Review

Not peer-reviewed version

Approaches to Building AC and AC-DC Microgrids on Top of Existing Passive Distribution Networks

Vladislav Volnyi , Pavel Ilyushin * , Konstantin Suslov , Sergey Filippov

Posted Date: 30 June 2023

doi: 10.20944/preprints202306.2177.v1

Keywords: microgrid; distribution network; distributed energy resources; automatic control system; protection system; information and communications technology infrastructure; power electronic converter

Review

Approaches to Building AC and AC-DC Microgrids on Top of Existing Passive Distribution Networks

Vladislav Volnyi [1], Pavel Ilyushin [2,*], Konstantin Suslov [1,3] and Sergey Filippov [2]

[1] Department of Hydropower and Renewable Energy, National Research University "Moscow Power Engineering Institute", 111250, Moscow, Russia; volnyyvs@yandex.ru (V.V.); dr.souslov@yandex.ru (K.S.)
[2] Department of Research on the Relationship between Energy and the Economy, Energy Research Institute of the Russian Academy of Sciences, 117186 Moscow, Russia; fil_sp@mail.ru (S.F.)
[3] Department of Power Supply and Electrical Engineering, Irkutsk National Research Technical University, 664074, Irkutsk, Russia
* Correspondence: ilyushin.pv@mail.ru

Abstract: The process of building microgrids on top of existing passive distribution networks warrants a multi-criteria analysis. Besides the calculation of investment outlays needed for the modernization of distribution networks, such an analysis covers an assessment of the technological and economic effects of building microgrids. The resulting effects depend on the topology and configuration of distribution networks, specific microgrid features, the choice of current type for the entire microgrid or its individual parts, the ways of connecting distributed energy resources (DER), the availability and condition of information and communications technology (ICT) infrastructure, and other factors. Complete input data allow one to design an optimal microgrid configuration, but the main technological and economic effects are determined by the algorithms of operation and the parameters setting of the automatic control system (ACS) and the protection system. Known approaches to designing microgrids focus on addressing basic tasks while minimizing investment required for their implementation. The above is fully justified when constructing new microgrids, but building microgrids on top of existing distribution networks, given the uniqueness of their topology and configuration, does not allow the use of standardized solutions. The development of approaches to the design of microgrids under such constraints, with minimized investment for the modernization of existing distribution networks, is an urgent task. The use of different types of current for microgrid segments determines the choice of particular ACS and protection system, which depends on the availability of information and communications technology infrastructure. This article contributes a review of approaches to designing AC and AC-DC microgrids to maximize their technological and economic effects. We review techniques for analyzing existing distribution networks aimed at choosing the type of current for the entire microgrid or its individual parts, the optimal connection points of microgrids to distribution networks, the mix and capacity of DERs, with such choices informed by the condition of switching devices and information and communications technology infrastructure. The article presents the results of the analysis of approaches to choosing the optimal configuration of microgrids, microgrid ACS and protection system, with an evaluation of the technological and economic effects subject to minimization of investment for the modernization of existing distribution networks.

Keywords: microgrid; distribution network; distributed energy resources; automatic control system; protection system; information and communications technology infrastructure; power electronic converter

1. Introduction

Current trends in energy sector development favor decentralization and decarbonization of generating capacities and the creation of hybrid energy complexes [1]. This facilitates the transformation of passive distribution networks into active ones by integrating a large number of heterogeneous distributed energy sources (DER) into them. Moreover, active distribution networks participate in power flow control of power systems, contributing to improved reliability of power supply to consumers by bringing DERs closer to electrical loads [2,3].

Distributed energy resources, in addition to DERs proper, include controllable loads. DERs include renewable electricity generation (wind and solar power plants), fuel generation (gas turbines units, gas piston units, diesel generator sets, microturbines, etc.), as well as energy storage systems (ESS) and fuel cells (FC) [4,5].

The creation of active distribution networks calls for improvements in both electric power generation and storage technologies and information and communications technology (ICT) infrastructure [6,7]. However, the integration of DERs is inherently limited in terms of both their quantity and total capacity. This is due to the fact that the growth of DER capacity presupposes the following: at the first stage, increasing the complexity of control algorithms in automatic control systems (ACS) [8]; at the second stage, application of more advanced types of ACSs and availability of ICT infrastructure that complies with the minimum requirements [9]; at the third stage, the use of centralized ACSs based on the "master-slave" principle [10]. The third stage requires a well-developed ICT infrastructure that meets high standards for reliability, transmission capacity, and redundancy [11].

The most promising way to create active distribution networks is to integrate into them scalable power supply systems, that is microgrids, rather than a large number of individual DERs. Each microgrid incorporates heterogeneous DERs, including hybrid power complexes and groups of interconnected consumers, has clearly defined electrical boundaries, and functions as a single object of control in relation to the distribution network [12,13]. Microgrids can operate both in the grid-connected (operating in parallel with the distribution network) and islanded modes. Switching of microgrids from one mode to the other and vice versa is implemented through a static switch without disturbing the power supply to consumers [14,15]. Taking into account the intermittency of renewable electricity generation in microgrids and the dynamic nature of electricity demand helps to ensure both the stability of their operation and the stability of active distribution networks as a whole [16].

Replication of microgrid designs has been facilitated by the development of power electronics as regards increased values of the basic parameters (rated current; blocking voltage) of power semiconductor devices [17]. This has made it possible to create various types of power electronic converters (PEC) of different configurations and topologies [18]. The main purpose of PECs is to connect heterogeneous DERs and controllable loads to microgrids. This facilitates the creation of microgrids of different types—AC, DC, and AC-DC (hybrid) microgrids [19].

The integrated implementation of DERs, PECs, and ICT infrastructure enables the transition from passive distribution networks to active ones with the integration of different types of microgrids into them. This also promotes the transformation of consumers into prosumers actively involved in power flow control of microgrids [20]. The qualitative change in the role of end users of electricity has led to the emergence of a new entity in the retail electricity market who is interested in the development of microgrid technologies [21]. However, the creation of microgrids raises the issues of implementation of optimal economic regulation of consumers/prosumers within a microgrid, between adjacent microgrids, and between microgrids and the distribution network [22].

A large number of PECs that are part of microgrids makes it difficult to implement control and protection algorithms, which is due to the small values (they tend to zero) of mechanical inertia constants (Tj) in DERs, as well as the presence of parts of microgrids running on DC [23,24]. This changes the traditional view of the structure of distribution networks due to an increase in the rate of transients, as well as a decrease in the values of fault currents [25].

The DC network of a hybrid microgrid requires replacement of switching devices (circuit breakers; fuses) and measuring current and voltage transformers. Moreover, one has to use new control algorithms in the microgrid ACS and protection system, due to the change in the regulating characteristics of PECs, the paths for the fault current flow, and their value [26].

Therefore, the creation of microgrids on top of existing distribution networks is accompanied by a large number of challenges that need to be addressed at the design stage [27].

The choice of the microgrid configuration can be approached based on the optimal power flow between the microgrid and the distribution network, scheduling (optimal microgrid power

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

generation/consumption profiles), and planning (future-proof optimal number, composition, and capacity of DERs, transmission lines, switching devices, taking into account unforeseen circumstances) [28].

Ref. [29] proposed to determine the optimal power flow based on the optimal control of heterogeneous DERs using different objective functions, which is a complex optimization problem that requires a high-accuracy solution. Ref. [30] argued for the use of a two-stage risk-based operating model. At the first stage, prosumers scheduled the power flow so as to maximize their profits from the operation of DERs and the data were sent to the microgrid operator. The microgrid operator formed the second stage that ensures maximization of the total profit by considering the intermittent nature of RES-based power generation by DERs.

Ref. [31] proposed a two-stage model, where the first stage minimized the operating costs of generation and reserve power, and the second stage optimized the costs of variations in the management owing to the stochastic nature of renewable electricity generation by DERs. The second stage applied an improved shuffled frog leaping algorithm. Ref. [32] reported an approach to optimal scheduling of operation modes of microgrids with heterogeneous DERs. The approach was based on the demand response method subject to minimizing operating costs. Ref. [33] discussed a stochastic model of DER-based power generation planning that took into account the uncertainty of wind speed, solar radiation, and the market price of electricity. Optimization was implemented on the basis of a multi-criteria objective function, including market profit, amount of CO2 emissions, and the average value of electricity not served. The multi-criteria firefly algorithm was used to find the optimal solution.

At their core, the approaches considered above use economic mechanisms, but they fall short of taking into account the key defining features of and requirements for power flow control in microgrids. A number of published studies were aimed at reducing the operating costs in microgrids or maximizing profits from the operation of DERs as part of microgrids [34–37].

Microgrid operation under growing demand for electricity, increased penetration of renewable electricity generation, and excessive wear of power grid infrastructure leads to overloads of transmission lines and power transformers in distribution networks [38]. The issues of microgrid operation have been addressed in published research, and various optimization methods with different objective functions have been applied to this end [39–41]. To ensure operational flexibility so as to comply with specified values of power supply reliability metrics, the algorithms implemented in microgrid ACSs must be adaptable enough to handle various combinations of network topologies and power flows. However, a large number of heterogeneous DERs in microgrids and flexible algorithms in the ACS do not guarantee the availability of electricity to consumers at a particular time [42].

Our analysis of Refs. [27–42] reveals that they failed to address the issues of transforming passive distribution networks into AC and AC-DC microgrids, as well as to consider approaches to creating microgrid ACS and protection systems in compliance with technological and economic performance standards.

The article gives an overview of approaches to the creation of AC and AC-DC microgrids on top of existing passive distribution networks with an analysis of the challenges it poses as well as suggestions for their solution.

The article is structured as follows. Section 2 presents the results of the analysis of the challenges posed by the creation of AC and AC-DC microgrids on top of existing passive distribution networks. Section 3 provides an overview of the methods for analyzing existing passive distribution networks with a view to choosing the type of current for the entire microgrid or its individual parts, the optimal connection points and the power of DERs, with such choices being informed by the condition of the switching devices and the information and communications technology infrastructure. Section 4 presents approaches to the selection of the optimal configuration of microgrids, microgrid ACS, and protection system, with an evaluation of their effects on technological and economic performance.

2. Challenges posed by creating microgrids on top of existing passive distribution networks

2.1. General requirements to be met by microgrids

Generally speaking, microgrids are a modern version of scalable active power supply systems with heterogeneous DERs, which allows for sufficient variability in their practical implementation. The vast global footprint of microgrid projects as well as the large number of research contributions and innovative solutions related to various components of microgrids have facilitated the development of various techniques. The already deployed experimental microgrids were used as purpose-specific research tools to establish criteria for their design, performance evaluation, and technological and economic performance. Refs. [43–58] discussed some of the issues of design, operation, and testing of microgrids that guide their operation as part of distribution networks. Key microgrid components are shown in Figure 1 [59].

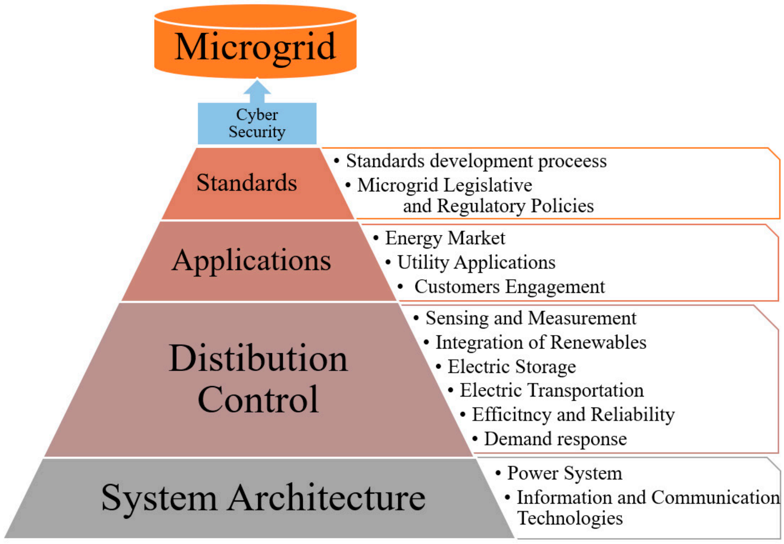

Figure 1. Key microgrid components.

