Renewable and Sustainable Energy Reviews 67 (2017) 341–363

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A comprehensive review on microgrid and virtual power plant concepts employed for distributed energy resources scheduling in power systems

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A R T I C L E I N F O

Article history:
Received 23 July 2015
Received in revised form
17 March 2016
Accepted 9 September 2016
Available online 16 September 2016

Keywords:
Demand response
Distributed energy resource
Microgrid
Renewable energy
Scheduling
Virtual power plant

A B S T R A C T

Due to different viewpoints, procedures, limitations, and objectives, the scheduling problem of distributed energy resources (DERs) is a very important issue in power systems. This problem can be solved by considering different frameworks. Microgrids and Virtual Power Plants (VPPs) are two famous and suitable concepts by which this problem is solved within their frameworks. Each of these two solutions has its own special significance and may be employed for different purposes. Therefore, it is necessary to assess and review papers and literature in this field. In this paper, the scheduling problem of DERs is studied from various aspects such as modeling techniques, solving methods, reliability, emission, uncertainty, stability, demand response (DR), and multi-objective standpoint in the microgrid and VPP frameworks. This review enables researchers with different points of view to look for possible applications in the area of microgrid and VPP scheduling.

Contents

1. Introduction

Electrical energy can be supplied in various ways, but the consumers want it with the highest quality, the lowest cost and the highest reliability. Microgrids and virtual power plants (VPPs) are two remarkable solutions for reliable supply of electricity in a power system. Since these structures include distributed energy

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http://dx.doi.org/10.1016/j.rser.2016.09.025
1364-0321/

resources (DERs), scheduling of these resources is then very important [1,2]. Microgrids and VPPs share some important features like the ability to integrate demand response (DR); generation of distributed renewable energy; and storage at the distribution level. It is estimated that some market participants share a lot of activities with these two platforms; however, there are some differences [3,4]:

- Microgrids may be in the grid-tied or grid-connected form, but VPPs are always in the grid-tied one.
- Microgrids can pose themselves as an island separated from the larger power grid but VPPs do not recommend this type of contingency.
- Microgrids normally require some levels of storage; however, the presence or absence of storage in VPPs is possible.
- Microgrids depend on hardware innovations such as smart inverters and switches, whereas VPPs heavily depend on smart metering and information technology.
- Microgrids include a fixed set of resources within a limited geographical area, whereas VPPs can combine a wide variety of resources in large geographic areas, and match them together.
- Microgrids are normally traded only in the form of retail distribution, while the VPPs can build a bridge to the wholesale market.
- Microgrids face legal and political hurdles, while VPPs can now be performed on the current structure and legal tariffs.

Given the lack of current standards, a variety of microgrid and VPP models are therefore on the increase. Some of them focus on their reliability, while other models concentrate on the maximization of the economic opportunities by selling the excess energy services to the larger networks [3,5]. So, this is very important to perform a comprehensive review by focusing on DER scheduling from different points of view.

Recently, some literature reviews have been published in the field of microgrid and VPP concepts by focusing on DERs to overcome concerns in power systems. Some of them are reviewed as follows.

Some features of microgrids are investigated in [6], and a literature review on the stochastic modeling and optimization tools for a microgrid is provided. The description of microgrid design principles considering the operational concepts and requirements arising from participation in active network management is presented in [7]. The paper proposes the application of IEC/ISO 62264 standards to microgrids and VPPs, along with a review of microgrids, including advanced control techniques, energy storage systems, and market participation. Reference [8] describes the developed operational concepts of microgrids that have an impact on their participation in active network management for achieving targets. The paper addresses the principles behind island-detection methods, black-start operation, fault management, and protection systems along with a review of power quality. Since the concept of smart controlled DER merits consideration, reference [9] reviews some VPP ideas and gives a general overview of VPP. Reference [10] reviews the challenges and the problems caused by charging/discharging of plug in electric vehicles and investigates their capabilities as a solution to integrate the renewable energy sources and DR programs in power systems. In [11], a review on uncertainty modeling methods for power system studies is given that makes sense about the strengths and weakness of these methods. The literature review in [12] reveals that the integration of DERs, operation, control, power quality issues, and stability of microgrid system should be explored to implement microgrid successfully in real power scenario. Reference [13] gives an idea about different optimization techniques, their advantage and disadvantage with respect to a wind farm. The main objective of [14] is to give a state-of-the-art description for distributed power generation systems based on renewable energy and to explore the power converters connected in parallel to grids which are distinguished by their contribution to the formation of the grid voltage and frequency. The study performed in [15] is aimed to review the basics of wind energy and pumped storage plant system along with their current status, applications, and challenges involved in their operation under deregulated market and optimization techniques used in the scheduling. Reference [16] reviews the concept of hybrid renewable energy systems and application of optimization tools and techniques to microgrids. In this reference, a framework of diverse objectives has been outlined for which optimization approaches were applied to empower the microgrid. A review of modeling and applications of renewable energy generation and storage sources is also presented. In [17], the technical literature on optimization techniques applied to microgrid planning is reviewed and the guide lines for innovative planning methodologies focused on economic feasibility are defined. Also, some trending techniques and new microgrid planning approaches are pointed out. Reference [18] presents an overview of the literature on residential DR systems; load-scheduling techniques; and the latest technology that supports residential DR applications. Furthermore, challenges are highlighted and analyzed to become relevant research topics with regard to the residential DR of smart grid. The literature review shows that most DR schemes suffer from an externality problem that involves the effect of high-level customer consumption on the price rates of other customers, especially during peak period. In [19], a review of different failure modes occurring in various microgrid components is presented and also a review on various fault diagnosis approaches available in the technical literature is provided. Reference [20] presents a literature review on microgrid central controller. The evolution and advancement of microgrid central controller technology is explored and presented in a compact form. The classification of microgrid central controllers based on the outcomes found in the process of review is proposed. The role of central controller in the domains of microgrid protection, stability, and power quality are also summarized. In [21], a review of existing optimization objectives, constraints, solution approaches, and tools used in microgrid energy management is presented. The contribution of [22] is to apply the literature review to the power quality problems and to test them in a real distribution system that has plug in electric vehicles and photovoltaic panels. The results show that a coordinated delay charge mode reduces loading on transformers at peak hours and improves voltage regulation. Additionally, it is shown that photovoltaic panels introduce a power factor reduction during daytime in the main feeder. Reference [23] offers a review of the research work carried out in planning, configurations, modeling, and optimization techniques of hybrid renewable energy systems for off-grid applications. This paper presents a review of various mathematical models proposed by different researchers. These models have been developed based on objective functions, economics, and reliability studies involving design parameters. Reference [24] provides a survey of control strategies for the converter interfaces of the DERs and shows detailed figures of the control schemes. In [25], scheduling methods are reviewed and categorized based on their computational techniques to integrate plug in electric vehicles and then, various existing approaches covering analytical scheduling are surveyed. Reference [26] proposes such strategies for integrating hybrid micro-generation power systems into the grid through homeostatic control as a means to reconcile power supply and DR management. These strategies can be designed and implemented in the microgrid supervisory control system for the purpose of eliciting energy efficiency and thriftiness in consumers to build energy sustainability in the system. Topologies and control strategies of multi-functional grid-connected inverters are reviewed in [27], and detailed explanation, comparison, and discussion on multi-functional grid-connected inverters are achieved.

Since, the microgrid and VPP concepts have some similar features and also have differences; many researchers have used them for different purposes in recent years. Therefore, it is very important for scientists and specialists to have a simultaneous perspective on them to select the best way for their DERs composition scheduling with regard to different aspects. With respect to the mentioned published reviews, the current paper concerns with some important contributions such as a survey on objective functions, reliability, reactive power, stability, and DR aspects in power systems for microgrid and VPP concepts comprehensively and completely. So, some different characteristics in the field of optimal scheduling and participation of DERs in microgrids and VPPs which have not been taken into consideration by the references or have not been investigated in detail are the modeling issues of scheduling, discussion of uncertainties, effect of emissions on the scheduling problem, reactive power consideration, control aspects, DR applications, stability and multi-objective consideration. Accordingly, an overview focusing on several cases including *Formulation Type and Objective Function* (stochastic or deterministic), *Solving Method* (mathematical or heuristic), *Uncertainty* (related to the renewable energies, load, price and etc.), *Reliability*, *Demand Response*, *Reactive Power*, *Emission*, *Stability*, *Control*, and *Multi-objective approach* has been carried out here. Therefore, the objective of this review is to consider the above subjects related to microgrid and VPP concepts simultaneously to show a suitable perspective for readers to select the best methods based on advantages in order to schedule the DERs in a power system. It is worth mentioning that in this paper, many different criteria such as the year of publication; journal and conference categories; and the subject, and novelty of papers are taken into consideration for the investigation and selection the literature. Here, the review is organized on the basis of the subject and novelty of the articles. Then, the papers are categorized on the basis of subjects such as formulations, solving methods, uncertainties, reliability, DR, etc.

2. Scheduling problem associated with formulation type and objective function

In a power system, utilization of new control methods along with DERs while considering security, quality, reliability levels, and availability of power causes these grids to be converted from the functionality state to a dynamic one, highlighting the microgrid concept. Also, since the penetration of DERs in the power systems is rapidly increasing, mostly with regard to the network control, providing ancillary services and improving the network performance are necessary. Therefore, providing new ways to control generation and prepare the appropriate grounds for their participation in the electricity market is essential. A suitable way to overcome the referred obstacles is using the VPP concept. As definition, a microgrid including various DERs shows significant improvements to reduce the costs, emissions, reliability, efficiency, and security in the power system. Also, to a set of loads, distributed generation and electrical energy storages when aggregated together are called VPPs. Therefore, using these expressions, microgrids and VPPs have the ability to schedule. It is assumed that microgrids and VPPs are the owner and the operator of generation units.

An illustrative microgrid energy management system (EMS) is shown in Fig. 1. Based on that, EMS is associated with policy, electricity market, load/DER/price forecast, customers, utility, loads, and DERs in a microgrid. EMS receives the load and energy resource forecasting data, customer information/preference, policy, and electricity market information to determine the best available controls on power flow, utility power purchases, load dispatch, and finally pre-formation of DER scheduling.

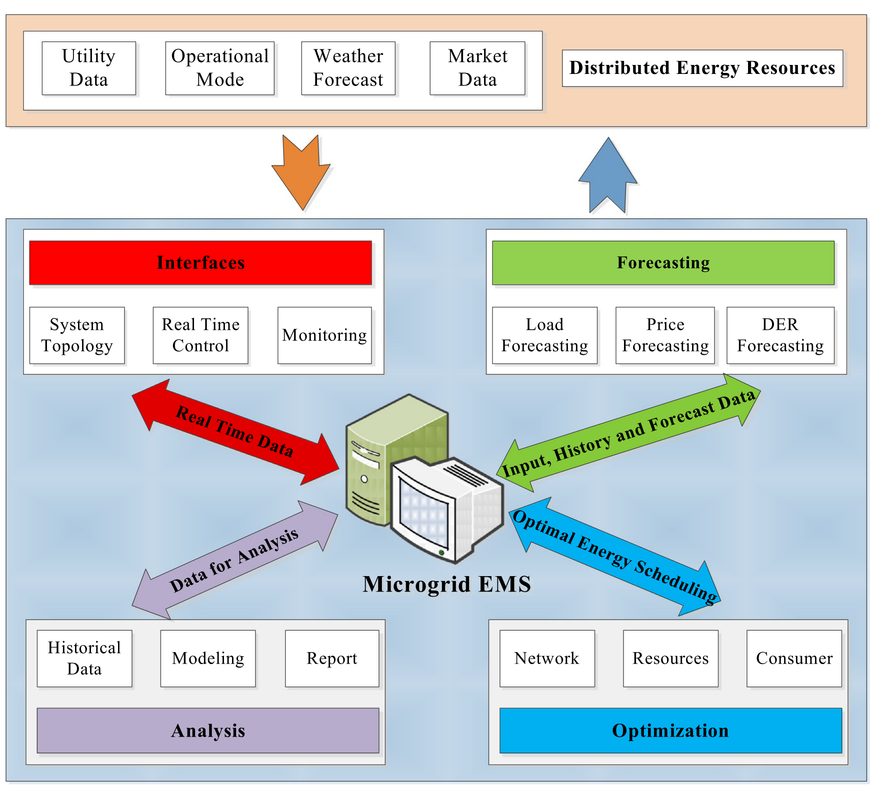

Fig. 1. EMS system in a typical microgrid.

