACCESS.2021.3079640.
[24] Z. Foroozandeh, S. Ramos, J. Soares, B. Canizes, Energy storage management system for smart home: an economic analysis, in: 2021 IEEE PES Innov. Smart Grid Technol. - Asia, ISGT Asia, 2021, p. 2021, https://doi.org/10.1109/ISGTASIA49270.2021.9715659.
[25] A.I. Nousdilis, G.C. Kryonidis, E.O. Kontis, G.K. Papagiannis, G.C. Christoforidis, I. P. Panapakidis, Economic viability of residential PV systems with battery energy storage under different incentive schemes, in: Proc. - 2018 IEEE Int. Conf. Environ. Electr. Eng. 2018 IEEE Ind. Commer. Power Syst. Eur. EEEIC/I CPS Eur, vol. 2018, 2018, https://doi.org/10.1109/EEEIC.2018.8494492. June.
[26] M.A. Hayat, F. Shahnia, G. Shafiullah, A Novel Dynamic Feed-In Tariff for Residential Rooftop PVs," *2018 IEEE 7th World Conf. Photovolt. Energy Conversion, WCPEC 2018 - A Jt*, Conf. 45th IEEE PVSC, 28th PVSEC 34th EU PVSEC, 2018, pp. 2417–2421, https://doi.org/10.1109/PVSC.2018.8547391.
[27] A. Kumar, D. Kumar, S.K. Jarial, A review on artificial bee colony algorithms and their applications to data clustering, Cybern. Inf. Technol. 17 (3) (2017) 3–28, https://doi.org/10.1515/cait-2017-0027.
[28] D. Karaboga, B. Gorkemli, C. Ozturk, N. Karaboga, A comprehensive survey: artificial bee colony (ABC) algorithm and applications, Artif. Intell. Rev. 42 (1) (2014) 21–57, https://doi.org/10.1007/s10462-012-9328-0.
[29] H. Zheng, G. Yang, J. Yi, Z. Yuan, X. Liu, M. Shuai, Simplify the basic artificial bee colony algorithm, in: Proc. - 2015 IEEE Int. Conf. Syst. Man, Cybern. SMC, vol. 2015, 2016, pp. 2141–2146, https://doi.org/10.1109/SMC.2015.374, 2007.
[30] L. Yang, J. Teh, Review on vulnerability analysis of power distribution network, Elec. Power Syst. Res. 224 (May) (2023), 109741, https://doi.org/10.1016/j.epsr.2023.109741.
[31] T. Song, J. Teh, Dynamic thermal line rating model of conductor based on prediction of meteorological parameters, Elec. Power Syst. Res. 224 (June) (2023), 109726, https://doi.org/10.1016/j.epsr.2023.109726.
[32] O.A. Lawal, J. Teh, Dynamic line rating forecasting algorithm for a secure power system network, Expert Syst. Appl. 219 (February) (2023), 119635, https://doi.org/10.1016/j.eswa.2023.119635.
[33] C.M. Lai, J. Teh, B. Alharbi, A. AlKassem, A. Aljabr, N. Alshammari, Optimisation of generation unit commitment and network topology with the dynamic thermal rating system considering N-1 reliability, Elec. Power Syst. Res. 221 (March) (2023), 109444, https://doi.org/10.1016/j.epsr.2023.109444.
[34] Y. Su, J. Teh, Two-stage optimal dispatching of AC/DC hybrid active distribution systems considering network flexibility, J. Mod. Power Syst. Clean Energy 11 (1) (2023) 52–65, https://doi.org/10.35833/MPCE.2022.000424.
[35] T. Nguyen-Duc, L. Hoang-Tuan, H. Ta-Xuan, L. Do-Van, H. Takano, A mixed-integer programming approach for unit commitment in micro-grid with incentive-based demand Response and battery energy storage system, Energies 15 (19) (2022), https://doi.org/10.3390/en15197192.
[36] M.R. Chakraborty, S. Dawn, P.K. Saha, J.B. Basu, T.S. Ustun, A comparative review on energy storage systems and their application in deregulated systems, Batteries 8 (9) (2022), https://doi.org/10.3390/batteries8090124.
[37] M. Aslani, H. Hashemi-Dezaki, A. Ketabi, Reliability evaluation of smart microgrids considering cyber failures and disturbances under various cyber network topologies and distributed generation's scenarios, Sustain. Times 13 (10) (2021), https://doi.org/10.3390/su13105695.
[38] Y. Wang, H. Ma, X. Xiao, Y. Wang, Y. Zhang, H. Wang, Harmonic state estimation for distribution networks based on multi-measurement data, IEEE Trans. Power Deliv. 38 (4) (2023) 2311–2325, https://doi.org/10.1109/TPWRD.2023.3239479.
[39] X. Lin, Y. Liu, J. Yu, R. Yu, J. Zhang, H. Wen, Stability analysis of Three-phase Grid-Connected inverter under the weak grids with asymmetrical grid impedance by LTP theory in time domain, Int. J. Electr. Power Energy Syst. 142 (PA) (2022), 108244, https://doi.org/10.1016/j.ijepes.2022.108244.
[40] W. Deng, Y. Zhang, Y. Tang, Q. Li, Y. Yi, A neural network-based adaptive power-sharing strategy for hybrid frame inverters in a microgrid, Front. Energy Res. 10 (January) (2023) 1–16, https://doi.org/10.3389/fenrg.2022.1082948.