However, the above approach is limited in its scope of application, as it is aimed exclusively at optimizing the operation of microgrids as part of the distribution networks to which they are connected [60,61]. Testing of microgrids can be performed on an experimental model implemented in a distribution network, or on a simulation model of a microgrid. However, the development and creation of microgrid simulation models, despite their relatively low cost, have not been widely adopted [62].

Currently, there are two main concepts for creating microgrids: the American one, developed by the Consortium for Electric Reliability Technology Solutions (CERTS) [63], and the European one, presented in the Microgrids and More Microgrids projects [64]. The most widespread is the concept advocated by the CERTS, in which microgrids are energy clusters based on DERs, including the generation, storage, and consumption of electricity, as well as heat recovery, with all part functioning as a single control object. The European concept of microgrid deals only with the supply of electricity to consumers. There are also other known microgrid projects, differing in size, mix of DERs, approaches to the implementation of ACS, protection systems and ICT infrastructure, and ways of integration into distribution networks, etc. [65–69].

ACSs of experimental and simulation microgrid models use different control schemes: centralized [65–67], decentralized [63,68], and distributed, which is based on the creation of agent-based systems [64,69]. Given the geographical location of the already deployed microgrid projects, we can draw conclusions about the preferences in the use of approaches underpinning the implementation of ACSs: in Asian countries, they prefer a centralized approach, in North American countries - the decentralized one, and in European countries - centralized or distributed control [70,71].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

Creation of microgrids improves the reliability of power supply to consumers, improves power quality, reduces electricity and power losses, as well as yields positive environmental and economic effects from the use of RES-based DERs and sales of surplus electricity [29–32]. Creation of microgrids helps to reduce the operating costs of maintaining the power grid infrastructure [72,73]. In addition, the investment appeal of microgrids for the prosumers allows for the modernization of existing distribution networks and information and communications technology infrastructure [74–76].

The greatest economic effect from the creation of microgrids can be obtained with a comprehensive approach to performing the entire range of tasks: determining the optimal mix and capacity of the DERs as well as the points of connection of microgrids to distribution networks, upgrading switching and metering devices (current and voltage sensors), the choice of the optimal approach to the implementation of control, and the creation of the ICT infrastructure serving as its backbone, etc. When creating a microgrid, it is not advisable to perform one or more individual task, as the lack of a comprehensive approach will not yield a full-fledged microgrid. For example, the microgrid thus built will be limited with regard to possible network reconfiguration options (one of the most important functional features of microgrids) due to the insufficient number of remotely controlled switching devices or poorly developed ICT infrastructure [77,78].

2.2. Optimization problems in microgrids

There are many criteria for classifying microgrids, such as type of current, voltage level, DER mix, total power, number of consumers served, number of connection points to the distribution network, the amount of controllable load, etc. That said, in all microgrids there are three groups of optimization problems that must be solved, and each of them must be solved at different time intervals: optimal power flow, scheduling, and planning (Figure 2) [79].

Microgrid performance is evaluated against the economic results obtained, which depend on the cost of generating and transmitting power to microgrids, as well as the balance in mutual settlements with the distribution network, to which surplus power is fed or which is used to offset power shortages.

The problems of optimal power flow and scheduling are applied problems and are solved by implementing control algorithms in the microgrid ACS, which can be updated (changed) during operation [80,81]. Unlike them, the problem of planning is of fundamental nature, as it ensures the minimization of investment costs for the creation and expansion of microgrids. In addition, the expansion planning solves the problem of preserving the stability of microgrids under various combination of network topologies and power flows, including the islanded mode, which is required to ensure the reliability of power supply to consumers and power quality.

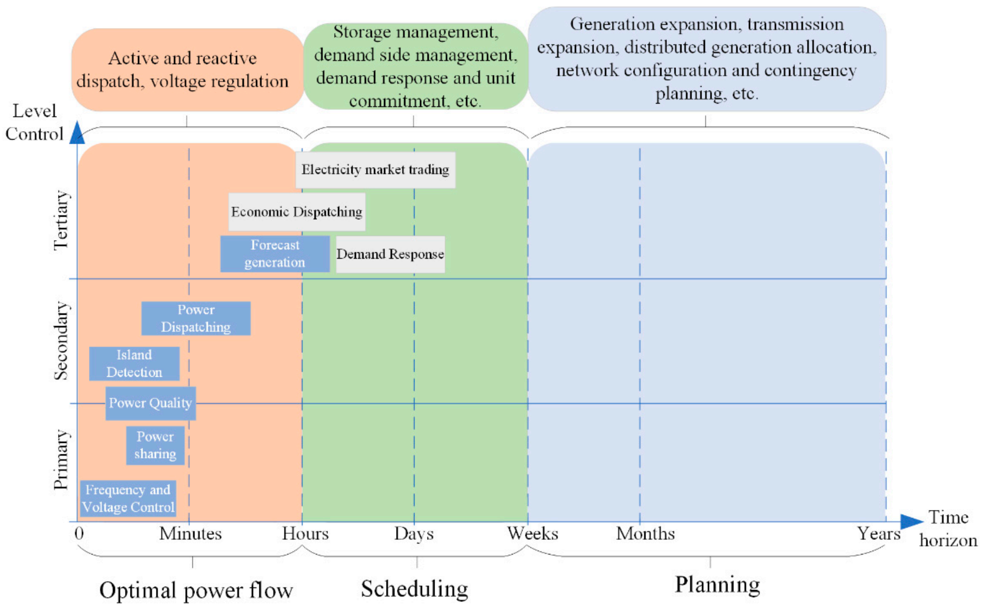

Figure 2. Time intervals for solving optimization problems in microgrids.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

2.3. *Planning microgrid creation and expansion*

Conventional microgrid planning and expansion is based on the deterministic approach, but due to the growing number of uncertainties and high investment costs of equipment, this approach is losing its relevance [82]. To boost the investment appeal of microgrids, it is necessary to use state-of-the-art planning methods based on the analysis of profitability under uncertainty to ensure required economic feasibility, reliability, and scalability of solutions [83]. Planning the creation and expansion of microgrids covers five main stages: the choice of generation technologies and ESS parameters, microgrid sizing, the choice of microgrid connection points to the distribution network, scheduling of energy resources use, and pricing [84,85]. The final conclusion about the effectiveness of the decisions made is formed in the process of testing on the experimental model, taking into account the adopted control scheme. The above is supplemented by the analysis of sensitivity of microgrid project parameters to changes in various factors (the effect of values of an independent variable on a particular dependent variable under the assumptions made).

2.3.1. Choosing generation technologies and ESS parameters

Replication of engineering solutions for microgrids proves possible because of their compact design and is based on the choice of the generation mix: the number and total/unit power of RES-based DERs as well as fuel DERs [86]. The conventional approach to the choice of the generation mix in microgrids is based on the results of the analysis of available RES (insolation level; average annual wind speed). Since these parameters are unique to each microgrid location, this limits the ability to replicate the solutions in other regions. To increase the investment appeal of microgrids, the share of RES-based on DERs in the generation mix should be higher than that of fuel-based DERs. The predominance of intermittent generation under the variability and uncertainty of electricity consumption leads to instantaneous power imbalances, which compromises microgrid stability. ESS are used to compensate for the instantaneous power shortages/surpluses in microgrids: they improve the stability and reliability of microgrid operation and reduce the levelized cost of electricity [87].

The key challenge posed by the use of ESSs in microgrids is how to properly set ESS parameters (power; energy capacity) to ensure microgrid stability [88,89]. Adopting an ESS with non-optimal parameters either leads to an increase in the cost of the ESS and the microgrid as a whole, as well as an increase in power losses in the ESS, or to a disruption of microgrid stability under certain combinations of network topologies and power flows.

2.3.2. Microgrid sizing

The main objectives of microgrid sizing are economic feasibility (low investment and operating costs), energy efficiency (low power and energy losses), and reliability [90]. For the purpose of microgrid sizing, statistical data (demand curves) are analyzed in order to identify characteristic points of peak and baseload electricity consumption, while considering the value of the power reserve to ensure the reliability of electricity supply to consumers [91].

The most difficult task is to establish correlations between fluctuations in power demand and specific production processes in microgrids. This is required to determine the necessary amount of generation at each moment of time and ways to maintain the balance of power [92,93]. Therefore, optimal microgrid sizing is based on the results of the analysis of statistical data, the possibilities of reducing the capacity fee, ESS power and energy intensity, as well as the power flow control capabilities of the ACS.

2.3.3. Choosing microgrid connection points

As noted above, microgrids can operate both in the grid-connected mode (operating in parallel with the distribution network) and in islanded modes. In some cases, it is justified for microgrids to operate in the stand-alone mode, i.e., without connection to the distribution network [94]. The decision to integrate microgrids into the distribution network, with the choice of one or more optimal connection points, or the choice of the islanded mode should be based on quantitative assessments.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

At the same time, one should analyze all potential points of connection, both at the time of the creation of a microgrid and with future expansion potential in mind. The solution is based on determining the break-even point, when it is cheaper to produce and distribute electricity within a stand-alone microgrid than to expand the distribution network and buy electricity from a power supply company. The break-even point differs on a case-by-case basis subject to the location of distribution network facilities and the amount of electricity consumption in microgrids [95].

Microgrid location determines the opportunities for its expansion [96]. Market mechanisms allow optimizing the process of choosing the point of connecting a microgrid to the distribution network while taking into account spatial and power parameters. Spatial modeling enables detection of useful patterns in the data space that are not obvious to their users, with such patterns used for electricity consumption forecasting linked to specific locations [97]. This allows for the application of local marginal pricing, a mechanism for using market electricity prices to manage power grid infrastructure congestion. This mechanism makes it possible to determine the capacity limits and their cost at each node of electricity consumption as based on the results of bidding in the competitive capacity market. This provides appropriate economic signals for all participants in the electricity market [98].

2.3.4. Scheduling the use of energy resources

Controlling the consumption of all energy resources in microgrids enables significant improvements in its economic performance. A microgrid simulation model makes it possible to predict the generation/consumption of electricity, as well as to determine optimal operating conditions of all DERs, taking into account the microgrid configuration and the control algorithms implemented in the ACS [99].

The economic feasibility of microgrid operation is for the most part determined by the control algorithms implemented in the ACS. In this regard, the microgrid ACS must provide the implementation of the following:

- online monitoring: the data on current electricity consumption make it possible to identify periods in which undesirable consumption of electricity from the distribution network occurs [100]. If there are production processes in the microgrid, it is required to coordinate the increase/decrease of power consumption with the DER operation schedules;
- optimal control algorithms: power consumption data allow us to determine demand coefficients for each consumer [101]. This makes it possible to obtain significant savings of non-renewable energy resources through maximum utilization of RES-based DERs and optimal use of ESSs.

2.3.5. Pricing in microgrids

Forecasting not only the amount of power generation but also its cost allows optimal decisions to be made when planning microgrid power flows [102]. This enables power supply companies, instead of responding to demand, to set a fixed tariff for electricity during periods of consumption from the distribution network [103]. This improves energy efficiency and controllability in the distribution network by efficiently managing electricity demand. Reliably serving consumer load profiles is possible with stable power generation by DERs, which makes the strategy of dynamic pricing and demand response unappealing [104].