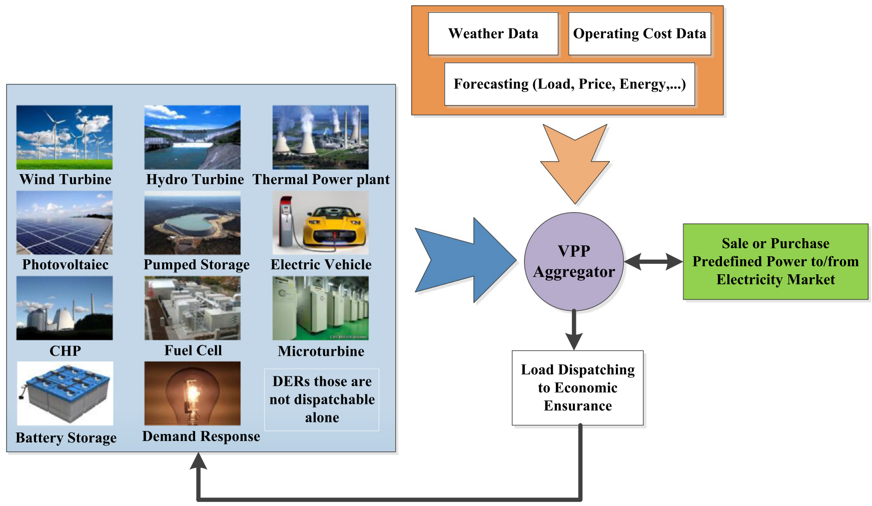

Fig. 2. A typical VPP structure with DER operation.

The structure of a VPP with regard to the DER aggregation is shown in Fig. 2. Based on it, the aggregator provides a power production profile. This is due to the negotiations with the power producers while considering their possible predictions for further power production profiles. As it can be seen in the figure, the process includes many details such as forecasting algorithms and scheduling of system components considering their technical and economical specifications.

In general, two types of formulation or modeling exist to be discussed for the optimal scheduling issues include stochastic or probabilistic and deterministic or robust modeling. The stochastic formulation for the generation of optimal scheduling problem in microgrids is presented in [28–46] and the deterministic modeling for the scheduling problem is proposed in [46–87]. Besides, the stochastic formulation for the generation of optimal scheduling problem in VPPs has been presented in [88–112] and the deterministic formulation for VPP frameworks has been defined in [113–144]. A stochastic procedure for the scheduling problem and then obtaining the optimal bidding in a microgrid or VPP is illustrated in Fig. 3. Based on this complete stochastic strategy, it can be seen that after receiving all scenarios and reducing them to a lower number, stochastic optimization is done and optimal bids of energies is resulted.

In the past, many papers focused on the deterministic formulation, but in recent years with regard to uncertain parameters in the modeling of the scheduling problems, stochastic formulation has attracted much attention too. As we know, stochastic

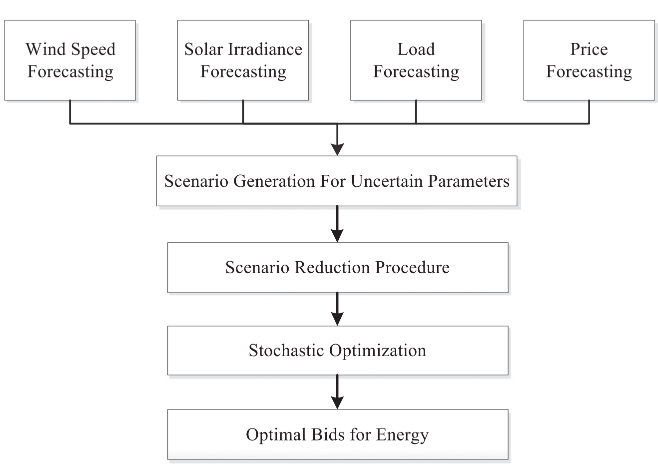

Fig. 3. Procedure of the bidding strategy in a microgrid or VPP.

programming models have been benefited from the fact that probability distributions ruling the data are known or can be estimated. The aim is to find some policy that is feasible for almost all the probable data instances and to maximize the anticipation of the random variables and some function of the decisions. In the modeling, deterministic simulations contain no random variables and no degree of randomness, but include many equations. They have known inputs and result in a unique set of outputs. The deterministic model is viewed as a beneficial access of reality that is easier to build and to interpret than a stochastic one. However, such models can be extremely intricate with a large number of inputs and outputs, and therefore they are often noninvertible and a single set of outputs can be generated by multiple sets of inputs. So, taking reliable account of the parameters and model uncertainty is critical, maybe even more than that for standard statistical models, but this is still an area that has received little consideration from statisticians.

One of the main objectives in a microgrid is supplying power with the aim of cost minimization. Therefore, with this objective in mind, an optimization problem considering different mandatory and optional constraints can be suggested. The output is the optimum power generated by different resources in the microgrid. So, it can be said that the scheduling problem of DERs in microgrid is expressed by (1) [34,48,80].

$$\begin{aligned}&\textbf{Minimum}\ \text{Cost}\\&\quad\text{Subject to:}\\&\qquad\text{Different Optional and / or Mandatory Constraints}\end{aligned} \tag{1}$$

Related to a VPP, the main purpose is to maximize its profit. It can be said that the scheduling is mainly based on maximization of profit subject to the constraints of the power system. When a VPP partly reduces its loads collection, this reduced load is a virtual generation. Some of the energy resources; when are alone in operation; don't have capacity, flexibility, and adequate controls for system administration and marketing activities. Therefore, these problems can be solved by creating a VPP through a group of energy resources and flexible loads. In general, the VPP scheduling problem of DERs is then defined in the form of Eq. (2) [95,117,137,138].

$$\begin{aligned}&\textbf{Maximum}\ \text{Profit}\\&\quad\text{Subject to:}\\&\qquad\text{Different Optional and / or Mandatory Constraints}\end{aligned} \tag{2}$$

The stochastic and deterministic formulation for scheduling in both of microgrid and VPP concepts can focus on different objective functions and related to that can obtain beneficial results and conclusions. Associated with different optimization objective functions (stochastic or deterministic), a complete review to know different considered terms of objective functions and the benefits obtained is performed in Table 1. As can be seen, a researcher can achieve many different aspects of different proposed objective functions for scheduling in both concepts with the stochastic or deterministic perspectives. In this table, all of the beneficial aspects of the proposed models such as accuracy, flexibility, time consuming issue, practicality and etc. are reviewed and listed to prepare a suitable and comprehensive outlook for readers.

3. Scheduling problem associated with solving method

If an optimization model is defined for a scheduling problem, there are some issues related to its solution. At first, some different input data should be prepared and then with the expression of optimization model, an appropriate method for its solution has to be selected. In this regard, many different methods have been carried out to solve the proposed optimal scheduling problems in the microgrids and VPPs. These solving methods can be divided into two main and important methods: mathematical and heuristic optimization methods.

The mathematical optimization related to microgrid can be categorized as linear programming [48,49,53,55], non-linear programming [62], mixed integer linear programming [29,32,33,41–45,47,52,54,59,60,64,68,77], mixed integer non-linear programming [34,46,50,54,60,63,67], time series and probabilistic methods [56], convolution method [53], non-linear regression technique [57], quadratic programming [58,66], mesh adaptive direct search [58], benders decomposition [60], connection matrix [61], branch-and-bound algorithm [62], lagrangian relaxation decomposition [65], combinatorial optimization [69], newton-raphson method [72] and constrained linear least-squares programming [74]. Also, the mathematical optimization related to VPP can be categorized in details as linear programming [120,122,134,135,140,143], non-linear programming [118], mixed integer linear programming [89–91,95,96,100–105,111–113,117,123], mixed integer non-linear Programming [98,107,133], interior point method and primal-dual sub-gradient algorithm [97,114,144], point estimate method [92,98], branch-and-bound method [99,139], primal-dual sub-gradient algorithm [115], decision Tree [88,116], event-driven service-oriented framework [118], hierarchical structure [119,121], dynamic programming [124], quadratic programming [99,126], game theory [93], area-based observe and focus algorithm [94], and fuzzy simulation and crisp equivalent [142].

As it can be seen, the mixed integer linear programming is the most appropriate approach for the solution of the scheduling problem in both microgrid and VPP frameworks. Sometimes the understudy modeling is nonlinear and it is difficult to solve it with the mentioned approaches, but with the use of some mathematical technics [47,52,54,95,101,111,113], the problem can become linear and its programming will be simple and appropriate to solve. The mentioned mathematical methods exhibit beneficial and unbeneficial properties in the problem of DERs scheduling. For linear programming and mixed integer linear programming, the main advantage is their simplicity since they make use of the available power resources in the scheduling problem, but they can work only with the decision variables that are linear; they do not consider the changes and evolutions of scheduling variables which are the unbeneficial features. These attributes work in a reverse direction for non-linear and mixed integer non-linear programming. Time series and probabilistic methods are other approaches whose goal is to identify the meaningful characteristics in the data that can be used in making statements about future outcomes of DER scheduling, but their disadvantage is their dependency on data history.

The most beneficial feature of mesh adaptive direct search [58] is the local exploration of the solution space that has been used to minimize the cost function of the system while constraining it to meet the customer demand and the system safety. In comparison with other proposed techniques, a significant reduction can be obtained. In [60], an iterative model based on the benders decomposition is employed to couple grid-connected operation as a master problem and islanded operation as a sub-problem. This model significantly reduces the problem computation burdens and enables a quick solution. In [65], the Lagrangian relaxation decomposition procedure is based on the dual optimization theory while minimizing the unit commitment cost. It generates a separable problem by integrating some coupling constraints into the objective function through the functions of the constraint violation with Lagrangian multipliers which are determined iteratively. Instead of solving the primal problem, one can solve the dual by maximizing the Lagrangian function with respect to the Lagrangian multipliers. The interior point method is another suitable approach to solve the nonlinear scheduling problems so that in [97,114], the VPP can maximize its economic benefit via local decision making and limited communication between distributed energy resources. It employs the centralized approach of the interior point method to solve the formulated optimal dispatch model and then uses the distributed primal-dual sub-gradient algorithm to solve the VPP optimal dispatch problem. Since the point estimate method [98] can be one of the best approaches to model the uncertainty of parameters like wind power or prices, then in order to have optimal bidding of a VPP in an electricity market, its use can be helpful to solve the scheduling of DERs in deregulated power systems in a scheduling procedure.

In the area of scheduling problem, the branch-and-bound method [62,99] enjoys some advantages such as the optimal selection of the next sub-problem, and having tighter bound to have shorter run time, so feasible solutions are found quickly. But its disadvantage is that it needs a lot of space to store the list; also, it might generate a lot of sub-problems in total requiring more run time to solve all sub-problems. Decision tree [116] is another method that implicitly performs VPP scheduling variable screening or feature selection and requires relatively little effort from VPP stakeholder for data preparation. Also, the nonlinear relationships existing between parameters (like power and market price) do not affect the tree performance, so it is easy to interpret and explain them to executives. In [124], dynamic programming approach is explained by tackling two elements of finding a local plan satisfying local constraints and minimizing the squared mismatch from the global production plan. So, by sending all the local production plans to a global planner, the sum of all production plans of a group of houses can be calculated to generate a global electricity output of the VPP. By using this method in an iterative approach, the aim is to minimize the mismatch by iteratively steering the local production plans in a mismatch-reducing direction. The scheduling problem of DERs in [142] facing a fuzzy chance constrained model, confronts two common ways to deal with its chance constraints. The first one is the fuzzy simulation in which random sampling is used to verify the credibility of chance constraints, but the result is only an estimation and the process is time consuming. The other one is to convert the chance constraints into their crisp equivalents that can be solved by traditional solutions making the process more efficient.