2.4. Control and protection in microgrids

Integration of microgrids into passive distribution networks allows for, in addition to improved power supply reliability and power quality, increased observability and controllability. However, this raises a new issue of ensuring the transient stability of DERs in emergency and post-emergency states due to the small values of the mechanical inertia constants. This imposes restrictions on the permissible microgrid power flows, as well as the control algorithms and their performance implemented in the ACS [105]. Consideration of these factors allows one to yield the maximum

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

technological and economic effect from the use of heterogeneous DERs in microgrids, as well as facilitate the formation of an active distribution network.

The presence of multiple microgrid configurations, which differ, among other things, in the type of current in the entire microgrid or its individual parts, affects the choice of algorithms of the ACS and the protection system. DC networks of hybrid microgrids require switching devices (circuit breakers; fuses) and measuring current and voltage transformers to be replaced by DC sensors [106].

The presence of heterogeneous DERs in microgrids, each having different protection setpoints and permissible operating ranges, affects the nature and parameters of transients. This requires individual control algorithms to be separated in time by building a hierarchical sequence of implementation of controls. This requires the implementation of a hierarchical microgrid structure in the ACS, which has three layers of control (sometimes zero layer is added, which is the PEC control layer). At the same time, the issues of reliability of power supply to consumers and power quality are addressed at the primary and secondary layers of control [107], and the tertiary layer ensures economic feasibility. When implementing control algorithms, ACSs should take into account the features unique to microgrids: bidirectional power flows, small values of mechanical inertia constants of DERs, intermittency of renewable power generation, variability and uncertainty of electricity consumption, short-term fluctuations in power flow parameters during transients when microgrids switch from the grid-connected to islanded mode.

At the physical level, the ACS can be implemented by adopting different approaches to the control scheme: centralized, decentralized, and distributed. The choice of an approach is determined by the goals of microgrid creation and their features, as well as the availability of the necessary resources and equipment to meet the requirements. The (un)availability of communication links between the central controller and local controllers, or between local controllers, is crucial [108]. The degree of decentralization depends on the features and control algorithms implemented in the microgrid ACS, as well as the computing power of local controllers [71]. To improve the technological and economic performance of microgrids by its involvement in the provision of system services, it is necessary to arrange the interaction of the central microgrid controller with the Energy service company and Distribution system operator.

Performing protection functions in microgrids comes down to correctly identifying and localizing the fault at the highest possible speed [109]. Therefore, microgrid protection systems have to meet the requirements for selectivity, speed, reliability, sensitivity, and cost-effectiveness. The protection system must function reliably withstanding known difficulties: bidirectional power flows, blinding of protections, significant reduction in the level of fault currents during the microgrid switching from the grid-connected to islanded mode, etc.

2.5. Information and communications technology infrastructure of microgrids

The creation of full-fledged microgrids is not possible without the ICT infrastructure, which consists of devices and systems that were part of the original passive distribution network, as well as new devices and systems that are put into operation when creating a microgrid [110]. First and foremost, the ICT infrastructure refers to the network of data transmission from peripheral devices installed on the electrical equipment (local controllers) to the decision-making center in the microgrid, which is the central controller [111]. Particular attention should be paid to the choice of ICT when creating microgrids.

In general, ICTs can be divided into wired and wireless technologies. Wireless ICTs use a non-physical medium to transmit data between devices and systems, while wired ICTs use a physical medium (cables, optical fiber). Typically, wireless ICTs transmit data through the air using electromagnetic waves within the radio frequency and infrared spectra. Wireless ICTs include the following well-known communication systems: GSM, GPRS, 3G, WiMAX, Zigbee, Wi-Fi, Bluetooth, Wireless Mesh [112,113]. For data transmission, one can utilize power cables that use the Power Line Communication (PLC) interface, in addition to purpose-made cables (four twisted pairs, used in Ethernet computer networks).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

Each kind and type of ICTs has its own advantages and disadvantages that make them may be more or less preferable when compared against one or more criteria (e.g., bandwidth and maximum data transfer rate). It is important to emphasize that choosing a wrong ICT can lead to a malfunction of the microgrid ACS and the protection system with all the issues that ensue [114]. Thus, a proper choice of ICTs to create an ICT infrastructure in a microgrid is a multi-criteria problem that requires special attention.

3. Implementation of optimization algorithms in microgrids

All techniques used in the creation of microgrids fall into two main groups. The first group includes a range of issues related to the creation of microgrids by analyzing the existing distribution network so as to select the type of current for the entire microgrid or its individual parts, the optimal connection points of microgrids, the mix and capacity of DERs. At this stage, the use of optimal power flow and scheduling makes it possible to evaluate the technological performance of the decisions taken to ensure microgrid resilience. The second group covers the issues of choosing an optimal configuration of microgrids, microgrid ACS, protection system, and ICT, with an assessment of the technological and economic effects of their implementation [115,116].

Oftentimes when solving optimization problems in microgrids (optimal power flow, scheduling, and planning) various metaheuristic methods are applied. Their application yields good results when solving multi-criteria problems peculiar to microgrids with a predominance of intermittent renewable electricity generation as well as variable and uncertain electricity consumption [117].

Metaheuristic methods include [118]:

- evolutionary computations: methods that simulate the evolution of population members (genetic algorithms, differential evolution);
- methods of swarm intelligence: methods capturing the properties of self-organizing groups of biological organisms with “smart” global behavior (ant colonies, harmony search algorithm, particle swarm optimization, etc.);
- artificial immune systems: methods inspired by theoretical immunology and modeling the processes used by the immune system to respond to external threats;
- non-population-based metaheuristics: methods based on finding a single solution, i.e., temporarily taking the worst solution with a probability that decreases as more iterations are run (simulated annealing, tabu search).

The applicability of specific metaheuristic methods is determined based on the available computing power of the controller and the number of function convergence estimates [119]. For example, evolutionary computations based on genetic algorithms [120] are applicable to any configurations of microgrids, allow the use of hybrid approaches, are easily scalable, and do not impose restrictions on the functions they perform. However, the performance of the algorithm is determined by the quality of the coding of the optimization problem, as well as by its sensitivity to parameters setting. At the same time, the differential evolution method, which has a higher rate of function convergence than the genetic algorithm, is a simple and reliable method applied to optimization problems with constraints that require a relatively small number of control variables. However, this algorithm strongly depends on parameters setting, which determines the convergence rate [121,122].

Swarm intelligence methods do not require special coding for their application. For example, the particle swarm optimization method is quite simple to implement and, given its efficiency, is the optimal solution in the case of limited computing power of the controller [123,124].

Artificial immune systems are formed on the basis of a distributed control model, when there is no single control center, and they require only local information. These methods require a minimal amount of computational resources, unlike population-based methods. However, these methods require calibration to solve optimization problems, unlike evolutionary computation and swarm intelligence methods [125].

Non-population-based metaheuristic methods have the lowest computational power requirements of all methods, but also the lowest accuracy, which is not suitable for solving a number of problems in microgrids [126].

To evaluate microgrid performance, one should use economic criteria and apply methods based on artificial intelligence. In the absence of convergence, it proves efficient to use combinations of two or more algorithms that form a hybrid optimization algorithm [127,128].

3.1. Optimal power flow and scheduling methods

Ref. [129] discussed the application of economic dispatch in microgrids that minimized fuel costs for fuel DERs that were either dispatchable or non-dispatchable under different operational constraints. The optimization problem was solved using four methods: direct search method, particle swarm optimization, lambda iteration method, and iteration-free method based on lambda logic.

Ref. [130] proposed to perform an economic and technological feasibility analysis of microgrids based on the cost of electricity when operating in the grid-connected and islanded modes. At the same time, a comprehensive analysis should be made of the available capacity of dispatchable and non-dispatchable DERs, taking into account the annual growth of electricity consumption by 12 %.

Ref. [131] reported information on the design of an optimal microgrid structure that provided maximum stability as well as the possibility of partial or complete recovery. To solve the nonlinear problem the authors proposed to apply a heuristic method made available by them in two versions. The first version was the stationary heuristic methods that used static worst-case scenarios to solve the problem. The second version was a time-dependent heuristic that searched for the optimal solution in a discrete representation of the time domain.

Ref. [132] presented an optimization model for minimizing operating costs in microgrids using a genetic algorithm. Considerable attention was paid there to the price aspect as related to the response to the growth of electricity consumption. Furthermore, the article presented the results of sensitivity analysis to changes in the factors affecting the value of microgrid operating costs.

Ref. [133] proposed to use mixed integer linear programming for the optimal design of microgrids with discrete catalog-based components selection. In addition, the authors established an explicit dependency of annuitized investment costs of the operation of fuel-fired DERs and ESSs on the selected configuration of the microgrid.

Ref. [134] proposed to apply a stochastic method for optimal power flow in microgrid operation under high uncertainty of generation and electricity consumption. For this purpose, the Benders decomposition method was used, which decoupled the optimal power flow problem into a master problem, related to the distribution network, and a sub-problem, solved iteratively with Benders cuts. This approach made it possible to ensure reliable operation of microgrids after switching operations on tie-lines connecting microgrids to the distribution network.

Ref. [135] discussed the application of a day-ahead electricity consumption scheduling method, taking into account network constraints, which requires minimum computing power of the controller. The method was based on the use of a second-order cone program algorithm - convex relaxation of power flow equations.

Ref. [136] contributed an alternative approach to the implementation of hierarchical control, in which only the primary and tertiary layers of control, as discussed above, were implemented. The optimal power flow was defined as the power flow that minimized the losses in microgrids and was determined by applying an iterative algorithm.

Ref. [137] proposed an approach to arriving at the optimal microgrid configuration based on DER classification aimed at selecting the optimal DER mix and capacity. For this purpose, the authors used the method of preference by similarity with the ideal solution and specified optimization criteria (maximization of energy efficiency, minimization of CO_2 emissions, labor costs, energy costs, and fuel costs). Next, using machine learning algorithms (random forest and light gradient boosting machine) an optimal DER mix was determined.

3.2. Methods for microgrid expansion planning

Microgrid expansion planning techniques are based on uncertainty modeling [138]. For this purpose, a probabilistic power flow calculated using the Monte Carlo method is determined, which requires considerable computational power [139]. An alternative to the above method is approximated and improved iterative algorithms [140,141] that have good accuracy in estimating variables and probabilistic parameters, while requiring much less computational resources.

Ref. [139] presented a mathematical model that allowed the optimal microgrid design and operation to be realized. The proposed approach presupposes taking into account technological constraints (the value of power flow from the distribution network, the power consumption in microgrids, the charge/discharge of the ESS), as well as economic constraints on the application of various DER technologies.

Ref. [142] discussed an approach to optimizing microgrid structure, when it is created on the basis of the existing distribution network in line with the brownfield principle, which implies the purchase or lease of existing power grid infrastructure. Multi-criteria optimization is used for this purpose.

Ref. [143] contributed a methodology for optimizing the structure of AC-DC microgrids, which serve the electricity consumption profile without power flow from the distribution network. This minimizes the cost of producing electricity in microgrids.

Ref. [144] examined optimal microgrid sizing in terms of the chosen optimization goals (minimization of the cost of electricity, maximization of the life cycle of DERs, increasing the reliability of power supply to microgrid consumers, etc.). A hybrid method of particle swarm and differential evolution with an appended fuzzy attainment module was chosen as the optimization method.

Ref. [145] reported a model for long-term strategic planning of investment in the creation of microgrids, which allowed improving the economic performance and controllability of the distribution network. The model took into account both existing microgrids and new ones, which made it possible to ensure the stable operation of the distribution network and optimal power flow when microgrids operate in both grid-connected and islanded modes.

The decisions made to determine the optimal mix of the DERs in a particular microgrid connected to a single distribution network do not allow their replication in other distribution networks. The process of finding similar solutions is quite time-consuming and inefficient. Ref. [146] examined an approach to the creation of microgrids that eliminated the need to determine the optimal connection point to the distribution network. It was based on tracking information about primary energy resources (fuel price; insolation level; average annual wind speed), which can be extrapolated to all microgrids that are built in the area. For this purpose, a unified index was introduced in order to determine the feasibility of including a certain type of DERs in the microgrid generation mix. Next, the weighted average cost of electricity for each type of DERs was determined. The resulting index was the sum of the three indices factored in the availability of primary energy resources in a given area. The resultant index omitted ESSs and FCs since their operating conditions do not depend on their location.

4. Approaches to the selection of microgrid ACS, protection system, and ICT infrastructure

4.1. Choosing the optimal ACS

The microgrid ACS must ensure reliable power supply to consumers and power quality for all combinations of network topologies and power flows, regardless of the state of the distribution network, including in the islanded mode. When emergency or abnormal states occur in microgrids, the protection system must ensure rapid fault localization, and the action of algorithms for emergency control of the microgrid ACS must restore power supply to the main consumers. The implementation of Energy Management System algorithms in the microgrid ACS allows one to optimize microgrid sizing and the investment outlays needed for its creation [147].

When choosing the ACS for AC microgrids, one should consider the following:

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

- selection of the ACS type should be based on the analysis of the mix of DERs, microgrid configuration, possible operating conditions, and other factors;
- control algorithms that do not use communication links based on frequency and voltage droop control (independent of the geographical distance between DERs and the consumers' electrical loads) are less efficient due to the lack of information exchange between the PECs of DERs [148];
- ACSs based on decentralized algorithms are increasingly being used because of the reduced risk of failure due to damage to a single component, as opposed to centralized or agent-based ACSs.

The ACS of AC-DC microgrids are unique in that:

- reliable and efficient management of power flows both within the microgrid and between the microgrid and distribution network requires the implementation of complex control algorithms;
- they require an additional intermediate PEC between the DC and AC network in the microgrid, which is necessary to maintain the balance of power in the microgrid, both in grid-connected and islanded modes [149];
- the lack of a system-wide variable used to distribute power between heterogeneous DERs, as well as the lack of frequency and voltage regulation necessitates the use of the ACS with a complex structure [150].

To ensure reliable operation of AC-DC microgrids under various combinations of network topologies and power flows, it is desirable to have an additional controller that coordinates the AC and DC parts.

4.2. Choosing the best protection system

The presence of intelligent devices in microgrids in the form of local controllers allows one to do away with such concepts as the protection device. The availability of computing power in local microgrid controllers enables implementation of all the necessary protection functions on their basis. This approach makes it possible to implement an adaptive protection system that outperforms conventional individual protections (overcurrent protections; voltage protections; distance protections; differential protections, etc.) [151,152].

The adaptive protection system of microgrids allows 1) adapting the algorithms and setting parameters so as to match the specifics of the current power flow, 2) implementing rapid self-healing of the microgrid normal power flow after the fault localization, and 3) restoring power supply to consumers in the shortest time possible. This is of highest importance given the application of economic dispatch in microgrids [153].

The development of more advanced protection algorithms is possible through the use of the following:

- machine learning and artificial intelligence methods;
- Wide-Area Monitoring, Protection, and Control (WAMPAC) devices;
- a data exchange protocol compliant with IEC 61850 [154].

Adaptive protection systems automatically factor in short-term imbalances of active and reactive power, possible options of network reconfiguration, changes in parameters of transmission lines that connect microgrids to distribution networks, as well as microgrid operation modes (grid-connected/islanded).

An adaptive microgrid protection system can be implemented based on decentralized or centralized approaches. Protection based on the decentralized approach comes into two designs: with communication with neighboring controllers (adaptive multi-agent protection) [155] and without such communication (with the use of intelligent algorithms based on artificial neural networks, metaheuristics, and fuzzy inference) [156].

Protections based on the centralized approach require broadband communication links and high-performance controllers to detect and locate any type of fault in under 10 ms. An example of the implementation of a centralized adaptive microgrid protection system, which includes two layers of

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

information transmission: the data transmission environment (level 2) and the data sub-transmission environment (level 1) is shown in Figure 3 [157].

The exchange of information between controllers of all levels (data transmission and sub-transmission) allows for selective action of the centralized adaptive protection system under all combinations of network topologies and power flows in any microgrid configuration.

IEEE 802.16 WiMAX can be used as a protocol for transmitting data between the levels in the centralized adaptive protection system, which allows for significantly cheaper implementation [158].

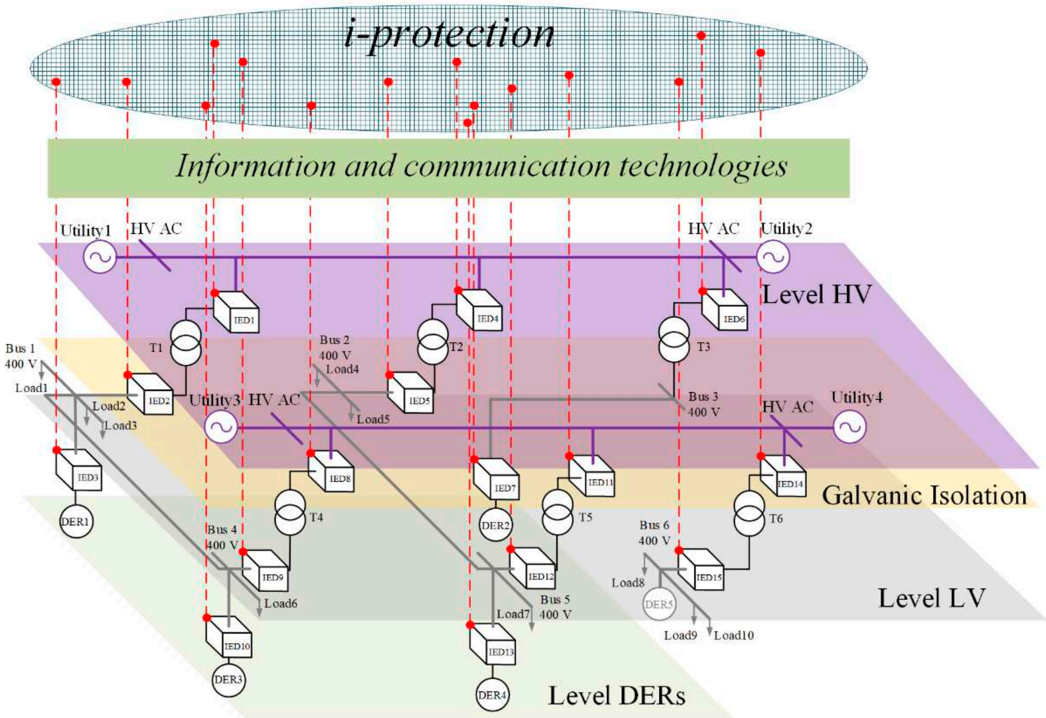

Figure 3. Centralized adaptive microgrid protection system.

4.3. Choosing the best ICTs

The information and communications technology infrastructure created as part of the digitalization of the existing distribution network makes it possible to solve a wide range of technological, economic, and other problems, including the provision of ancillary services by microgrid participants.

When creating a microgrid, the main requirements to be met by the ICT are low power consumption, wide signal spectrum, broad bandwidth, large signal coverage, and high cost-effectiveness. Taking the above requirements into account when selecting ICTs for a particular microgrid, the advantages and disadvantages of each of them (given in Table 1) should be considered and traded off against each other [159,160].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 June 2023 doi:10.20944/preprints202306.2177.v1

Table 1. Microgrid communications technologies.

Type	Technology	Data Rate	Coverage Range	Network Topology	Max Number of Cell Nodes	Limitations	Applications
Wire-less	**GSM**	Up to 14,4 kbps	0,5-35 km	Multipoint to multipoint	7cells/ cluster 9, 12, 13	Low date rates	AMI [1], HAN [2], Demand Response
	GPRS	Up to 170 kbps	0,5-35 km	Multipoint to multipoint	7cells/ cluster 9, 12, 13	Low date rates	AMI, HAN, Demand Response
	3G	Up to 2 Mbps	0,1-10 km	Multipoint to multipoint	1–7cells	Costly spectrum	AMI, HAN, Demand Response, Monitoring for Remote Distribution
	ZigBee	250 kbps	10-100 m	Star, mesh, cluster-tree	more than 65,000	Low data rate, short range	Automation, Remote Load Control, AMI
	WiMAX	Up to 50 Mbps	10-50 km (LOS) 1-5 km (NLOS)	Point to multipoint; multipoint to multipoint	1	Not widespread	AMI, Demand Response, Wireless Automatic Meter Reading
Wired	**PLC**	Up to 0,5/200 Mbps	3/0,2 km	Star, point-to-point	1	Harsh, noisy channel environment	AMI, Fraud Detection

[1] AMI – advanced metering infrastructure; [2] HAN – home area network.

For example, in the case of GSM and GPRS, even though they operate in the same frequency range with the same signal coverage area, GPRS has a better data transfer rate. WiMAX has the best data transfer rate specifications, but its power consumption is the highest. Therefore, the choice of ICTs for a particular microgrid requires solving a multi-criteria problem subject to a set of basic and additional goals of its application.

Ref. [4] provided the results of a multi-criteria evaluation of ICT. Various methods were used to evaluate the weights of individual criteria, with such methods classified as objective, subjective, or complex. Objective methods of evaluation, including the Unified Weighting Method (UWM), the Criteria Importance Through Intercriteria Correlation (CRITIC) method, and the entropy method prove crucial in selecting ICTs. As a result, the ICT rating was compiled as shown in Figure 4 [4].

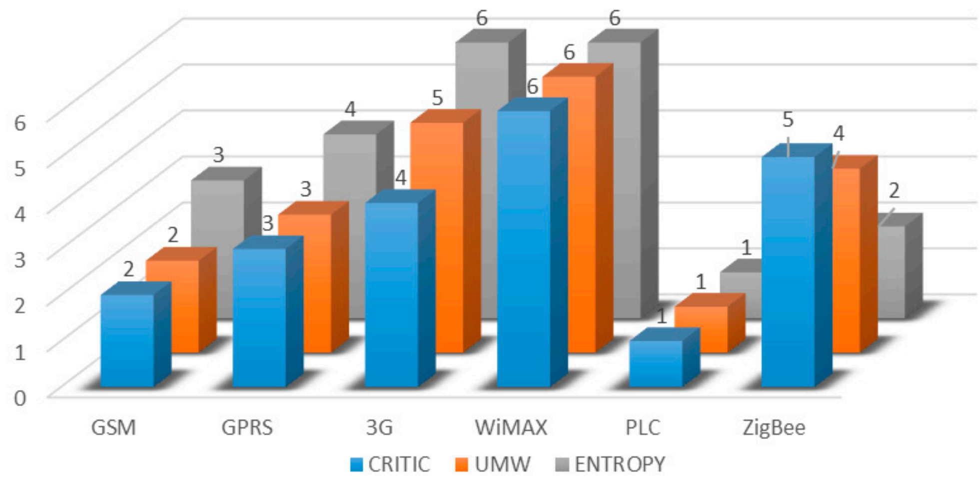

Figure 4. Information and communications technology rating.

Thus, WiMAX is most suitable for the creation of information and communications technology infrastructure in microgrids, whereas PLC turns out to be the least suitable.

5. Conclusion

Creating microgrids involves a comprehensive approach to modernizing existing distribution networks (switching devices; metering devices; information and communications infrastructure) and solving problems of optimal power flow, scheduling, and planning.