In addition to mathematical methods to solve the scheduling problem for microgrids, different algorithms and heuristic methods have been proposed which can be indicated as Binary Gravitational Search Algorithm (BGSA) [36], Binary Particle Swarm

Table 1
Survey of the optimization objective functions considering contributed terms and advantages perspectives.

Ref. No.	Objective Function Different Terms	Advantages of the Proposed Scheduling Optimization Function
[28]	energy, operational, startup and shutdown cost of distributed conventional generators	intensively use of the renewable resources, assistance of DISCOs to coordinate and operate intermittent renewable resources, purchasing power from the day-ahead market and minimize energy acquisition costs from the real-time market
[29]	capital cost of energy storage and inverter and operating cost of the distributed energy generation system and efficiency factor	preparation of guideline to designers of distributed energy generation system on how an energy storage should be scheduled to operate within the system to either achieve minimal investment cost or to enhance system energy efficiency
[30]	expectations of the global cost and energy not supplied combined with their respective risk values	possibility of optimizing expected performances while controlling the uncertainty in its achievement and also analyzing the contribution of each type of renewable DG technology indicating which is more suitable for specific preferences of the decision makers
[31]	generation and reserve power costs, and the cost-pertaining to the variations of the scheduling of the units caused by changes in the behaviors of wind and PV powers	decrease the system emission and increase the incentives of the owner of EV and responsive loads as well as wind and PV for the revenue obtained
[32]	facilities and customer charges, monthly power demand charges, time-of-use power demand charges, time-of-use energy charges inclusive of carbon taxation, costs of demand response measures, revenue from electricity sales, on-site generation fuel and O&M costs, carbon taxation on on-site generation, and annualized DER investment costs	providing the relatively small payback periods and also little impact of uncertainty in EV driving schedules on total energy costs, flexibility provided both by the large amount of EV adoption and the additional installation of local generation, although variation of the optimal adopted capacity depending on the EV availability
[33]	decentralized energy options for demand supply, and determining these options to suitably plug the existing demand supply gap at varying levels of grid unavailability	social, economic and policy level discussions to choose the best microgrid solution and enabling a dialog process with the stakeholders
[34]	cost of purchased power from the main grid, costs of reserve provided by DGs or DR loads, fixed running and start-up cost of DGs, generation running costs of DGs, load reduction costs of DR loads, cost of involuntary load shedding and cost of emissions	demand side participation in energy and reserve scheduling allowing reduction of the total operation costs and emission, increase the operation cost and DR participation in reserve scheduling changes DGs scheduling by inclusion of the emission target and prevention of DGs to be stand-by only for providing reserve
[35]	fuel cost of DGs, start-up and shut-down costs, emission cost and costs of power exchange between the microgrid and the utility	a true and well-distributed set of Pareto-optimal solutions which gives the microgrid controller several chances to select an appropriate power dispatch plan according to environmental or economical considerations
[36]	the expectation of operating costs over all possible set of scenarios	the feasibility and effectiveness to solve the unit commitment problem with wind power integration
[37]	energy losses, fuel consumption cost and the CO_2 emission	execution monitoring and anticipating forthcoming situations, adjusting the plan in accordance, capability of incorporation encouraging and suggest to incorporate into the microgrids software technology approaches to manage the uncertainties for accounting the dynamic
[38]	fuel cost for power generation by the units and the cost of start-up and shut-down	to improve the dependability of the optimal solutions with capturing more uncertainty spectrum
[39]	total revenue from bidding in market and selling power to end customers within the brace, the total generation, start-up and shut-down costs of DG units	more risky bids and the higher profits compared with deterministic bidding strategy
[40]	fuel cost for DGs, power exchange between the microgrid and the utility and the start-up and shut-down cost of the power sources	investigating the optimal management of some of the most well-known renewable power sources as well as storage devices in a day under different scenarios
[41]	fuel cost for producing electric power, start-up and shut-down costs of individual units, total pollutant emission cost of thermal generation units, total operational cost of gas turbine units and total gaseous emission (SO_2) cost	noticeable cost saving in both power system operation cost and pollutant gaseous emissions and more utilization of DER units
[42]	fuel, start-up and shut-down costs, valve point loading cost, and the start-up cost of hydro units	coping of ISO with the uncertainties of the daily hydrothermal generation scheduling problem, concerning of ISO about the system security with tolerable and reasonable total cost and application of the model in the large scale and real size system
[43]	revenue from selling of reserve and non-spinning reserve by hydro units, revenue of selling energy at spot market and start-up cost of hydro units	application of the model in the large scale and the real size power systems and rationale situation of the solution time
[44]	revenue from bilateral contract, expected profit over scenarios by hydro units, hydro units start-up cost, the expected downside risk for a retailer	GENCO is able to adopt different risk-control bidding strategies to gain acceptable benefit/risk trade-off between the expected benefits of financial activities and how much risk it is willing to assume
[45]	hydro units start-up cost, thermal operating cost including fuel, shut-down, start-up costs and valve point loadings cost	application of the model in the large scale and the real size power system and preparation a rationale solution time
[46]	energy and spinning and non-spinning reserves costs, lost opportunity cost and expected interruption cost	clearing of the market while considering AC load flow equations of network and also some system security related concerns such as bus voltage limits and branch flow constraints, more efficient utilization of energy and reserve resources as well as load curtailment and possible actions to cope with the contingencies
[47]	daily primary energy consumption	increasing the energy-saving effect by employing the power interchange, contributing the power interchange to energy savings rather than the heat interchange, decreasing the energy-saving effect of residential energy supply network employing power and heat interchanges with the increase in the number of residence units involved in the hot water supply network, Neglecting the energy loss from the pipes due to the hot water retention overestimates the energy-saving effect.
[48]	Initial and operational cost of energy and the reliability assessment	imposing the least energy cost with higher reliability for the consumers if the loads or the similar loads are connected to a separated feeder of a microgrid
Ref. No.	**Objective Function Different Terms**	**Advantages of the Proposed Scheduling Optimization Function**
[49]	annual electricity, fuel and maintenance cost and annualized capital cost of microgrid	offering a positive case for investment when compared with the situation where those demands are met via grid electricity and a boiler cooperative

Table 1 (*continued*)

Ref. No.	Objective Function Different Terms	Advantages of the Proposed Scheduling Optimization Function
		action rather than pure self-interest provides the best economic outcome for the microgrid, and also indicating that development of a fair settlement system between microgrid participants should be developed
[50]	fixed cost, production cost and start-up cost of the producers, the charge cost and the discharge benefit for energy storages and inclusion of producers' preference in operator's decisions	Increasing the revenue of the DSO while trying to remember the orientation of producers toward maximum profit by having their units online during the high price periods and minimizing the total system cost is also the main property of the model
[51]	price index of electricity, service quality index and air emission index	increasing the microgrid power generated from renewable energy resources
[52]	sale/purchase of electricity to national grid, sale of electricity to local market, sale of hydrogen, purchase of natural gas, purchase of biomass, penalty for demand that is not met and operational costs for the different facilities	effectiveness of the diversity constraint in maintaining diversity in electricity generation as well as in providing solutions that are easy to implement
[53]	fuel and other variable O&M costs, disregards long-run retirement and entry decisions	a power network in which fossil-fueled microgrids and a price on CO_2 emissions are included has the highest composite sustainability index
[54]	operational costs of the microgrid and the amount of pollutants released into the air such as SO_2 and NO_X caused by thermal units	implementing DR loads along with energy storages can reduce the daily operational cost noticeably and also it is implementable easily in the microgrid central controllers
[55]	operation cost of the cogeneration gas turbines, the boilers, and the photovoltaic system, and cost of electricity exchange with the external grid	achievement of significant reduction of operating cost, primary energy consumption and CO_2 emission with respect to a traditional scenario in the smart synergy between the local generation units and the external national grid, and also successfully transferring the smart grid concept from the confined area of a Campus to a larger area consisting for example in an urban residential or tertiary district
[56]	annual and monthly emissions available and monthly 24 h emission curve different from month to month according to the type of marginal units	significantly reduce pollutants, provided sufficient remuneration from CO_2 emission trading market participation
[57]	the power drawn from the grid and keeping the battery's state of charge above 60%	the battery is always ready by the starting time of the peak period with a high state of charge, which helps it to supply the load and reduce the power drawn from the grid during peak with the high tariff, and having a saving economic impact on the consumer and moreover, it is also beneficial to the utility grid since the total microgrid demand is shaved and made smoother
[58]	fuel cost, operation and maintenance cost, start-up cost, daily cost of purchased electricity, daily income for sold electricity and emissions of CO_2, SO_2 and NO_X	the capability of the proposed model and the proposed algorithm to achieve both reduction in the operatingcosts and meeting the load demand, and also the effect of changing the sold tariffs results in different optimal settings of the microgrid depending on the optimization technique
[59]	total annualized cost for the residential energy system, annual operation cost of distributed energy system, income from selling electricity to the grid, cost of purchasing electricity power from the grid, annual operational and maintenance cost, annualized system investment cost for CHP plants, PV arrays, back-up boilers, heat storage tanks, pipeline network and the microgrid and annual cost for carbon emissions	the adoption of DER technologies combined with a heating pipeline network and a microgrid
[60]	generation, start-up, and shut-down costs of dispatchable units, cost of power transfer from the main grid based on the market price at point of common coupling	providing significant reliability benefits while slightly increasing the microgrid total operation cost
[61]	reliability indices of customers in sections of a distribution system	the accuracy of the proposed technique is comparable to that of Monte-Carlo simulation, and the configuration of system divided into several microgrids changes the reliability of customers in the microgrids
[62]	cost of electricity production by CHP systems, cost of heat production by the boilers, total operation cost of PV systems, electricity purchased from upstream network and the revenue of selling electricity to the upstream network	optimizing the hourly heat and electricity generation schedules for individual factories, occurring the peak of most industrial electricity loads during daytime and coinciding with the maximum output of PV generation
[63]	revenue resulting from selling electricity to the upstream network, cost of electricity production by CHPs, cost of heat production by the boilers, cost of purchased electricity from upstream network and cost of interruptible loads	managing the factories such that when the price of electricity is low, part of the required electricity is purchased from the upstream network and, when the electricity price is high, the industrial microgrid will sell the electricity, and implementation of the interruptible loads of factories to increase the total profit and decrease the overall cost of industrial microgrid
[64]	operational cost and environmental impact	the microgrid is efficient in saving cost and reducing environmental impacts, the model can be further exploited to manage the capacity of each source at the planning and design phase, and balancing the reliance on the national grid and renewable sources
[65]	total thermal energy, fuel cost and start-up cost	the load following requirements can be reduced in the renewable-thermal units, peaking generators can be kept off during peak hours by utilizing renewable-battery, and the modeling is very flexible and it can be applied to any size of power system
[66]	cost functions associated with DERs, power sold or purchased to/from the electric utility and cost of energy storage device	stable operation of micro-grid with maintaining near fixed DC bus voltage under both grid-connected and islanding operations
[67]	generation cost, cost of importing energy from up grid and cost of load shedding and DR loads	exploiting the demand elasticity and significantly reduction of the total operation cost
[68]	cost of energy production and start-up and shut-down decisions, possible earnings and curtailment penalties	studying realistic and effective stochastic approaches to cope with inherent uncertainty due to renewable energy sources production, energy demand and prices
Ref. No.	**Objective Function Different Terms**	**Advantages of the Proposed Scheduling Optimization Function**
[69]	cost of energy consumed for the whole day	successfully scheduling the loads while saving money for the consumers as well as keeping the maximum demand curtailed at a limit which benefits the utility, making the DR case a win-win scenario
[70]	total investment cost included inner cost, environment cost and compensation cost	even when the disaster occurs to the power grid, the power loss in the microgrid is zero based on the economic investment. Also the capacities are not needed to guarantee the largest load demand in a day

Table 1 (*continued*)

Ref. No.	Objective Function Different Terms	Advantages of the Proposed Scheduling Optimization Function
[71]	DERs cost, start-up cost and shut-down cost	relevant considerations and procedures for the model fine-tuning and performance evaluation
[72]	generation cost	increasing the battery capacity when wind turbine and PV are installed together because the fluctuation of renewable generated power
[73]	generation, storage and load costs	excellent scalability properties, which allow concluding that framework is capable of fulfilling microgrid management system requirements
[74]	costs of each generation units (both electric and thermal)	development of specific functions able to reallocate the DER set points during the islanding maneuver and subsequent operation, with the minimum amount of required load shedding
[75]	fuel efficiency of the online generators and emissions	significantly improving of the fuel efficiency while reducing toxic emissions
[76]	inverter control parameters	satisfactorily regulation of the voltages and frequency in the microgrid by the EVs
[77]	reliability assessment indices	possible to improve the microgrid performance by finding weak points of the microgrid and implementing some suitable management methods for those weaknesses
[78]	fuel cost and start-up cost of the generating units	scalable, robust and easily reconfigurable multi-agent system, and also extendable model for managing and controlling any kind of power system with DERs by extending the functions of the agents and creating additional agents in the system
[79]	fuel, start-up and shut-down costs of DGs, costs of power exchange between the microgrid and the utility and the pollutants of CO_2, SO_2 and NO_X	demonstrating superior performances shows dynamic stability and excellent convergence of the swarms and yield to a true and well distributed set of Pareto-optimal solutions giving the system operators various options to select an appropriate power dispatch plan according to environmental or economical considerations
[80]	fuel cost of conventional units and small thermal units, paid consumers incentives, cost of hourly expected energy not served and the cost of EVs	responsibility of coordinating DERs in the most secure and reliable manner
[81]	total fuel cost	solution quality, computational efficiency, robustness and stability
[82]	generation cost of PV and FC, operating and maintenance costs, replacement cost of DER in microgrid at the end of its lifetime and battery wear cost	finding the optimal sizes of microgrid and DGs for the hybrid electricity mode in hybrid market, and decreasing the optimal power of DG units because of buying power from main utility grid
[83]	cost of producing/ buying electrical and thermal energy, maintenance cost, operation cost and start-up cost	indicate the viability of the mathematical model and proof the viability of evolutionary programming technique for obtaining near global optimal solution for the problem
[84]	investment cost, operation and maintenance cost, replacement cost, fuel cost of diesel generators, total fuel emissions produced by diesel generators and total loss of load probability	effectively employing of the proposed method for any composition of hybrid energy systems
[85]	worth of energy, electricity cost during the period of interruption of the main grid, electricity cost after the period of interruption till the end of the tariff period during which the interruption ends and electricity cost for the remaining tariff periods after the end of the interruption	providing cost advantage to loads with the increase in reliability
[86]	cost of grid electricity, cost of the external gas and operating and switching cost of local CHP generators	achieve near offline-optimal performance
[87]	technical performance of distributed power supply, local available energy resources and load demand, environment protection expenses and operation and maintenance expenses of microgrid power supply	prevent earlier convergence in algorithm, increase accuracy of optimization method and meet accuracy and promptness requirements with convergence speed
[88]	energy sold/bought by the VPP to/from the market, reserves of the DGs of the VPP, load served within the VPP, cost function of each DG or storage device	It is not required for renewable energy units to be specifically curtailed, moreover, the technique can tackle part of the stochastic behavior of the renewable energy DG through the various profitability levels considered
[89]	the revenue from the energy sold in the day-ahead energy market associated with the VPP, aggregated energy production directly injected into the electricity network, the energy procurement cost associated with the VPP aggregated load consumption directly absorbed from the network, and anticipated real-time production and consumption imbalance charges or revenues calculated on the basis of the balance market prices	enables a CVPP to act as a price-maker in a day-ahead market, minimizing at the same time the anticipated imbalance costs imposed from the balance market, the incorporation of DR schemes into the optimization model, and capability of the CVPP owner to decide the desired risk level prior the construction of his optimal bidding strategy
[90]	income from selling energy to the customers, revenues obtained from the energy sold in the future market, the expenditures incurred by the energy purchased in the contractual market, income/cost from selling/buying the excess/deficit production of the coalition units to/from the day-ahead market, cost of coalition forming contracts for a given medium-term period, and the risk measure	efficient and robust motivate VPP agents, coordination of the larger share of small distributed generation units and increasing the number of their coalition members as far as they could
Ref. No.	**Objective Function Different Terms**	**Advantages of the Proposed Scheduling Optimization Function**
[91]	control index of the power consumed by a number of electric space heaters in the building	controlling the parameters like CO_2 level and humidity using actuators for control of natural ventilation of the building
[92]	scheduled exchanged cash flow between VPP and the electricity market (energy market and spinning reserve market), selling power to and purchasing power from energy market, scheduled energy, spinning reserve up/down costs corresponding to the DR loads, start-up and shut-down costs of CHP, cost of CHP and boilers fuel, operational cost of electrical and thermal storages, scheduled energy, spinning reserve up/down costs of DG units, scheduled penalty for not served electrical loads, scheduled obtained revenue from end-consumers, expected supplementary revenue in the exchanged cash flow between VPP and the electricity market, expected supplementary energy costs of DG units and DR loads, expected supplementary penalty for not served electrical loads, and expected supplementary revenue in the exchanged cash flow between VPP and end-consumers	the VPP's reserve providing resources are not only able to compensate the plausible shortage of VPP's committed energy to the energy market due to the existing uncertainties, but also can bid the specific amounts of reserve to the spinning reserve market in some periods, also, the coordination performance of storages and the proposed DR resources could increase VPP's profit and reduce its dependency on the upstream network
[93]	controllable unit generating cost, cost of DR and cost of energy storage	applicable model and also providing a new idea for multi-VPP dispatch system

Table 1 (*continued*)

Ref. No.	Objective Function Different Terms	Advantages of the Proposed Scheduling Optimization Function
[94]	the fuel and start-up cost of DERs	effective share of the extra requirements of the pre-defined power sale profile after the power productions of the renewable energy units are transmitted to the grid, and reduction of the total weekly operating cost by the VPP structure
[95]	revenues and costs of energy production, positive and negative imbalance costs, and risk criterion	the wind farm imbalance costs and consequently its cost of participation in an energy market is decreased by a combined bidding from a wind farm and cascade hydro plants, the amount of positive and negative imbalance penalties affects the GENCO bidding strategy in day-ahead market, an ineffective imbalance mechanism brings losses to both market operator and GENCO, and the GENCO profit is decreased when its risk is minimized and it would not experience high and low profit scenarios
[96]	fuel cost of the CHPs and the boilers, revenues due to the electricity that is sold to the grid and the savings due to the self-consumption of the electricity generated by the CHP, total operational cost and imbalance cost	reduction of the deviation between the scheduled electricity and the actual delivery using the rescheduling strategy to reduce imbalance or cost
[97]	income from selling electricity to customers, fuel cost, charging/discharging costs of ES devices, cost of interrupting loads, cost of wind power and cost of purchasing electricity	employing extreme learning machine to estimate the nonlinear relationship between the wind power costs and wind turbine outputs, and transform the estimated relationship into a set of equality constraints in the optimal dispatch model to ensure the model is computable, determination of the optimal outputs of all DERs in the VPP via only limited communication between neighboring DERs
[98]	income from selling energy to the consumers, income from selling the excess production of theDG sources to the day-ahead market, cost of generation from DG units, operational, start-up and shut-down costs, and cost of curtailing dispatchable loads	effective and robust model, and also highly sensitive local operation of the DERs to the market price variations
[99]	costs of energy and spinning reserve markets, the purchase cost of electrical energy from the energy market to charge the battery of EVs, the purchase cost of electrical energy in order to meet the aggregator obligations in the spinning reserve market, the aggregator income resulted from participation in the spinning reserve market, the aggregator income resulted from being called by the ISO in order to generate electrical energy in the spinning reserve market, the aggregator income resulted from receiving the batteries charge cost from EV owners, and the aggregator income resulted from participation in the energy market	an aggregator can intelligently convert some threats to changes in market regulations and this can be an opportunity to increase the profit of itself and its customers and to enhance the market efficiency
[100]	the electricity sold/purchased in the day-ahead market, sold in the down-regulation market, and purchased in the up-regulation market, and the production and start-up cost of the CPP	in case of high day-ahead market prices, the CPP starts operating in the morning and stays on until the late evening, the PHSP operation is fairly independent on the WPP output, CPP output, and even the day-ahead market prices, in case of high day-ahead market price scenarios, the balancing market is mostly used for purchasing electricity, WPP output does not influence significantly the PHSP or the CPP operation, higher WPP output reduces the off-peak electricity purchased in the market, and the VPP association results in higher expected profits while slightly disturbing the individual operation of individual plants integrated in the VPP association
[101]	the impact of volatile energy resource	quantifying the effects of heat demand and generation forecasts
[102]	the electricity production and start-up cost of CPP	the choice of the CPP, especially its technical minimum characteristic is a major issue within the VPP set up, and the lower technical minimum results in less electricity wasted from renewable energy sources
[103]	the electricity sold in the market, and the electricity production and start-up cost of CPP	the amount of produced electricity by the CPP depends exclusively on the electricity price in the market, the amount of electricity produced by the renewable energy source does not influence the CPP production, and also, the technical minimum of CPP does not influence its production since CPP always produces electricity at its installed capacity
[104]	active power generated by DG and production cost of DG	effective and robust model
[105]	power interchange with grid and micro-CHP cost	facilitate the scheduling using micro-CHP system along with heat and electrical storage
Ref. No.	**Objective Function Different Terms**	**Advantages of the Proposed Scheduling Optimization Function**
[106]	active power wanted and power generated (total generation, wind power and PV power)	VPPs are able to play different roles in producing power and providing ancillary services
[107]	cost of power demand of load, active power charge of storage, active power discharge of storage, active power supply, active power generation of generation unit, excess active generated energy, active power reduction in DR program, non-supplied active energy demand, and differences of the bus voltage magnitude	suitable results for the management of reactive power by distributed generation owners
[108]	impact of cables on voltage deviation and active power and reactive power indices	to offer the opportunity to optimize the power flow in the network and thereby the voltage profile and optimization of the energy storage location by network configuration
[109]	fuel cost, start-up and shut-down costs and revenue from active generation of GENCOs, spinning and non-spinning reserves	regulator neglecting from simulation of short-term strategic behavior of players especially associated with collusion can cause the adverse consequences in long-term horizon and also the market rule may bankrupt the wind power plant and decrease the investment incentives for that
[110]	DER's electricity generation sold, operation costs of DER and penalty for undelivered energy	providing high quality solutions while meeting constraints
[111]	electricity sell/purchase in the day-ahead market, electricity sell/purchase in balancing market, operation, start-up and shut-down costs of the CPPs and risk measure formulation	the CPPs start operating when day-ahead energy prices are high, in the case of low day-ahead energy prices, the balancing market is used mostly for selling the VPPs electric energy, moreover, the VPPs profit distribution is more concentrated and therefore, the VPP operator would not experience low profit scenarios

Table 1 (*continued*)