Ensuring reliable power supply to consumers and power quality in microgrids is possible with the correct operation of the protection system and ACS under various combinations of network topologies and power flows. The choice of information and communications technology infrastructure is crucial for the economic performance of microgrids as it determines the set of approaches and algorithms that can be used in the protection system and ACS.

Choosing an optimal protection system and ACS for a particular microgrid is a multi-criteria problem. The centralized approach has the greatest advantages in creating a protection system, but it requires a proper information and communications technology infrastructure. When designing the microgrid ACS, a decentralized approach is most preferable as it reduces the risk of ACS failure due to damage to the central controller or a single component of the information and communications technology infrastructure. However, with a decentralized approach to ACS design, it is impossible to implement economic dispatch, which is essential for boosting the investment appeal of microgrids. The distributed approach to ACS design, which requires data transmission links between local controllers of the microgrid, is an optimal solution.

The proper choice of information and communications technology can address a wide range of technological, economic, and other issues, including the provision of ancillary services by the entities operating as part of a microgrid.

When the intermittent nature of RES-based power generation by DERs as well as the variability and uncertainty of electricity consumption are addressed in the algorithms of the microgrid ACS, one can ensure stable operation of microgrids in the grid-connected and islanded modes, as well as that of the active distribution network as a whole.

Author Contributions: Conceptualization, V.V. and P.I.; methodology, P.I and S.F.; software, V.V.; validation, P.I.; formal analysis, K.S.; investigation, V.V., P.I. and K.S.; resources, S.F.; data curation, V.V. and S.F.; writing—original draft preparation, V.V. and P.I.; writing—review and editing, S.F. and K.S.; visualization, V.V.; supervision, K.S.; project administration, P.I.; funding acquisition, S.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data sharing not applicable. No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Abbreviations

DER	distributed energy resources
ACS	automatic control systems
ICT	information and communications technology
ESS	energy storage systems
FC	fuel cell
PEC	power electronic converters
CERTS	Consortium for Electric Reliability Technology Solutions
PLC	Power Line Communication
WAMPAC	Wide-Area Monitoring, Protection, and Control

References

1. Filippov, S.P.; Dilman, M.D.; Ilyushin, P.V. Distributed Generation of Electricity and Sustainable Regional Growth. *Thermal Engineering* **2019**, 66, 12, 869-880.
2. Bassam, N.El. Grid challenges: Integration of distributed renewables with the national grid. *Distributed Renewable Energies for Off-Grid Communities: Empowering a Sustainable, Competitive, and Secure Twenty-First Century* **2021**, 451–456. https://doi.org/10.1016/B978-0-12-821605-7.00002-7.
3. Chen, X.; Zhai, J.; Jiang, Y.; Ni, C.; Wang, S.; Nimmegeers, P. Decentralized coordination between active distribution network and multi-microgrids through a fast decentralized adjustable robust operation framework. *Sustainable Energy, Grids and Networks* **2023**, *34*, 101068. https://doi.org/10.1016/J.SEGAN.2023.101068.
4. Abdulsalam, K. A., Adebisi, J., Emezirinwune, M., & Babatunde, O. (2023). An overview and multicriteria analysis of communication technologies for smart grid applications. *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, *3*, 100121. https://doi.org/10.1016/J.PRIME.2023.100121.
5. Panda, D.K.; Das, S. Smart grid architecture model for control, optimization and data analytics of future power networks with more renewable energy. *Journal of Cleaner Production* **2021**, *301*, 126877. https://doi.org/10.1016/J.JCLEPRO.2021.126877.
6. Sinsel, S.R.; Riemke, R.L.; Hoffmann, V. H. Challenges and solution technologies for the integration of variable renewable energy sources—a review. *Renewable Energy* **2020**, *145*, 2271–2285. https://doi.org/10.1016/J.RENENE.2019.06.147.
7. Park, C.; Heo, W.G. Review of the changing electricity industry value chain in the ICT convergence era. *Journal of Cleaner Production* **2020**, *258*, 120743. https://doi.org/10.1016/J.JCLEPRO.2020.120743.
8. Ilyushin, P.V.; Pazderin, A.V. Approaches to organization of emergency control at isolated operation of energy areas with distributed generation. In Proceedings of the International Ural Conference on Green Energy (URALCON), Chelyabinsk, Russia, 4–6 October 2018. https://doi.org/10.1109/URALCON.2018.8544361.
9. Kumar, S.; Islam, S.M.; Jolfaei, A. Microgrid communications – protocols and standards. *Variability, Scalability and Stability of Microgrids* **2019**, 291–326. https://doi.org/10.1049/PBPO139E_CH9/CITE/REFWORKS.
10. Pena Ramirez, J.; Garcia, E.; Alvarez, J. Master-slave synchronization via dynamic control. *Communications in Nonlinear Science and Numerical Simulation* **2020**, *80*, 104977. https://doi.org/10.1016/J.CNSNS.2019.104977.
11. Ilyushin, P.; Volnyi, V.; Suslov, K.; Filippov, S. State-of-the-Art Literature Review of Power Flow Control Methods for Low-Voltage AC and AC-DC Microgrids. *Energies* **2023**, 16, 3153. https://doi.org/10.3390/en16073153.
12. IEEE joint task force on quadrennial energy review https://smartgrid.ieee.org/images/files/pdf/IEEE_QER_Microgrids_October_3_2014.pdf, 2014.
13. Onu, U.G.; Zambroni de Souza, A.C.; Bonatto, B.D. Drivers of microgrid projects in developed and developing economies. *Utilities Policy* **2023**, *80*. https://doi.org/10.1016/j.jup.2022.101487.
14. Kroposki, B.; Pink, C.; Lynch, J.; John, V.; Daniel, S.M.; Benedict, E.; Vihinen, I. Development of a high-speed static switch for distributed energy and microgrid applications. *Fourth Power Conversion Conference-NAGOYA, PCC-NAGOYA 2007 – Conference Proceedings*, 2007, 1418–1423. https://doi.org/10.1109/PCCON.2007.373150.

15. Ilyushin, P.V.; Suslov, K.V. Operation of automatic transfer switches in the networks with distributed generation. In Proceedings of the 2019 IEEE Milan PowerTech. Milan, Italy, 23-27 June 2019. doi:10.1109/PTC.2019.8810450.
16. Chatterjee, A.; Burmester, D.; Brent, A.; Rayudu, R. Research Insights and Knowledge Headways for Developing Remote, Off-Grid Microgrids in Developing Countries. *Energies* **2019**, 12, 2008. https://doi.org/10.3390/EN12102008.
17. Jiang, J.; Bao, Y.; Wang, L.Y. Topology of a Bidirectional Converter for Energy Interaction between Electric Vehicles and the Grid. *Energies* **2014**, *7*, 4858-4894. https://doi.org/10.3390/EN7084858.
18. Wang, X.; Taul, M.G.; Wu, H.; Liao, Y.; Blaabjerg, F.; Harnefors, L. Grid-Synchronization Stability of Converter-Based Resources—An Overview. *IEEE Open Journal of Industry Applications* **2020**, *1*, 115–134. https://doi.org/10.1109/OJIA.2020.3020392.
19. Wang, J.; Jin, C.; Wang, P. A Uniform Control Strategy for the Interlinking Converter in Hierarchical Controlled Hybrid AC/DC Microgrids. *IEEE Transactions on Industrial Electronics* **2018**, *65*(8), 6188–6197. https://doi.org/10.1109/TIE.2017.2784349.
20. Rocabert, J.; Luna, A.; Blaabjerg, F.; Rodríguez, P. Control of power converters in AC microgrids. *IEEE Transactions on Power Electronics* **2012**, *27*(11), 4734–4749. https://doi.org/10.1109/TPEL.2012.2199334.
21. López González, D.M.; Garcia Rendon, J. Opportunities and challenges of mainstreaming distributed energy resources towards the transition to more efficient and resilient energy markets. *Renewable and Sustainable Energy Reviews* **2022**, *157*, 112018. https://doi.org/10.1016/J.RSER.2021.112018.
22. Ilyushin, P.V.; Pazderin, A.V. Requirements for power stations islanding automation an influence of power grid parameters and loads. In Proceedings of the 2018 Int. Conf. on Industrial Engineering, Applications and Manufacturing (ICIEAM), Moscow, Russia, 15–18 May 2018.
23. Prabhakar, K.; Jain, S.K.; Padhy, P.K. Inertia estimation in modern power system: A comprehensive review. *Electric Power Systems Research* **2022**, *211*, 108222. https://doi.org/10.1016/J.EPSR.2022.108222.
24. Musca, R.; Vasile, A.; Zizzo, G. Grid-forming converters. A critical review of pilot projects and demonstrators. *Renewable and Sustainable Energy Reviews* **2022**, *165*, 112551. https://doi.org/10.1016/J.RSER.2022.112551.
25. Ilyushin, P.; Volnyi, V.; Suslov, K.; Filippov, S. Review of Methods for Addressing Challenging Issues in the Operation of Protection Devices in Microgrids with Voltages of up to 1 kV That Integrates Distributed Energy Resources. *Energies* **2022**, 15, 9186. https://doi.org/10.3390/EN15239186.
26. Ghadi, M. J.; Rajabi, A.; Ghavidel, S.; Azizivahed, A.; Li, L.; Zhang, J. From active distribution systems to decentralized microgrids: A review on regulations and planning approaches based on operational factors. *Applied Energy* **2019**, *253*, 113543. https://doi.org/10.1016/J.APENERGY.2019.113543.
27. Sivakumar, K.; Jayashree, R.; Danasagaran, K. Efficiency-driven planning for sizing of distributed generators and optimal construction of a cluster of microgrids. *Engineering Science and Technology, an International Journal* **2021**, *24*(5), 1153–1167. https://doi.org/10.1016/J.JESTCH.2021.02.015.
28. Sanusi, J.; Oghenewvogaga, O.; Adetokun, B.B.; Abba, A.M. In Proceedings of the 2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON). Lagos, Nigeria, 05-07 April 2022. DOI: 10.1109/NIGERCON54645.2022.9803162.
29. Jabbari-Sabet, R.; Moghaddas-Tafreshi, S.M.; Mirhoseini, S.S. Microgrid operation and management using probabilistic reconfiguration and unit commitment. *International Journal of Electrical Power & Energy Systems* **2016**, *75*, 328–336. https://doi.org/10.1016/J.IJEPES.2015.09.012.
30. Dorahaki, S.; Rashidinejad, M.; Fatemi Ardestani, S.F.; Abdollahi, A.; Salehizadeh, M.R. An integrated model for citizen energy communities and renewable energy communities based on clean energy package: A two-stage risk-based approach. *Energy* **2023**, *277*, 127727. https://doi.org/10.1016/J.ENERGY.2023.127727.
31. Hai, T.; Zhou, J.; Rezvani, A.; Le, B.N.; Oikawa, H. Optimal energy management strategy for a renewable based microgrid with electric vehicles and demand response program. *Electric Power Systems Research* **2023**, *221*, 109370. https://doi.org/10.1016/J.EPSR.2023.109370.
32. di Somma, M.; Graditi, G.; Heydarian-Forushani, E.; Shafie-khah, M.; Siano, P. Stochastic optimal scheduling of distributed energy resources with renewables considering economic and environmental aspects. *Renewable Energy* **2018**, *116*, 272–287. https://doi.org/10.1016/J.RENENE.2017.09.074.
33. Bornapour, M.; Hooshmand, R.A.; Khodabakhshian, A.; Parastegari, M. Optimal stochastic scheduling of CHP-PEMFC, WT, PV units and hydrogen storage in reconfigurable micro grids considering reliability enhancement. *Energy Conversion and Management* **2017**, *150*, 725–741. https://doi.org/10.1016/J.ENCONMAN.2017.08.041.
34. Kumar, A.; Deng, Y.; He, X.; Singh, A.R.; Kumar, P.; Bansal, R.C.; Bettayeb, M.; Ghenai, C.; Naidoo, R.M. Impact of demand side management approaches for the enhancement of voltage stability load ability and customer satisfaction index. *Applied Energy* **2023**, *339*, 120949. https://doi.org/10.1016/J.APENERGY.2023.120949.