Ref. No.	Objective Function Different Terms	Advantages of the Proposed Scheduling Optimization Function
[112]	revenue from day-ahead and balance up markets, cost of balance down, operation cost of dispatchable units and risk value	VPP trading in the day-ahead and balance markets, VPP becomes more risk-averse as the owners of the DERs, a decrease in the total profit and an increase in the surplus profit due to more salient risk-hedging role of the integration, increasing the risk-aversion level, and also less reduction of total profit of integrated DERs in comparison with uncoordinated DERs
[113]	fixed costs, variable costs, start-up costs and cost of non-served energy	a system-wide adoption of the VPP concept affects not only the VPP outcome but also the rest of the electric energy system, self-supplying VPPs can achieve very high rates of self-sufficiency in the supply of local load
[114]	average generation cost of the DG units in VPP	take the VPP concept centralized system intuitively, make sure capacities of controllable DG units match that of non-controllable ones, and use an accurate, reasonable local and optimal control algorithm
[115]	output power costs function from DER agent	communication connection topology and parameters have little effect on optimal solution but more effect on optimal process
[116]	energy, spinning reserve and retail energy cost function of each DG, interruptible load or storage device and start-up cost of each DG	the available renewable energy resources are fully exploited and if the available margins are fully exploited, the results are ever positive
[117]	selling the produced thermal and electric energy and cost of CHP and boiler	there is quite a high economical potential in managing cogeneration plants, with usage of local storage capacities the degrees of freedom for operation management can be increased, the typically thermally driven operation based on fixed feed-in tariffs leads to more operation time and more benefit, and in case of a variable tariff curve the degrees of freedom can be used to shift operation to high price times to maximize profit
[118]	fuel cost for conventional prime movers, penalty to the deviation of VPP production and the possibility of a fully controllable part of the VPP system not complying with the requested power	the solution is flexible, expandable and applicable to numerous use cases and DER portfolios in future smart grid applications, and the IEC – 61850 is capable to handle specialized optimization algorithms and is suitable for realizing novel ancillary services
[119]	overall emissions and the revenue of the environmental VPP	system emissions is controlled with a good accuracy, small deviations between desired and actual emissions output are observed, and the VPP controllability increases significantly by increasing the number of participating micro-generators
[120]	revenues of VPP from the electricity sold in the market	the VPP method is more profitable to both wind farms and EVs compared to not participating in the VPP, Receding horizon optimization is simple and computationally cheap since, at each time step, a linear optimization problem is solved using standard linear programming techniques, moreover, it also delivered a control policy that guaranteed a profit for all VPP participants
[121]	operating capacity for reliability assessment	two step sampling, zone partitioning and minimal path search techniques are employed to accelerate the state sampling and evaluation process in the Monte Carlo simulation
[122]	cost of satisfying the residential loads and EV travel requirements, cost of energy generation, start-up costs, gasoline prices and battery degradation cost	the benefits of VPP formation can flourish if energy generation costs of renewable energy resources decrease or the capacities of the contracted energy providers increase
[123]	electricity sold/purchased in the market and the CPP production and start-up costs	the model practically nullifies the risk of not meeting bilaterally contracted and/or day-ahead market sold electricity, the downside is relatively large, electricity surplus in case of a high renewable energy production scenario comes true, to devise offering strategies becomes more apparent as the stochastic parameters, and particularly renewable energy production become increasingly accurate
[124]	produced electricity in house and production plan power	the models are accurate enough that it is possible to make a plan for a group of houses based on predicted heat demand, to determine a plan based on a prediction one day ahead and to control the micro-CHP
[125]	active and reactive power	the flow independent control of active and reactive power in medium length transmission lines and making the inverter to output the desired active and reactive power
[126]	imbalance compensation	proving the optimality of an associated dispatch strategy when the local units are power and energy constrained integrators
Ref. No.	**Objective Function Different Terms**	**Advantages of the Proposed Scheduling Optimization Function**
[127]	power and gas consumption of a residential district	to prepare a business model for an virtual control power plant
[128]	VPP profit from trading on the spot market and network losses	balancing, to enable a producer to meet spot markets bids and avoid purchases of balancing power, minimize peak load in order to reduce subscribed power and tariff to the regional 130- kV network, decrease network losses, and the contribution from reactive power control using the power converters to reduce the reactive power flow to the overlying network
[129]	regulating power reserve	the potential capability of EV to respond in real-time to different charging/discharging requests based on different coordination plans
[130]	index of system protection	efficiency of the system protection scheme in large scale power systems can be improved fundamentally with the taking into account VPPs as a component of emergency control actions
[131]	absorbed power by the consumer	the reduction major investments for the grid and maintains the environment clean, and to develop a storage system coordinated by the VPP
[132]	VPP revenue, DR saving and DR cost	the flexible loads could easily cover the wind power uncertainties and reduce the penalties for wind supply imbalances, flexible load can be coordinated with wind power as a storage, and the storage can be utilized in peak hours (decrease its consumption) to cover wind intermittence
[133]	VPP bids into the wholesale market, a bilaterally contract, expected reduction of consumer, and start-up cost	identifying the optimal DR pricing set up, its limits and dynamics
[134]	sold energy by wind, PV, CHP, and storage, sold/bought energy to/from grid, and controllable loads cost	explicitly takes into account only direct costs, application to compute the optimal power management in any other example of VPP or microgrid

Table 1 (*continued*)

Ref. No.	Objective Function Different Terms	Advantages of the Proposed Scheduling Optimization Function
[135]	bid of VPP to energy market, bid of VPP to secondary frequency control market, cost of power generation of DG for energy market, cost of power generation of a DG for secondary frequency control market, hourly interruption cost for DG in standby mode, and hourly interruption cost for DG in peak shaving mode	possible to integrate DER not only to be visible in energy market but also to be visible for system operator, decreasing the operating cost of the VPP with considering the reliability worth, supply power to the main grid or introducing the VPP as a consumer apart from providing secondary frequency control reserve service
[136]	fuel, variable O&M costs and CO_2 emission rights, fixed operating cost of the autonomous power station, capital and fixed cost expenses of an equivalent conventional power station, annual capital amortization expenses of any power station, and fixed operating costs of the autonomous power station and all renewable energy stations besides the hybrid power station	the integration of a relatively small and properly sized hybrid power station leads to a reduction of the island system levelized cost of energy and at the same time increase of renewable energy penetration, even in island systems characterized by low thermal generation costs (heavy fuel oil), higher renewable energy penetration levels come for substantially larger hybrid power stations, leading to an increase in the levelized cost of energy of the system, and in island systems with a high generating cost (light fuel oil), the renewable energy penetration increase due to hybrid power station integration is combined with a reduction of the levelized cost of energy
[137]	bid of VPP to energy and spinning reserve markets, operational cost of storage, generation, start-up and shut-down costs of DGs, and supplied load of VPP	the modeling makes it possible to integrate DER not only to be visible in energy market but also to be visible for system operator
[138]	bid of VPP to energy and spinning reserve markets, operational cost of storage, generation, start-up and shut-down costs of DGs, and supplied load of VPP	the modeling makes it possible to integrate DER not only to be visible in energy market but also to be visible for system operator
[139]	the revenue for selling electricity or the cost for purchasing it, the incentive received for renewable energy sources, fuel cost for feeding boilers and co-generation, cost of risk, the possible extra bonus obtained to respect the power exchange with the network at virtual point of common coupling	able to elaborate very complex strategies for the VPP daily profit maximization in presence of hourly prices of fuel and electricity
[140]	cost of supply the load and total system disutility to be occurred	ensuring a fair distribution of system, wide benefits and guaranties, accurate treatment of each participant in the market, incorporation of the essential concepts of renewable energy participation in electricity markets coupled with the extensive DR application in the submarket
[141]	residual power and penalty to dispatching each local unit	determined solutions are both agile and well balanced even for problems of 100.000 units, 100 samples and with a computation time of just 10 s
[142]	income from trading with the day-ahead market, income from selling energy to the local demand, operating and start-up costs of controllable DGs and cost of curtailed load	VPP economic return will increase while resulting in risk of loss of load, VPP operator tends to be conservative facing profit and adventurous toward risk in decision making and also preparation of the proper utilization of chance constrained programming while maintaining system reliability
[143]	reference power of each PV, large penalty factor, actual power of VPP and reference power of VPP	The aggregated power of the VPP can be precisely and quickly controlled, provide ancillary services like primary frequency reserve, moreover, the idea offers a more economical way to accommodate a high penetration of DERs
[144]	revenue or cost of power injection to/from the distribution system from/to VPP, demand benefit, and cost functions of DG and ES	practical, flexible, and scalable modeling and lower communication investment requirement for VPP dispatch

Optimization (BPSO) [80], Krill Herd Algorithm (KHA) [81], Teaching–Learning-Based Algorithm (TLBA) [35], Non dominated Sorting Genetic Algorithm II (NSGA-II) [30,37], Genetic Algorithm (GA) [78,82,85], Adaptive Modified Firefly Algorithm (AMFA) [38], Evolutionary Programming (EP) [83], Hill Climbing Technique (HC) [83], θ-Particle Swarm Optimization (θ-PSO) [40], Differential Evolution Algorithm (DEA) Accompanied with Fuzzy Technique [84], Particle Swarm Optimization (PSO) [28,31,79,85], Competitive Heuristic Algorithm for Scheduling Energy-generation (CHASE) [86], hybrid algorithm of Lagrangian Relaxation and GA Algorithm (LRGA) [65] and Habitat Isolation Niche Immune Genetic Algorithm (HINIGA) [87]. Besides that, the heuristic optimization methods to solve the scheduling problem in VPP framework are Multi-Objective Genetic Algorithm [136], GA [137,138,142], PSO [109], Accelerated Particle Swarm Optimization (APSO) [110] and Hill Climber and Greedy Randomized Adaptive Search Procedure (GRASP) [141].

It can be seen that both of the methods mentioned have been widely used to solve the DER scheduling optimization problem. By studying the papers, beneficial and unbeneficial aspects of these methods become evident. Some beneficial aspects related to the proposed heuristic algorithm concerning microgrid are as follows: BGSA [36] is competitive in terms of dealing with those unit commitment optimizations. Because of the search ability of the BPSO algorithm [80], it causes the deceleration of the lost information at local optimums. It also causes the search process to focus on optimums in the final iterations which can lead to more in-depth search process. An appropriate robustness can be carried out by the proposed KHA algorithm [81]. The TLBA algorithm does not require any algorithm-specific control parameters [35]. The proposed AMFA makes use of a powerful modification process to enhance the diversity of the firefly population [38]. This is a self-adaptive technique to increase the ability of the algorithm to move towards the promising global optimal solution quickly as well. EP and HC can obtain a near global optimal solution [83]. The θ-PSO algorithm uses the phase angle vectors to update the velocity/position of particles so that faster and more stable convergence is achieved [40]. The GA and PSO best results are obtained for scheduling in terms of time of execution and memory utilization by comparing them with dynamic programming [78,79,82,85]. The CHASE advantage is that it is an online algorithm for the microgrid generation scheduling problem and can track the offline optimal in an online fashion [86]. LRGA algorithm can improve the performance of LR method [65]. Moreover, some advantages of the proposed heuristic algorithm related to VPP are as follows: the chance of being involved in a local optimum is less than that of mathematical methods in the GA method [137,138]. The PSO [109] has a high convergence characteristic in comparison with others and APSO [110] provides high quality solutions when subject to constraints. In addition to these advantages, there are some unbeneficial aspects related to the heuristic methods. Some of them are as follows: The optimal solution is related to estimations and the possible situation associated with the divergence is more than that of the mathematical methods. Sometimes the simulation time is high and it may fall into local minimum instead of the global one.

4. Scheduling problem associated with uncertainty

Uncertainty is a term used skillfully in different ways and in a number of fields including philosophy, physics, statistics, economics, finance, insurance, psychology, sociology, engineering, and information science. It is used for the prediction of future events and for the unexplained or physical measurements that have already been performed. Uncertainty occurs in partially observable or random environments and also due to ignorance. In a technical classification, there are some main approaches such as Monte Carlo Simulation (MCS), Analytical Methods, and Approximate Methods to study the uncertainty effect. Due to importance of the uncertainty aspect of stochastic scheduling problems, an investigation related to both microgrid and VPP concepts is carried out.

To study the uncertainty issue related to microgrid, it is firstly needed to know the uncertain parameters employed. There are many different parameters to apply to uncertainties (scenario generation) which are in the area of generation, load, price, etc. Some of them are electric vehicle driving schedules [32], wind power [28,30,31,34–36,38–41,44,49,72,84], solar power [28,30,31,34,35,38–40,84], load [28,33–35,37–40,42,45,64,71,72], market price [35,38,40,43,49], generating units' outages [46], weather forecasts [29,37,64], and storage systems [37]. Also, in the field of uncertainty study related to VPP scheduling, there are different parameters to propose regarding the uncertainty in the area of generation, load, price, etc. These are classified as plug-in electric vehicles [99], wind power [89,90,92,94,97,100,101, 103,106,109,111,112,132], solar power [90,92,94,103,106,111,112], load [89,92,106,112], market price [90,92,98,100,105,109,111, 112,132], marginal cost [89], and heat demand [91,101].

As it can be seen, the most important components of a microgrid or VPP scheduling that can be uncertain are wind power, solar power, load and market price. Therefore, in order to have real results in studying the scheduling problem in both frameworks, it is really necessary to suppose that these parameters are uncertain and to select an appropriate method to analyze their behavior.

After knowing uncertain parameters, it is important to identify the uncertainty analysis methods. The proposed methods used are related to different elements concerning the uncertainty in microgrid scheduling (scenario generation method) and have been introduced as Monte Carlo Simulation (MCS) [30,46,49], Lattice Monte Carlo Simulations (LMCS) [35,42], Roulette Wheel Mechanism (RWM) [35,38,41–43], Latin Hypercube Sampling (LHS) [36,39], Cholesky Decomposition (CD) [36], GAMS Model [32], Execution Monitoring and Re-planning Architecture [37], Two Point Estimate Method [40], Autoregressive Moving Average Series (ARMA) [39,44,45], Weibull Distribution [38,49,84], Rayleigh Distribution [30,34], Beta Distribution [30,34,84], Normal Distribution [34,38,39,72], Scenario Tree [31], and Gaussian Distribution [39]. Also, like the uncertainty analysis in microgrids, the methods regarding the uncertainty in VPP scheduling (scenario generation method) related to different parameters have been proposed as Weibull Distribution [97,109], Hong's Two-Point Estimate [92,98], RWM [109], Normal Distribution [99,106], Historical Data [100], MCS [111], ARMA [101,132], and Scenario Tree [105].

To illustrate the beneficial and unbeneficial aspects of the methods used for uncertainty analysis of both microgrid and VPP scheduling, it can be said that the MCS method is accurate to handle complex uncertain variables, but it is expensive when considering computational aspects. On the other hand, analytical methods such as probabilistic methods and point estimation methods can overcome this disadvantage of MCS, but they need some mathematical suppositions to simplify the problem. However, some methods based on approximation have been proposed that can overcome the shortages of MCS and analytical methods.

Sometimes, the scheduling formulation is complex and when a lot of scenarios are used, the computational burden will be high. So, to solve this problem, it is necessary to reduce their number to a lower number of beneficial scenarios. Then, two appropriate scenario reduction methods that have been used in the problem of microgrid scheduling are backward scenario reduction method [35,36,39] and most probable scenarios method [38,41–46]. Also, the scenario reduction mechanisms that have been used in the problem of VPP scheduling are Kantorovich distance [101] and most probable scenarios method [105]. The backward scenario reduction method is essential to achieve the computation tractability while keeping the stochastic information embedded in the original scenario set as much as possible. This procedure depends on the accuracy of the uncertain parameter approximation. One of the most commonly used probability distance defined between two probability distributions is used in Kantorovich distance method. It is obtained by assigning the probabilities of non-selected scenarios to the closest scenario in the selected scenario set. Using this procedure, it is anticipated that accurate scenarios will be achieved for a number of generated scenarios.

5. Scheduling problem associated with reliability

Reliability assessment in the scheduling problems is a procedure that emphasizes dependability in the lifecycle management of DER power. Reliability in the power system describes the ability of the system or component acting under stated conditions for a determined period of time. This aspect of the system is expressed as the probability of failure, the frequency of failure, or expressed in terms of a probability derived from reliability, availability, and maintainability. It plays an important role in cost-effectiveness of the power systems, so any power system programming such as scheduling problem should be associated with reliability resolution. Then if there is no analysis related to that, there is no guarantee of a reliable supply for demands. In DER scheduling problem in the form of microgrid and VPP concepts, reliability has been considered as different forms. The reliability of the power system can be consisted as a part of the objective function or as a constraint with some indices used. In this section, the research papers assessing the reliability in both microgrid and VPP concepts for the scheduling problem are classified and reviewed.

Table 2 illustrate some papers referring to some indices about reliability assessment in microgrid and VPP scheduling problem. Also, the calculation methods for these indices and time horizon for the assessment are summarized in this table.

Some standard and widely used indices for reliability assessment in DER scheduling problem in power systems (transmission and distribution levels) are System Average Interruption Frequency Index (SAIFI); System Average Interruption Duration Index (SAIDI); Energy Expected Not Served (EENS); Customer Average Interruption Duration Index (CAIDI); Average Service Availability Index (ASAI); and Average Service Unavailability Index (ASUI). As it can be seen in Table 2, the EENS index [30,33,48,53,61,77, 80,84,121,139,140] is the most appropriate and important index to assess the reliability in both microgrid and VPP scheduling. Also, some of the important indices like Loss of Load Probability (LOLP) [53,70,80,84] or Maintenance Cost [50,84] can be performed for the above-mentioned aim.

In order to obtain a more detailed analysis about the above-mentioned literature in this area, some of the references concerning the procedure employed for reliability evaluation have been explained in more detail. In [50], maintenance decisions related to reliability assessment are first determined by generating companies, and then the operator has to check and probably modify them for final approval. The method proposed in [61]

Table 2
Reliability assessment related to the microgrid and VPP scheduling problem.

Ref. no.	Index	Calculation method	Time horizon
[30]	EENS	MCS Method	Daily
[33]	Load Not Supplied	–	–
[48]	NDE (Non-delivered energy)	Failure Probability of Elements	Seasonal
[50]	Maintenance Cost	Maintenance Plans with Different Priorities	Daily
[53]	LOLP (expected number of hours of capacity deficiency in the system in a given period of time), ELOE (indication of the amount of load that cannot be serviced in a given period of time)	Normal Mixture Approximation	Seasonal
[61]	EENS, COST (annual interruption energy and interruption cost), SAIFI, SAIDI and MAIFI (annual average values of all customers)	MCS and Analytical Technique	–
[64]	Reliability improvement index as a constraint	–	Daily
[70]	Loss of Power Supply Probability	Analytical Technique	Daily
[71]	Reliability Constraint	–	–
[75]	Reliability improvement index	–	Daily
[77]	SAIFI, SAIDI and ENS	Analytical Technique	Daily
[80]	EUE (Expected Unserved Energy), LOLP (Loss of Load Probability)	Analytical Technique	Daily
[84]	Maintenance Cost, LOEE (Loss of Energy Expected), LPSP (Total Loss of Load Probability)	Mathematical	Monthly
[85]	Probability of Interruption and Average Duration of Interruption	Analytical Technique	Daily
[121]	ASUI, ASAI, EENS, SAIDI, and SAIFI	MCS	–
[135]	Reliability Worth Index (hourly interruption cost)	Analytical Method and MCS	Daily
[139]	EENS	MCS	Daily
[140]	EENS	Analytical Method	Daily

includes PV systems and fuses as well as an impact factor to obtain the interruption cost. Also, the equations presented are generalized to include more than one component in a section. In order to guarantee the reliability of the users when sudden incidents occur to the microgrid, the index presented in [70], for Loss of Power Supply Probability is especially specified as one of the constrains calculated in the islanded mode of the microgrid. The major parts of the investment are variable ones, which are closely related to the generation scheduling. In [80], the reliability constrained unit commitment formulation is proposed by analytical method for taking the whole aspects of DERs into account while considering some new features of electricity markets.

In [121], a new method for reliability evaluation of active distribution systems based on a Monte Carlo simulation is proposed. Multi-state models are developed on the basis of generalized capacity outage tables (GCOTs) to better represent various types of DGs for reliability evaluation. Then, the VPP is introduced to model microgrids with intermittent sources. Furthermore, the reliability behavior of VPP is efficiently characterized by an equivalent GCOT. The non-sequential Monte Carlo method is then adopted to evaluate the reliability of active distribution system considering different operation modes under single or multiple contingencies. In [135], the reliability worth evaluation done by applying the Monte Carlo simulation method is discussed to determine whether DG should be operated in peak shaving mode or as standby power. In [139], the scheduled load curtailment is penalized by a very high value of lost load in the objective function in order to avoid this extreme event. In this scheduling activity, scheduled EENS represents a preventive load curtailment due to system inadequacy. In [142], since VPP operator aims to maximize the profit while minimizing the risk, a satisfaction function is introduced to quantify its satisfaction degree towards profit and risk. The function can reflect VPP's psychological preference, including conservative, neutral, and adventurous. In the satisfaction function of profit, a high profit is given with a high satisfaction value, whereas in the function of EENS, the satisfaction value becomes lower with a higher EENS.

6. Scheduling problem associated with reactive power

In a power system, the reactive power control is one of the main aspects related to scheduling. Sometimes this issue may be considered as a constraint throughout the system and sometimes it can be the output of the scheduling problem in both of the concepts mentioned. Therefore, the reactive power associated with microgrid and VPP concepts are investigated in this section.

In the scheduling problem of a practical microgrid, some relevant situations regarding the reactive power as a constraint may be considered of which some are reactive loads in a bus, i.e. the reactive power output of unit and reactive load shedding of bus [46,82]. Some studies have considered the reactive power generated by generating unit as the reactive power injected into the grid by all the generating units connected to a bus at a time period; the reactive power passing through a line at a period of time; the reactive load demand at a bus; the time period as the constraint; and the output of scheduling [37,41,50]. In [55,72], the reactive power flow control is considered to be at the interface of the external grid in the scheduling problem of microgrid. The reactive power generation via CHP system of the factory; the total reactive load power at a bus; the reactive power of the factory; and the total reactive power generation in an industrial microgrid for a scheduling problem are investigated in [62,63]. The reactive power supplied from different converters of battery models has been considered in [74]. In addition, the operation of individual sources on the basis of the voltage droop is taken into account in [75] to provide the reactive power sharing.

In the VPP concept, reactive power consideration can be studied by different DERs as well as by different management systems, so that the following studies are included in these categories. Reactive power control can be carried out by the power converters [125,128]; by a reactive power compensator at each generator [131]; by different reactive power management options [107]; and by small hydro-power plants [108]. To clarify the issues brought up in papers for scheduling problem, it can be said that in [125], the reactive power consideration is done by a control scheme for voltage source inverters connected via a medium-length transmission line. In [128], the reactive power is considered by reactive power control possibilities of the coordinating DER. Due to the generators, the reactive power can be fed by the distribution network creating an increase in loading which is unwanted in the distribution system; therefore, a reactive power compensator can be installed at each generator to avoid this problem [131]. To manage the DERs, an energy resource management simulation tool has been developed in [107] while considering different reactive power management options in the scheduling process. In this work, an objective function is proposed by considering the minimization of differences of the bus voltage magnitude. Additionally, in [108] the reactive power control is carried out by small hydro-power plants at the time of high feed-in.

7. Scheduling problem associated with control and automation

To schedule the available resources in a power system, it is necessary to take a comprehensive control and management system into consideration along with all the performances such as microgrid and VPP in the system. For example, in [28], a control strategy is proposed that all switches are remotely controlled in the scheduling optimization procedure and this performance allows automatic reconfiguration. The automation, the control, the SCADA and the management system can be considered as organized in three levels [55]: the field level (data acquisition and decentralized control), the SCADA level (supervision and control functions), and the planning and management level, which can be a decentralized energy management system (DEMS).

One of the famous controllers is fuzzy one. This controller can be designed to control the amount of power that should be taken out of the battery system in case of power deficiency to cover the load demand in a scheduling process [57]. Designing a fuzzy logic controller is achieved through three basic steps: fuzzification, inference mechanism, and defuzzification. In [71], the control system represents the individual control steps of each DER that keeps the balance of the active power and regulates the voltage in the microgrid. The control system of the microgrids is typically based on the implementation of droop controllers that emulate the behavior of synchronous generators against changes in the frequency and voltage of the grid. In [73], the management system architecture can be classified into three main parts as follows:

- Relational data base server which holds measurements, generation schedules, and demand side management data.
- Microgrid agent platform that provides the basic infrastructure and services where the Microgrid Central Controller (MGCC), Micro Source Controller (SC), and Load Controller (LC) agents are executed.
- Source and load device controllers that have been adjusted to support both the proprietary protocols and standards.