35. Mochi, P.; Pandya, K.; Soares, J.; Vale, Z. Optimizing Power Exchange Cost Considering Behavioral Intervention in Local Energy Community. *Mathematics* **2023**, *11*(10). https://doi.org/10.3390/MATH11102367.
36. Beenish, S.; Ahmad, A. Optimization of Microgrid Energy Cost with Electrical Vehicles and Demand Response. *PakJET* **2023**, 6, 1, pp. 57-62. DOI: https://doi.org/10.51846/vol6iss1pp57-62.
37. Hemmati, R. Dynamic expansion planning in active distribution grid integrated with seasonally transferred battery swapping station and solar energy. *Energy* **2023**, *277*, 127719. https://doi.org/10.1016/J.ENERGY.2023.127719.
38. Ilyushin, P.; Filippov, S.; Kulikov, A.; Suslov, K.; Karamov, D. Specific Features of Operation of Distributed Generation Facilities Based on Gas Reciprocating Units in Internal Power Systems of Industrial Entities. *Machines* **2022**, 10, 693. https://doi.org/10.3390/machines10080693.
39. Gielen, D.; Boshell, F.; Saygin, D.; Bazilian, M.D.; Wagner, N.; Gorini, R. The role of renewable energy in the global energy transformation. *Energy Strategy Reviews* **2019**, *24*, 38–50. https://doi.org/10.1016/J.ESR.2019.01.006.
40. Zhan, W.; Wang, Z.; Zhang, L.; Liu, P.; Cui, D.; Dorrell, D.G. A review of siting, sizing, optimal scheduling, and cost-benefit analysis for battery swapping stations. *Energy* **2022**, *258*, 124723. https://doi.org/10.1016/J.ENERGY.2022.124723.
41. Rahimi, M.; Ardakani, F.J.; Olatujoye, O. Improving flexible optimal scheduling of virtual power plants considering dynamic line rating and flexible supply and demand. *International Journal of Electrical Power & Energy Systems* **2023**, *150*, 109099. https://doi.org/10.1016/J.IJEPES.2023.109099.
42. Cagnano, A.; de Tuglie, E.; Mancarella, P. Microgrids: Overview and guidelines for practical implementations and operation. *Applied Energy* **2020**, *258*, 114039. https://doi.org/10.1016/J.APENERGY.2019.114039.
43. *IEEE STD 1547-2018*; IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. IEEE: Manhattan, NY, USA, 2018; pp. 1–138.
44. IEC 61000-4-30:2015+AMD1:2021 CSV|IEC Webstore. (n.d.). IEEE 115 [115-2019—IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis. 2020. Available online: https://webstore.iec.ch/publication/68642]/ (accessed on 10 June 2023).
45. IEC 61508:2010 CMV|IEC Webstore. (n.d.). Available online: https://webstore.iec.ch/publication/22273 (accessed on 11 June 2023).
46. IEC 61499-1:2012|IEC Webstore. (n.d.). Available online: https://webstore.iec.ch/publication/5506&preview=1 (accessed on 11 June 2023).
47. IEC 61499-2:2012|IEC Webstore. (n.d.). Available online: https://webstore.iec.ch/publication/5507 (accessed on 11 June 2023).
48. IEC 61499-4:2013|IEC Webstore. (n.d.). Available online: https://webstore.iec.ch/publication/5508 (accessed on 11 June 2023).
49. IEC 61970:2023 SER|IEC Webstore| Automation, Cyber Security, Smart City, Smart Energy, Smart Grid, CGMES. (n.d.). Available online: https://webstore.iec.ch/publication/61167 (accessed on 11 June 2023).
50. IEC Smart Grid Standardization Roadmap. International Electrotechnical Commission (IEC), Tech. Rep. Ed. 1.0, 2010. SMB Smart Grid Strategic Group (SG3). Publishing house: IEC, Geneva, Switzerland. – 136 p. https://www.smartgrid.gov/files/documents/IEC_Smart_Grid_Standardization_Roadmap_201005.pdf (accessed on 10 June 2023).
51. Tissue Overview of All Parts|IEC 61850 Tissue Database. (n.d.). Available online: https://iec61850.tissue-db.com/parts.mspx (accessed on 12 June 2023).
52. IEC 62351:2023 SER|IEC Webstore|Cyber Security, Smart City. (n.d.). Available online: https://webstore.iec.ch/publication/6912 (accessed on 14 June 2023).
53. IEC TR 62357-1:2016|IEC Webstore|Smart Energy, Smart Grid. (n.d.). Available online: https://webstore.iec.ch/publication/26251 (accessed on 14 June 2023).
54. IEC TR 62357-2:2019|IEC Webstore. (n.d.). Available online: https://webstore.iec.ch/publication/28523 (accessed on 14 June 2023).
55. IEEE Std P2030|IEEE Standards Coordinating Committee 21 (SCC21). (n.d.). Available online: https://sagroups.ieee.org/scc21/standards/ieee-std-2030-2011/ (accessed on 14 June 2023).
56. IEEE SA—IEEE 2030.10-2021. (n.d.). Available online: https://standards.ieee.org/ieee/2030.10/10742/ (accessed on 14 June 2023).
57. ISO—ISO 52016-1:2017—Energy Performance of Buildings—Energy Needs for Heating and Cooling, Internal Temperatures and Sensible and Latent Heat Loads—Part 1: Calculation Procedures. (n.d.). Available online: https://www.iso.org/standard/65696.html (accessed on 14 June 2023).
58. IEC 61851-23:2014|IEC Webstore|LVDC. (n.d.). Available online: https://webstore.iec.ch/publication/6032 (accessed on June 2023).

59. Refaat, S.S.; Ellabban, O.; Bayhan, S.; Abu-Rub, H.; Blaabjerg, F.; Begovic, M.M. Smart Grid and Enabling Technologies. John Wiley & Sons, 2021.
60. Ilyushin, P.V.; Filippov, S.P. Under-frequency load shedding strategies for power districts with distributed generation. In Proceedings of the 2019 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM). 25-29 March 2019. Sochi, Russia. DOI: 10.1109/ICIEAM.2019.8743001.
61. Ilyushin, P.V.; Pazderin, A.V.; Seit, R.I. Photovoltaic power plants participation in frequency and voltage regulation. In Proceedings of the 17th International Ural Conf. on AC Electric Drives (ACED 2018), Ekaterinburg, Russia, 26–30 March 2018. https://doi.org/10.1109/ACED.2018.8341712.
62. Ajewole, T.O.; Olabode, O.E.; Babalola, O.S.; Omoigui, M.O. Use of experimental test systems in the application of electric microgrid technology across the sub-Saharan Africa: A review. *Sci. Afr.* **2020**, *8*, e00435. https://doi.org/10.1016/J.SCIAF.2020.E00435.
63. The CERTS Microgrid Concept, as Demonstrated at the CERTS/AEP Microgrid Test Bed. (n.d.). Available online: https://www.researchgate.net/publication/328600356_The_CERTS_Microgrid_Concept_as_Demonstrated_at_the_CERTSAEP_Microgrid_Test_Bed (accessed on 4 June 2023).
64. Jiayi, H.; Chuanwen, J.; Rong, X. A review on distributed energy resources and MicroGrid. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2472–2483. https://doi.org/10.1016/J.RSER.2007.06.004.
65. Hatziargyriou, N. (n.d.). Microgrids: Architectures and Control. Available online: https://books.google.com/books/about/Microgrids.html?hl=ru&id=ywxzAgAAQBA (accessed on 10 June 2023).
66. Case Studies of Smart Community Demonstration Project|NEDO. (n.d.). Available online: https://www.nedo.go.jp/english/news/reports_20130222.html#India (accessed on 11 June 2023).
67. Jayawarna, N.; Jones, C.; Barnes, M.; Jenkins, N. Operating MicroGrid energy storage control during network faults. In Proceedings of the 2007 IEEE International Conference on System of Systems Engineering, SOSE, San Antonio, TX, USA, 16–18 April 2007. https://doi.org/10.1109/SYSOSE.2007.4304254.
68. Krishnamurthy, S.; Jahns, T.M.; Lasseter, R.H. The operation of diesel gensets in a CERTS microgrid. In Proceedings of the IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century, PES, Pittsburgh, PA, USA, 20–24 July 2008. https://doi.org/10.1109/PES.2008.4596500.
69. Bossi, C.; Degner, T.; Tselepis, S. Distributed generation with high penetration of renewable energy sources. In *Dispower, Final Public Report, Laboratory Tests Case Studies and Field Experience*; Kessel, Germany, 2006. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=wwOk4OoAAAAJ&citation_for_view=wwOk4OoAAAAJ:M3ejUd6NZC8C.
70. Lidula, N.W.A.; Rajapakse, A.D. Microgrids research: A review of experimental microgrids and test systems. *Renew. Sustain. Energy Rev.* **2011**, *15*, 186–202. https://doi.org/10.1016/J.RSER.2010.09.041.
71. Martin-Martínez, F.; Sánchez-Miralles, A.; Rivier, M. A literature review of Microgrids: A functional layer based classification. *Renew. Sustain. Energy Rev.* **2016**, *62*, 1133–1153. https://doi.org/10.1016/J.RSER.2016.05.025.
72. Zhang, D.; Kong, Q. Renewable energy policy, green investment, and sustainability of energy firms. *Renewable Energy* **2022**, *192*, 118–133. https://doi.org/10.1016/J.RENENE.2022.04.092.
73. Kavousi-Fard, A.; Khodaei, A.; Bahramirad, S. Improved efficiency, enhanced reliability and reduced cost: The transition from static microgrids to reconfigurable microgrids. *The Electricity Journal* **2016**, *29*(10), 22–27. https://doi.org/10.1016/J.TEJ.2016.11.007.
74. Koubai, N.; Bouyakoub, F. Myrestaurant: A smart restaurant with a recommendation system. *International Journal of Computing and Digital Systems* **2019**, *8*(02), 143-156.
75. Shahidehpour, M.; Fotuhi-Friuzabad, M. Grid modernization for enhancing the resilience, reliability, economics, sustainability, and security of electricity grid in an uncertain environment. In *Scientia Iranica D* (Issue 6), 2016. www.scientiairanica.com.
76. Rodrigues, S.D.; Garcia, V.J. Transactive energy in microgrid communities: A systematic review. *Renewable and Sustainable Energy Reviews* **2023**, *171*, 112999. https://doi.org/10.1016/J.RSER.2022.112999.
77. Alemohammad, S.H.; Mashhour, E.; Saniei, M. A market-based method for reconfiguration of distribution network. *Electric Power Systems Research* **2015**, *125*, 15–22. https://doi.org/10.1016/J.EPSR.2015.03.014.
78. Gazijahani, F.S.; Salehi, J. Integrated DR and reconfiguration scheduling for optimal operation of microgrids using Hong's point estimate method. *International Journal of Electrical Power and Energy Systems* **2018**, *99*, 481–492. https://doi.org/10.1016/j.ijepes.2018.01.044.
79. Papadimitrakis, M.; Giamarelos, N.; Stogiannos, M.; Zois, E.N.; Livanos, N.A.I.; Alexandridis, A. Metaheuristic search in smart grid: A review with emphasis on planning, scheduling and power flow optimization applications. *Renewable and Sustainable Energy Reviews* **2021**, *145*, 111072. https://doi.org/10.1016/J.RSER.2021.111072.