Interest in military microgrids has been investigated by the SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security) project in [76], with the goal of microgrid capability security for islanding. This is augmented by frequency, power, and voltage control algorithms for the inverters that connect DERs to the microgrid, and also charge and discharge control algorithms for EVs. A control strategy comprising three critical control levels as the local micro-source controllers and load controllers, microgrid controller, and distribution management system has been proposed in [78] for the integrated microgrid application.

The control issue in a VPP structure used to schedule the power is also very important and a progressive problem. In [88], the presented control concept finds its application concerning grid support in case of over-frequency. This concept is also meant as a response to related reports and studies asking for the increased contribution of DG to overcome such phenomena. A model is derived in [91] for heat load predictions and an optimization problem is formulated for the control of electric space heating in a building. In [92], VPP is controlled in a centralized form and the aim of control coordination center is to maximize the net profit of VPP by providing optimal bids to the electricity market. An optimal control strategy for the battery bank in a VPP in order to control the risk of low profit scenarios has been presented in [111]. In [114], to illustrate a real-time control strategy in dispatching the active power among DG units, a mechanism is presented to cover variations of loads and fluctuated or intermittent active power outputs of non-controllable DG units, and further to optimize the average generation cost of VPP. Based on VPP hierarchical control architecture, a bi-level optimal dispatch mathematic model is constructed in [115] and a novel distributed algorithm to solve bi-level optimization with uncertain agent number is proposed.

Using the exist standards in control process is also taken into account in some literatures. A novel VPP control concept has been proposed in [118]. The idea is based on using communication standard capabilities and optimization methods to obtain VPP ancillary services in a scheduling problem. In [119], three control policies are considered to reflect the environmental and commercial aspects in a VPP. These policies utilize fuzzy logic deduction methods to infer the number of carbon credits which it feeds into the internal agent market. In [124], the control procedure focuses on the extension of algorithms to control the energy streams in a group of houses. This consists of a CHP, a heat store, controllable heat and electricity appliances, and control algorithms implemented in software. The proposed control strategy consists of three steps:

1. To predict the generation and consumption pattern for all appliances,
2. To exploit the potential to reach a global objective,
3. To decide at what times appliances are switched on/off; when and how much energy flows from or flows to the buffers; and when and which generators are switched on.

Sometimes a control strategy is employed to achieve an independent and accurate control of active and reactive power flow through a medium-length transmission line which is a prominent part of VPP [125]. The whole portfolio can be managed by a master controller which trades the generation capacity on the energy markets [126]. In [129], the control concept for EV fleet management is used as a framework. The control requests for the EV test bed are generated by the VPP based on the grid requirements of power reserves of the transmission operator. In [108], some hydro-power plants are included in a VPP and can be controlled by an EMS. In this system, the Q-control and P-control agents have a direct impact on the hydro-power plants and the energy storage to control the network voltage. The feed-in and the load forecast agent estimates the voltage profile and return the results to the EMS. Regarding the centralized control, a control method of VPP comprising multiple PVs and controllable loads is proposed in [143]. In this reference, the power output of the PVs and power consumption of the controllable loads are also coordinated.

8. Scheduling problem associated with emission

The emission and environmental issues in a power system are one of the significant problems which have to be considered due to the environmental limitations. Some DERs, especially conventional ones have unsuitable effects on environment because of generated greenhouse gases. In the scheduling problem in both the concepts studied, the literatures have considered emission problem as a function that should be minimized. In this section some of these functions are investigated and the type of consideration is explained too.

Due to the uncertainties associated with wind and PV powers, the emission function is formulated in [31] for the problem of microgrid scheduling, in two stages. In the first stage, the pollution resulting from the scheduled power generation for load and reserve supplies is calculated and in the second stage, the pollution pertaining to the variations of scheduling of the units caused by changes in the behaviors of wind and PV powers is calculated. In this context, an objective function related to the total emissions during the scheduling period is proposed in [34]. In this function, emission of each DG and all the committed power plants in the main grid are considered. In addition to the amount of pollutants emitted from each generation unit, storage unit and utility are considered in [35]. In [41], quantifying the economic impact of DG on pollutant emission cost reduction is presented in the form of a new techno-economic factor. Using this approach would enable operators to have control on network losses and pollutant emission rate of thermal generation unit in the case of deciding to obtain DER economic advantages. In the proposed formulation in [42,45], the emission function are modeled in linear form, and prohibited operating zones of thermal units are considered. In [51], the average atmospheric emission for the electricity consumed in a microgrid, and the emission from a fire-power plant are considered and then an air emission index is presented. The CO_2 emitted in an hour from a DER [37,53,56,59,75] and the amount of pollutants such as SO_2 and NO_x caused by conventional thermal units, CHP units, heat-only units, energy storage systems, and grid released into the air are investigated in [54]. CO_2 emission of each gas turbine, boiler, and from the national electricity grid in each time interval is considered in [55]. The costs of the emissions including NO_x, SO_2, and CO_2 [58,79,87] and the total fuel emissions produced by diesel generators [84] are also thought-out. Minimization of the global warming potential of different emissions with relevant function is presented in [64]. In addition, the environmental punishment cost per kg production to the total amount of the carbon dioxide emission is another type of emission functions that is taken into consideration in [70].

In the scheduling problem focused on the emission related to VPP, some research activities have been performed too. In [113], it is discussed how system emissions change with the VPP strategy and which generation technologies experience changes in their production profile and level. In [119], the category of Environmental Virtual Power Plant (EVPP) is proposed. The EVPP can be described as a sub-category of a Commercial VPP (CVPP). The aim in this category is the reduction of the overall emissions resulting from EVPP components. It is cost-effective for the micro-generators when their emissions are matched with their carbon credits, and the EVPP output is thus regulated. Moreover, in [122], a case study performed in the state of California by using the real-world data and indirect minimization of gasoline prices that with using this presented methodology the emission impacts of VPP can be reduced.

9. Scheduling problem associated with stability

Power system stability is expressed as the exclusivity of the system that enables it to stay in a state of operating equilibrium under normal conditions and to take back an acceptable state of equilibrium after being exposed by a disturbance. Two main stability categories are introduced in the field of power system dynamics which are voltage and frequency stabilities. Some papers have considered these cases in the scheduling problem which are in the form of microgrid and VPP. In [57], the voltage stability problem is investigated in a microgrid and a smart energy commitment method has been designed to control the batteries in a way that they are allowed to discharge. This will happen only when no very big load is forecasted within the next time period. So, they act as a buffer for the predicted large loads to increase the stability of the system and reduce the voltage dips. In [76], the voltage and frequency regulations are considered. In this study, a model is presented by power, frequency, and voltage control algorithms for the inverters that connect micro-sources to the microgrid. It also incorporates charging/discharging control algorithms for EVs. Using this model, the impact of EVs on the microgrid at different penetration levels and for different control parameters is studied. In [88], a methodology is proposed that dispatches a requested reduction of active power within a VPP to support the mitigation of over-frequency. Active power loss and voltage rise have been considered to be the criteria in the field of stability in [106]. In this study, the proposed strategy is to investigate the various modes of VPP management and define its capabilities through the preparation of various ancillary services such as reducing grid losses, frequency, and voltage control. Sometimes the goal is to study the power loss and the voltage magnitude, therefore, several reactive management perspectives are presented in [107] while considering the operation of distribution network by a VPP. In addition to this, voltage control is the stability issue in [108] that can be performed in a VPP by a small hydro-power plant. In [131], loading of the lines and the voltage level are considered as the stability criteria and the effect of small hydro-power plants is presented as a VPP. Since it is beneficial that a VPP provides primary frequency regulation to contribute to frequency stability in the power grid, then a droop control is designed in [143] for VPP so that VPP power changes according to frequency deviation. Also, since frequent mode change of a flexible load may decrease its lifespan, a frequency tolerance band is considered in the droop design so that VPP power remains unchanged as long as frequency is within a normal range.

10. Scheduling problem associated with demand response

Demand Response (DR) programs can be divided into two basic categories, namely time-based programs, and incentive-based programs. Each of them includes some programs as indicated in Fig. 4.

In time-based programs such as Time of Use (TOU), Real-Time Pricing (RTP), and Critical Peak Pricing (CPP), the price of electricity varies according to the supply cost of electricity for different time periods; for example, a high price in a peak-load period; a medium price in an off-peak-load period; and a low-price in a low-load period. In this kind of DR program, there is not any incentive or penalty. TOU rates establish two or more daily periods, i.e. those reflecting hours when the system load is higher (peak) or lower (off peak), and charging a higher rate during peak hours. RTP rates vary continuously during the day reflecting the wholesale price of electricity. CPP is an overlay on either TOU or flat pricing. CPP uses real-time prices at times of extreme system peak.

Incentive-based programs are included in Direct Load Control (DLC); Interruptible/Curtailable (I/C); Emergency Demand Response Program (EDRP); Capacity Market Program (CAP); Demand Bidding (DB); and Ancillary Service (A/S) programs. In DLC and EDRP programs, there are voluntary options and if customers do not interrupt their consumption, they are not penalized. I/C and CAP are mandatory programs and the participating customers have to pay penalties if they do not curtail when directed. DB program persuades customers to provide load reductions at a price at which they are willing to be curtailed or to identify how much load they would be willing to curtail at posted prices. A/S programs allow customers to bid load interruptions in electricity markets as operational reserves.

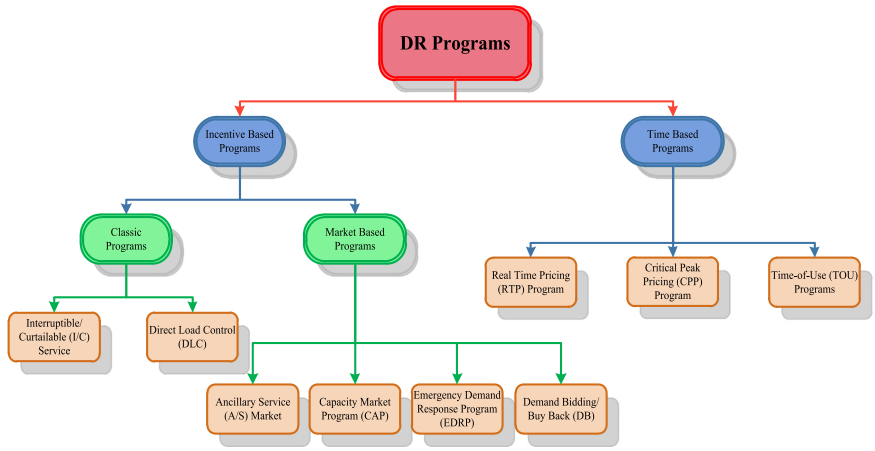

Fig. 4. Classification of the DR programs.

DLC refers to a program in which a utility or system operator remotely shuts down or cycles a customer's electrical equipment on short notice to address system or local reliability contingencies in exchange for an incentive payment or bill credit. Customers on I/C service rates receive a rate discount or bill credit in exchange for agreeing to reduce the load during system contingencies. If customers do not curtail, they can be penalized. DB program encourages a great number of customers to offer load reductions at a price at which they are willing to be curtailed, or to identify how much load they would be willing to curtail at posted prices. EDRP provides incentive payments to customers for reducing their loads during reliability triggered events, but curtailment is voluntary. In CAP, customers commit to provide pre-specified load reductions during system contingencies and are subject to penalties if they do not curtail consumption when directed. A/S program allows customers to bid load curtailments in ISO markets as operating reserves. If their bids are accepted, they are paid the market price for committing to be on standby. If their load curtailments are needed, they are called by ISO and may be paid the spot market electricity price. Considering DR in the scheduling problem can be one of the important methods which can assist the incorporation of customers to supply the energy as a suitable DER in the electricity market environment.

In Table 3, an investigation related to the DR application in the microgrid and VPP for scheduling problem is summarized. For each reference, the type of DR program, the functions, and descriptions are presented.

To clarify some references for the proposed procedures, it can be said that in [31] the values of the consumed load and its prices are assumed to be arranged into a scheme and can be presented at day-ahead market by load response providers (who are responsible for collecting minor consumers' response). In [33], the type of DR can vary from low to medium and to high. In [80], the network-driven load management programs are developed and used to simulate the participation of consumers in DR programs. A DR management system has been proposed in [34]. This system receives enrolment information of the DR participants from the customer information system and is also responsible for the payment calculation. So, after the scheduling period, the exact consumption and generation data are received and the amount of the customer load curtailments and DGs power generation are calculated. The DR providers (DRPs) [34] can be defined to aggregate

Table 3
Type and functions of DR program related to the microgrid and VPP scheduling.