80. Tooryan, F.; Hassanzadeh Fard, H.; Collins, E.R.; Jin, S.; Ramezani, B. Optimization and energy management of distributed energy resources for a hybrid residential microgrid. *Journal of Energy Storage* **2020**, *30*, 101556. https://doi.org/10.1016/J.EST.2020.101556.
81. Chukkaluru, S.; Ramprabhakar, J. Optimization Techniques for Operationand Control of Microgrids Review. *Journal of Green Engineering* **2018**, *8*, 621–644. https://doi.org/10.13052/jge1904-4720.847.
82. Kiptoo, M.K.; Lotfy, M.E.; Adewuyi, O.B.; Conteh, A.; Howlader, A.M.; Senjyu, T. Integrated approach for optimal techno-economic planning for high renewable energy-based isolated microgrid considering cost of energy storage and demand response strategies. *Energy Conversion and Management* **2020**, *215*, 112917. https://doi.org/10.1016/J.ENCONMAN.2020.112917.
83. Esmaili, M.; Firozjaee, E.C.; Shayanfar, H.A. Optimal placement of distributed generations considering voltage stability and power losses with observing voltage-related constraints. *Applied Energy* **2014**, *113*, 1252–1260. https://doi.org/10.1016/J.APENERGY.2013.09.004.
84. Gamarra, C.; Guerrero, J.M.; Montero, E. A knowledge discovery in databases approach for industrial microgrid planning. *Renewable and Sustainable Energy Reviews* **2016**, *60*, 615–630. https://doi.org/10.1016/J.RSER.2016.01.091.
85. Zidan, A.; Gabbar, H.A.; Eldessouky, A. Optimal planning of combined heat and power systems within microgrids. *Energy* **2015**, *93*, 235–244. https://doi.org/10.1016/J.ENERGY.2015.09.039.
86. Liu, X.; Yan, Z.; Wu, J. Optimal coordinated operation of a multi-energy community considering interactions between energy storage and conversion devices. *Applied Energy* **2019**, *248*, 256–273. https://doi.org/10.1016/J.APENERGY.2019.04.106.
87. Khalilpour, R.; Vassallo, A. Planning and operation scheduling of PV-battery systems: A novel methodology. *Renewable and Sustainable Energy Reviews* **2016**, *53*, 194–208. https://doi.org/10.1016/J.RSER.2015.08.015.
88. Alsaidan, I.; Gao, W.; Khodaei, A. Optimal design of battery energy storage in stand-alone brownfield microgrids. *2017 North American Power Symposium, NAPS 2017*. https://doi.org/10.1109/NAPS.2017.8107245.
89. León, L.M.; Romero-Quete, D.; Merchán, N.; Cortés, C.A. Optimal design of PV and hybrid storage based microgrids for healthcare and government facilities connected to highly intermittent utility grids. *Applied Energy* **2023**, *335*, 120709. https://doi.org/10.1016/J.APENERGY.2023.120709.
90. Yang, Y.; Li, H.; Aichhorn, A.; Zheng, J.; Greenleaf, M. Sizing strategy of distributed battery storage system with high penetration of photovoltaic for voltage regulation and peak load shaving. *IEEE Transactions on smart grid* **2013**, *5*(2), pp. 982-991.
91. Yang, Y.; Bremner, S.; Menictas, C.; Kay, M. Battery energy storage system size determination in renewable energy systems: A review. *Renewable and Sustainable Energy Reviews* **2018**, *91*, pp. 109–125. https://doi.org/10.1016/J.RSER.2018.03.047.
92. Ilyushin, P.; Filippov, S.; Kulikov, A.; Suslov, K.; Karamov, D. Intelligent Control of the Energy Storage System for Reliable Operation of Gas-Fired Reciprocating Engine Plants in Systems of Power Supply to Industrial Facilities. *Energies* **2022**, 15, 6333. https://doi.org/ 10.3390/en15176333.
93. Chebabhi, A.; Tegani, I.; Benhamadouche, A.D.; Kraa, O. Optimal design and sizing of renewable energies in microgrids based on financial considerations a case study of Biskra, Algeria. *Energy Conversion and Management* **2023**, 291, 117270. https://doi.org/10.1016/J.ENCONMAN.2023.117270.
94. Wong, L.A.; Ramachandaramurthy, V.K.; Taylor, P.; Ekanayake, J.B.; Walker, S.L.; Padmanaban, S. Review on the optimal placement, sizing and control of an energy storage system in the distribution network. *Journal of Energy Storage* **2019**, *21*, pp. 489–504. https://doi.org/10.1016/J.EST.2018.12.015.
95. Jannesar, M.R.; Sedighi, A.; Savaghebi, M.; Guerrero, J.M. Optimal placement, sizing, and daily charge/discharge of battery energy storage in low voltage distribution network with high photovoltaic penetration. *Applied Energy* **2018**, *226*, 957–966. https://doi.org/10.1016/J.APENERGY.2018.06.036.
96. Dulău, L.I.; Abrudean, M.; Bică, D. Optimal Location of a Distributed Generator for Power Losses Improvement. *Procedia Technology* **2016**, *22*, 734–739. https://doi.org/10.1016/J.PROTCY.2016.01.032.
97. Kumar, M.; Soomro, A.M.; Uddin, W.; Kumar, L. Optimal Multi-Objective Placement and Sizing of Distributed Generation in Distribution System: A Comprehensive Review. *Energies* **2022**, 15(21), 7850. DOI: 10.3390/en15217850.
98. Park, H.; Kim, J.K.; Yi, S.C. Optimization of site utility systems for renewable energy integration. *Energy* **2023**, *269*, 126799. https://doi.org/10.1016/J.ENERGY.2023.126799.
99. Zou, W.; Sun, Y.; Gao, D.; Zhang, X.; Liu, J. A review on integration of surging plug-in electric vehicles charging in energy-flexible buildings: Impacts analysis, collaborative management technologies, and future perspective. *Applied Energy* **2023**, *331*, 120393. https://doi.org/10.1016/J.APENERGY.2022.120393.
100. Kamal, M.M.; Ashraf, I.; Fernandez, E. Planning and optimization of microgrid for rural electrification with integration of renewable energy resources. *Journal of Energy Storage* **2022**, *52*, 104782. https://doi.org/https://doi.org/10.1016/j.est.2022.104782.

101. Akram, U.; Khalid, M.; & Shafiq, S. Optimal sizing of a wind/solar/battery hybrid grid-connected microgrid system. *IET Renewable Power Generation* **2018**, *12*(1), 72–80. https://doi.org/https://doi.org/10.1049/iet-rpg.2017.0010.
102. Rehman, A.U.; Shafiq, A.; Ullah, Z.; Iqbal, S.; Hasanien, H.M. Implications of smart grid and customer involvement in energy management and economics. *Energy* **2023**, *276*, 127626. https://doi.org/10.1016/J.ENERGY.2023.127626.
103. Vankudoth L. Badar A. Lokesh Optimal Sizing of RES and BESS in Networked Microgrids based on Proportional Peer-to-Peer and Peer-to-Grid Energy Trading. *Energy Storage* **2023**. DOI: 10.1002/est2.464.
104. Rezaei, N.; Pezhmani, Y.; Khazali, A. Economic-environmental risk-averse optimal heat and power energy management of a grid-connected multi microgrid system considering demand response and bidding strategy. *Energy* **2022**, *240*, 122844. https://doi.org/10.1016/J.ENERGY.2021.122844.
105. Kryukov, A.; Suslov, K.; Ilyushin, P.; Akhmetshin, A. Parameter Identification of Asynchronous Load Nodes. *Energies* **2023**, 16, 1893. https://doi.org/10.3390/en16041893.
106. Alam, M.S.; Al-Ismail, F.S., Rahman, S.M., Shafiullah, M.; Hossain, M.A. Planning and protection of DC microgrid: A critical review on recent developments. *Engineering Science and Technology, an International Journal* **2023**, *41*, 101404. https://doi.org/10.1016/J.JESTCH.2023.101404.
107. Kulikov, A.; Ilyushin, P.; Suslov, K.; Filippov, S. Organization of Control of the Generalized Power Quality Parameter Using Wald's Sequential Analysis Procedure. *Inventions* **2023**, 8, 17. https://doi.org/10.3390/inventions8010017.
108. Ahmed, M.; Meegahapola, L.; Vahidnia, A.; Datta, M. Stability and Control Aspects of Microgrid Architectures-A Comprehensive Review. *IEEE Access* **2020**, *8*, 144730–144766. https://doi.org/10.1109/ACCESS.2020.3014977.
109. Eroshenko, S.A.; Ilyushin, P.V. Features of implementing multi-parameter islanding protection in power districts with distributed generation units. In Proceedings of the 2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 12–14 November 2018. https://doi.org/10.1109/RTUCON.2018.8659857.
110. Ali, S.S.; Choi, B.J. State-of-the-art artificial intelligence techniques for distributed smart grids: A review. *Electronics* **2020**, *9*(6), 1030. DOI: 10.3390/electronics9061030.
111. Khan, F.; Siddiqui, M.A.B.; Rehman, A.U.; Khan, J.; Asad, M.T.S.A.; Asad, A. IoT based power monitoring system for smart grid applications. In *2020 International Conference on Engineering and Emerging Technologies (ICEET).* IEEE 2020, pp. 1-5.
112. Dunuweera, M.S.; Porawagamage, G.D.; Hemapala, K.T.M.U.; De Silva, N. Design and implementation of an optimized communication method for Remote Meter Reading using Zigbee. In *2017 Third International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB).* IEEE 2017, pp. 231-236.
113. Ben Youssef, N.E.H. Analytical analysis of information-centric networking in smart grids. *International Journal of Wireless Information Networks* **2022**, *29*(3), 354-364. DOI: 10.1007/s10776-022-00565-8.
114. Dileep, G. A survey on smart grid technologies and applications. *Renewable energy* **2020**, *146*, 2589-2625. DOI: 10.1016/j.renene.2019.08.092.
115. Abdi, H.; Beigvand, S.D.; Scala, M. A review of optimal power flow studies applied to smart grids and microgrids. *Renewable and Sustainable Energy Reviews* **2017**, *71*, 742–766. https://doi.org/10.1016/J.RSER.2016.12.102.
116. Koltsaklis, N.E.; Giannakakis, M.; Georgiadis, M.C. Optimal energy planning and scheduling of microgrids. *Chemical Engineering Research and Design* **2018**, *131*, 318–332. https://doi.org/10.1016/J.CHERD.2017.07.030.
117. Zheng, Z.; Yang, S.; Guo, Y.; Jin, X.; Wang, R. Meta-heuristic Techniques in Microgrid Management: A Survey. *Swarm and Evolutionary Computation* **2023**, *78*, 101256. https://doi.org/10.1016/J.SWEVO.2023.101256.
118. Maier, H.R.; Razavi, S.; Kapelan, Z.; Matott, L.S.; Kasprzyk, J.; Tolson, B.A. Introductory overview: Optimization using evolutionary algorithms and other metaheuristics. *Environmental Modelling & Software* **2019**, *114*, 195–213. https://doi.org/10.1016/J.ENVSOFT.2018.11.018.
119. Memari, M.; Karimi, A.; Hashemi-Dezaki, H. Reliability evaluation of smart grid using various classic and metaheuristic clustering algorithms considering system uncertainties. *International Transactions on Electrical Energy Systems* **2021**, 31(6). DOI: 10.1002/2050-7038.12902.
120. Das, B.K.; Hoque, N.; Mandal, S.; Pal, T.K.; Raihan, M.A. A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh. *Energy* **2017**, *134*, 775–788. https://doi.org/10.1016/J.ENERGY.2017.06.024.
121. Li, W.; Wang, R.; Zhang, T.; Ming, M.; Lei, H. Multi-scenario microgrid optimization using an evolutionary multi-objective algorithm. *Swarm and Evolutionary Computation* **2019**, *50*, 100570. https://doi.org/10.1016/J.SWEVO.2019.100570.

122. Bharothu, J.N.; Sridhar, M.; Rao, R.S. Modified adaptive differential evolution based optimal operation and security of AC-DC microgrid systems. *International Journal of Electrical Power & Energy Systems* **2018**, *103*, 185–202. https://doi.org/10.1016/J.IJEPES.2018.05.003.
123. Mukherjee, D.; Mallick, S. Utilization of adaptive swarm intelligent metaheuristic in designing an efficient photovoltaic interfaced Static Synchronous Series Compensator. *Engineering Applications of Artificial Intelligence* **2023**, *123*, 106346. https://doi.org/10.1016/J.ENGAPPAI.2023.106346.
124. Suvorov, A.; Askarov, A.; Kievets, A. A freely configurable structure of virtual synchronous generator for grid-forming converters. *Electrical Engineering* **2023**. https://doi.org/10.1007/s00202-023-01742-5.
125. Tavana, M.; Kazemi, M.R.; Vafadarnikjoo, A.; Mobin, M. An Artificial Immune Algorithm for Ergonomic Product Classification Using Anthropometric Measurements. *Measurement: Journal of the International Measurement Confederation* **2016**, 93, 621-629. DOI: 10.1016/j.measurement.2016.09.007.
126. Katsigiannis, Y.A.; Georgilakis, P.S.; Karapidakis, E.S. Hybrid simulated annealing-tabu search method for optimal sizing of autonomous power systems with renewables. *IEEE Transactions on Sustainable Energy* **2012**, *3*(3), 330–338. https://doi.org/10.1109/TSTE.2012.2184840.
127. Thirunavukkarasu, M.; Sawle, Y.; Lala, H. A comprehensive review on optimization of hybrid renewable energy systems using various optimization techniques. *Renewable and Sustainable Energy Reviews* **2023**, *176*, 113192. https://doi.org/10.1016/J.RSER.2023.113192.
128. Srinivasan, D.; Ng, W.S.; Liew, A.C. Neural-network-based signature recognition for harmonic source identification. *IEEE Transactions on Power Delivery* **2006**, *21*(1), 398–405. https://doi.org/10.1109/TPWRD.2005.852370.
129. Maulik, A.; Das, D. Optimal operation of microgrid using four different optimization techniques. *Sustainable Energy Technologies and Assessments* **2017**, *21*, 100–120. https://doi.org/10.1016/J.SETA.2017.04.005.
130. Ahmed, M.; Abbas, G.; Jumani, T.; Rashid, N.; Bhutto, A.; Eldin, S. Techno-economic optimal planning of an industrial microgrid considering integrated energy resources. *Frontiers in Energy Research* **2023**, *11*, 12. https://doi.org/10.3389/fenrg.2023.1145888.
131. Borghei, M.; Ghassemi, M. Optimal planning of microgrids for resilient distribution networks. *International Journal of Electrical Power & Energy Systems* **2021**, *128*, 106682. https://doi.org/10.1016/J.IJEPES.2020.106682.
132. Wang, Y.; Huang, Y.; Wang, Y.; Li, F.; Zhang, Y.; Tian, C. Operation Optimization in a Smart Micro-Grid in the Presence of Distributed Generation and Demand Response. *Sustainability* **2018**, *10*, 847. https://doi.org/10.3390/su10030847.
133. Moretti, L.; Astolfi, M.; Vergara, C.; Macchi, E.; Pérez-Arriaga, J.I.; Manzolini, G. A design and dispatch optimization algorithm based on mixed integer linear programming for rural electrification. *Applied Energy* **2019**, *233–234*, 1104–1121. https://doi.org/10.1016/J.APENERGY.2018.09.194.
134. Liu, D.; Zhang, C.; Chen, G.; Xu, Y.; Dong, Z.Y. Stochastic security-constrained optimal power flow for a microgrid considering tie-line switching. *International Journal of Electrical Power & Energy Systems* **2022**, *134*, 107357. https://doi.org/10.1016/J.IJEPES.2021.107357.
135. Grover-Silva, E.; Heleno, M.; Mashayekh, S.; Cardoso, G.; Girard, R.; Kariniotakis, G. A stochastic optimal power flow for scheduling flexible resources in microgrids operation. *Applied Energy* **2018**, *229*, 201–208. https://doi.org/10.1016/J.APENERGY.2018.07.114.
136. Riva Sanseverino, E.; Nguyen Quang, N.; di Silvestre, M.L.; Guerrero, J.M.; Li, C. Optimal power flow in three-phase islanded microgrids with inverter interfaced units. *Electric Power Systems Research* **2015**, *123*, 48–56. https://doi.org/10.1016/J.EPSR.2015.01.020.
137. Hai, T.; Zhou, J.; Muranaka, K. Energy management and operational planning of renewable energy resources-based microgrid with energy saving. *Electric Power Systems Research* **2023**, *214*, 108792. https://doi.org/10.1016/J.EPSR.2022.108792.
138. Shamarova, N.; Suslov, K.; Ilyushin, P.; Shushpanov, I. Review of Battery Energy Storage Systems Modeling in Microgrids with Renewables Considering Battery Degradation. *Energies* **2022**, 15, 6967. https://doi.org/10.3390/en15196967.
139. Ruban, N.; Suvorov, A.; Andreev, M.; Ufa, R.; Askarov, A.; Gusev, A.; Bhalja, B. Software and Hardware Decision Support System for Operators of Electrical Power Systems. *IEEE Transactions on Power Systems* **2021**, 36(5), pp. 3840-3848. https://doi.org/10.1109/TPWRS.2021.3063511.
140. Meng, Y.; Wang, Y.; Sun, S.; Wang, S.; Zhang, H. Multi-objective optimal dispatching of demand response-enabled microgrid considering uncertainty of renewable energy generations based on two-level iterative strategy. *Energy Reports* **2023**, *9*, 1842–1858. https://doi.org/10.1016/J.EGYR.2022.12.149.
141. Ma, Y.; Zhang, M.; Yang, H.; Wang, X.; Xu, J.; Hu, X. Decentralized and coordinated scheduling model of interconnected multi-microgrid based on virtual energy storage. *International Journal of Electrical Power & Energy Systems* **2023**, *148*, 108990. https://doi.org/10.1016/J.IJEPES.2023.108990.
142. Stevanato, N.; Pellecchia, G.; Sangiorgio, I.; Shendrikova, D.; Soares, C.A.; Mereu, R.; Colombo, E. Planning third generation minigrids: Multi-objective optimization and brownfield investment approaches in

modelling village-scale on-grid and off-grid energy systems. *Renewable and Sustainable Energy Transition* **2023**, *3*, 100053. https://doi.org/10.1016/J.RSET.2023.100053.
143. Dufo-López, R.; Cristóbal-Monreal, I.R.; Yusta, J.M. Optimization of PV-wind-diesel-battery stand-alone systems to minimise cost and maximise human development index and job creation. *Renewable Energy* **2016**, *94*, 280–293. https://doi.org/10.1016/J.RENENE.2016.03.065.
144. Singh, P.; Pandit, M.; Srivastava, L. Multi-objective optimal sizing of hybrid micro-grid system using an integrated intelligent technique. *Energy* 2023, *269*, 126756. https://doi.org/10.1016/J.ENERGY.2023.126756.
145. Azimian, M.; Amir, V.; Mohseni, S.; Brent, A.C.; Bazmohammadi, N.; Guerrero, J.M. Optimal Investment Planning of Bankable Multi-Carrier Microgrid Networks. *Applied Energy* **2022**, *328*, 120121. https://doi.org/10.1016/J.APENERGY.2022.120121.
146. Hubble, A.H.; Ustun, T.S. Composition, placement, and economics of rural microgrids for ensuring sustainable development. *Sustainable Energy, Grids and Networks* **2018**, *13*, 1–18. https://doi.org/10.1016/J.SEGAN.2017.10.001.
147. Alagoz, B.B.; Kaygusuz, A.; Karabiber, A. A user-mode distributed energy management architecture for smart grid applications. *Energy* **2012**, *44*(1), 167–177. https://doi.org/10.1016/J.ENERGY.2012.06.051.
148. Ilyushin, P.; Kulikov, A.; Suslov, K.; Filippov, S. An Approach to Assessing Spatial Coherence of Current and Voltage Signals in Electrical Networks. *Mathematics* **2022**, 10, 1768. https://doi.org/10.3390/math10101768.
149. Li, Q.; Gao, M.; Lin, H.; Chen, Z.; Chen, M. MAS-based distributed control method for multi-microgrids with high-penetration renewable energy. *Energy* **2019**, *171*, 284–295. https://doi.org/10.1016/J.ENERGY.2018.12.167.
150. Muyeen, S.M.; Islam, S.M.; Blaabjerg, F. Variability, scalability and stability of microgrids. *Variability, Scalability and Stability of Microgrids* **2019**, 1–623. https://doi.org/10.1049/pbpo139e.
151. Marín-Quintero, J.; Orozco-Henao, C.; Percybrooks, W.S.; Vélez, J.C.; Montoya, O.D.; Gil-González, W. Toward an adaptive protection scheme in active distribution networks: Intelligent approach fault detector. *Applied Soft Computing* **2021**, 98, 106839. https://doi.org/10.1016/J.ASOC.2020.106839.
152. Kulikov, A.L., Ilyushin, P.V., Suslov, K.V., Karamov, D.N. Coherence of digital processing of current and voltage signals at decimation for power systems with a large share of renewable power stations. *Energy Reports* **2022**, 8. 1464–1478.
153. Kaur, G.; Prakash, A.; Rao, K.U. A critical review of Microgrid adaptive protection techniques with distributed generation. *Renewable Energy Focus* **2021**, 39, 99–109. https://doi.org/10.1016/J.REF.2021.07.005.
154. Alvarez de Sotomayor, A.; della Giustina, D.; Massa, G.; Dedè, A.; Ramos, F.; Barbato, A. IEC 61850-based adaptive protection system for the MV distribution smart grid. *Sustainable Energy, Grids and Networks* **2018**, *15*, 26–33. https://doi.org/10.1016/J.SEGAN.2017.09.003.
155. Shobole, A.A.; Wadi, M. Multiagent systems application for the smart grid protection. *Renewable and Sustainable Energy Reviews* **2021**, *149*, 111352. https://doi.org/10.1016/J.RSER.2021.111352.
156. Marín-Quintero, J.; Orozco-Henao, C.; Velez, J.C.; Bretas, A.S. Micro grids decentralized hybrid data-driven cuckoo search based adaptive protection model. *International Journal of Electrical Power & Energy Systems* **2021**, *130*, 106960. https://doi.org/10.1016/J.IJEPES.2021.106960.
157. Fan, X.; Dudkina, E.; Gambuzza, L.V.; Frasca, M.; Crisostomi, E. A network-based structure-preserving dynamical model for the study of cascading failures in power grids. *Electric Power Systems Research* **2022**, 209, 107987. https://doi.org/10.1016/J.EPSR.2022.107987.
158. Gungor, V.C.; Sahin, D.; Kocak, T.; Ergut, S.; Buccella, C.; Cecati, C.; Hancke, G.P. Smart grid technologies: Communication technologies and standards. *IEEE transactions on Industrial informatics* **2011**, *7*(4), 529-539.
159. Bayindir, R.; Colak, I.; Fulli, G.; Demirtas, K. Smart grid technologies and applications. *Renewable and sustainable energy reviews* **2016**, *66*, 499-516.
160. Ramezy, B.; Saadatmand, M.; Mozafari, B. Review of Communication Technologies for Smart Grid applications. In Proceedings of the National Conference on: New Approaches in Power Industry, Tehran, Iran, 2017. 31.