Ref. no.	Type	Function
[28]	DLC	–
[32]	TOU	Costs of demand response measures
[33]	incentive-based	The consumers have the option of foregoing, reducing or shifting their load
[34]	incentive-based	The load reduction costs of DRPs and the option to use DR programs in reserve scheduling for distribution systems
[54]	incentive-based	Demand response programs are treated as virtual generation units.
[60]	incentive-based	Include Adjustable Loads (Shiftable and Curtailable)
[67]	TOU	–
[68]	(I/C) service rates	–
[69]	TOU	–
[80]	incentive-based	The incentives which are paid to consumers in order to reduce their demands
[85]	TOU	The interruptible loads are fixed intervals loads or any short duration loads in a day.
[93]	TOU	–
[97]	incentive-based	–
[98]	I/C service rates	–
[105]	DLC	Controllable loads must be on continuously for some hours when they turn on
[107]	DLC	Load curtailment and load reduction
[112]	DLC	Load curtailment and load reduction
[113]	TOU	Using flexible demand in the energy balance constraint
[116]	DLC	Demand side management is provided on non-interruptible or interruptible loads
[132]	TOU	The load model is modified to obtain flexible load participation cost in offering procedure
[133]	DB Program	The VPP is buying the reductions from internal consumers on a day-ahead basis
[134]	DLC	The controllable loads have been prioritized in three categories
[137,138]	I/C service rates	A penalty is paid to each interruptible consumer for curtailing its consumption
[143]	DLC	Controllable loads

offers for load reduction made by determined consumers. In particular, for each hour, a DRP submits its price-quantity offer as a package. Each package offered by a DRP consists of a minimum and a maximum quantity for load reduction presented in several steps.

In [89], a selection of the various DR parameters such as maximum load interruption per consumer and load interruption horizon are investigated. The analysis leads to antithetical results, since the relaxation of specific DR parameters not only leads to increased day-ahead profits, but it also increases the respective imbalance costs. This is due to the fact that an increase in the day-ahead profits outweighs the increased imbalance costs, resulting in significant increase in the total profits expected. A VPP set-up and a theory are proposed in [91] for the implementation of flexible heat consumption in an intelligent building heated by electric resistive heaters. In [140], an alternative individual billing mechanism based on a new DR model that eliminates the need to forecast demand and estimates demand price elasticity or predicts demand reductions is proposed. In the designed day-ahead DR market, each customer can act as a DR provider by submitting a defined number of candidate load profiles ranked in order of preference corresponding to the next day's needs. A centralized DR aggregator would then select an optimal combination of individual daily load profiles, one for each customer, in order to minimize cost and maximize consumer utility, which in turn excludes the creation of rebound peaks in the system. Additionally, the flexible units in [141] are modeled as batch processes which are characterized by constant power consumption, a run time, and a deadline by which the process must be finished. Also, the size of the time-step is considered.

11. Scheduling problem associated with multi-objective

Multi-objective optimization or solution decision-making is an important part of the scheduling problem in the power systems. It may encounter different options so that it should choose the best one among them in every scheduling problem and in every situation. In general, three different methods can be presented to solve a multi-objective problem. The first is the Pareto-based approach to get a set of non-dominated solutions in the process of optimization. The second is the weighting method and the last is converting the multi-objective functions into a single-objective model and optimizing it through single-objective methods. In addition, to facilitate the selection of the best option, many different methods can be applied by the system operator. When the Pareto optimal set is obtained, one of the solutions can be chosen by the system operator as the best compromise solution by using the preferences.

To consider the multi-objective scheduling problem of DERs in the form of the microgrid and VPP concepts, different objectives have been investigated as sub-functions by the authors. Also different solution methods have been applied and the suitable strategy for the selection of the best solution is considered. These aspects are summarized in Table 4.

As it can be seen in Table 4, the important multi-objective considerations focused on minimization of the operational costs and emission [34,35,37,51,54,79,84]; maximization of the benefit and minimization of the cost [44,113,142]; minimization of the generation cost and optimal renewable energy source penetration [30,136]; and energy cost minimization and reliability consideration as energy loss index [37,44,48,51,84]. According to this classified explanation, it can be found that the operational cost, emission, and reliability consideration are the important functions from a multi-objective view in both microgrid and VPP scheduling problems. In addition, with regard to the solution of these problems, the algorithms based on Pareto method [30,35,37,79,84,136] are widely used due to the conflict of the objectives. Also, in some conditions when the objectives can be aggregated together, the weighting method [48,51,142] is the best and suitable way to solve these types of problems. In addition, epsilon constraint method [34,54] is the other approach that can deal with the multi-objective problems for the proper scheduling of DERs. By using the weighting method, this approach is able to identify a number of non-inferior solutions that are not obtainable on a nonconvex boundary using the weighting method. A further disadvantage of this approach is that the use of hard constraints is rarely adequate for expressing true design objectives. The optimization proceeds with reference to these priorities and allowable bounds of acceptance. Moreover, to select the best solution out of a set of solutions in the scheduling problem, fuzzy technique [54,79,84] can play a proper role because it can propose different importance degrees in the understudy process.

Table 4
Different aspects of the multiobjective scheduling of DERs in microgrids and VPPs.

Ref. no.	Objectives	Solution method	Selection of the best
[30]	optimal integration of DG in terms of selection, sizing and allocation of the different renewable generation units	Non dominated Sorting Genetic Algorithm II (NSGA-II)	–
[34]	operational costs and emission	Augmented ε-Constraint Method	using a reference trade-off set by the decision maker
[35]	total operation costs and total operation emissions	Improved Teaching–Learning-Based Optimization (ITLBO) based on Pareto method	Weight Factors
[37]	energy losses in the system, fuel consumption costs and CO_2 emissions	Non dominated Sorting Genetic Algorithm II (NSGA-II)	–
[44]	to maximize participants' benefits and minimize the corresponding risks in the multi-product market environment	mixed-integer programming stochastic framework	–
[48]	energy cost and reliability	Weighting Method	–
[51]	electricity price, environmental effect due to atmospheric emissions, and service quality	Weighting Factor	–
[54]	operational costs and emission	combination of Lexicographic optimization and hybrid augmented weighted ε-constraint technique	Fuzzy Decision Making
[79]	total operation costs and total operation emissions	multi-objective AMPSO (Adaptive Modified Particle Swarm Optimization algorithm)	Fuzzy Technique
[84]	investment cost, operation and maintenance cost, total fuel emissions produced by diesel generators and total loss of load probability	Differential Evolution algorithm	Fuzzy Technique
[113]	to maximize the benefit of the VPP and minimizing the cost of the VPP self-supplying	an iterative procedure by CPLEX	–
[136]	overall generation cost and renewable energy sources penetration	Multi-objective GA	–
[142]	satisfaction values toward profit and EENS	Weighting Method	–

Table 5
Comparative review of the cited literatures related to microgrid concept.

Ref. No.	Formulation Type		Solving Method		DER Type										Uncertainty	Reliability	Reactive Power	Control	Emission	Stability	Demand Response	Multi-objective
	Stochastic	Deterministic	Mathematical	Heuristic	WT	PV	CHP	HT	PS	FC	Th	EV	MT	ES								
[28]	√	–	–	√	√	√	–	–	–	–	√	–	–	–	√	–	–	√	–	–	√	–
[29]	√	–	√	–	–	√	–	–	–	–	–	–	–	√	√	–	–	–	–	–	–	–
[30]	√	–	–	√	√	√	–	–	–	–	–	√	–	√	√	√	–	–	–	–	–	√
[31]	√	–	–	√	√	√	–	–	–	√	–	√	√	–	√	–	–	–	√	–	√	–
[32]	√	–	√	–	–	√	√	–	–	√	√	√	√	√	√	–	–	–	√	–	√	–
[33]	√	–	√	–	–	–	–	–	–	–	√	–	–	–	√	√	–	–	–	–	√	–
[34]	√	–	√	–	√	√	–	–	–	√	√	–	–	–	√	√	–	–	√	–	√	√
[35]	√	–	√	–	√	√	–	–	–	√	–	–	√	√	√	–	–	–	√	–	–	√
[36]	√	–	–	√	√	–	–	–	–	–	√	–	–	–	√	–	–	–	–	–	–	–
[37]	√	–	–	√	–	√	√	–	–	–	–	–	–	√	√	–	√	–	√	–	–	√
[38]	√	–	–	√	√	√	–	–	–	√	–	–	√	√	√	–	–	–	–	–	–	–
[39]	√	–	–	√	√	√	–	–	–	√	–	–	√	√	√	–	–	–	–	–	–	–
[40]	√	–	–	√	√	√	–	–	–	√	–	–	√	√	√	–	–	–	–	–	–	–
[41]	√	–	√	–	√	–	–	–	–	–	√	–	–	–	√	–	√	–	√	–	–	–
[42]	√	–	√	–	–	–	–	√	–	–	√	–	–	–	√	–	–	–	√	–	–	–
[43]	√	–	√	–	–	–	–	√	–	–	√	–	–	–	√	–	–	–	–	–	–	–
[44]	√	–	√	–	√	–	–	√	–	–	–	–	–	–	√	–	–	–	–	–	–	√
[45]	√	–	√	–	√	–	–	√	–	–	√	–	–	–	√	–	–	–	√	–	–	–
[46]	√	√	√	–	–	–	–	–	–	–	√	–	–	–	√	–	√	–	–	–	–	–
[47]	–	√	√	–	–	–	√	–	–	√	–	–	–	√	–	–	–	–	–	–	–	–
[48]	–	√	√	–	–	–	–	–	–	√	√	–	–	√	–	√	–	–	–	–	–	√
[49]	–	√	√	–	√	√	√	–	–	–	√	–	–	√	√	–	–	–	–	–	–	–
[50]	–	√	√	–	√	–	–	√	–	√	√	–	–	√	–	√	√	–	–	–	–	–
[51]	–	√	√	–	–	√	–	–	–	√	–	–	–	√	–	–	–	–	√	–	–	√
[52]	–	√	√	–	√	√	–	–	–	√	–	–	–	√	–	–	–	–	–	–	–	–
[53]	–	√	√	–	√	√	√	√	–	√	√	–	√	–	–	√	–	–	√	–	–	–
[54]	–	√	√	–	–	–	√	–	–	–	√	–	–	√	–	–	–	–	√	–	√	√
[55]	–	√	√	–	–	√	√	–	–	–	√	√	–	√	–	–	√	√	√	–	–	–
[56]	–	√	√	–	√	√	–	–	–	√	–	–	√	–	–	–	–	–	√	–	–	–
[57]	–	√	√	–	√	√	–	–	–	–	–	–	–	√	–	–	–	√	–	√	–	–
[58]	–	√	√	–	√	√	–	–	–	√	√	–	√	√	–	–	–	–	√	–	–	–
[59]	–	√	√	–	–	√	√	–	–	–	–	–	–	√	–	–	–	–	√	–	–	–
[60]	–	√	√	–	–	–	–	–	–	–	√	–	–	√	–	–	–	–	–	–	√	–
[61]	–	√	√	–	–	√	–	–	–	–	√	–	–	–	–	√	–	–	–	–	–	–
[62]	–	√	√	–	–	√	√	–	–	–	√	√	√	√	–	–	√	–	–	–	–	–
[63]	–	√	√	–	–	–	√	–	–	–	√	–	–	–	–	–	√	–	–	–	–	–
[64]	–	√	√	–	√	√	–	–	–	–	–	–	–	√	√	√	–	–	√	–	–	–
[65]	–	√	√	–	√	√	–	–	–	√	–	–	√	√	–	√	–	–	–	–	–	–
[66]	–	√	√	–	√	√	–	–	–	√	–	–	–	√	–	–	–	–	–	–	–	–
[67]	–	√	√	–	√	√	–	–	–	√	–	–	√	√	–	–	–	–	–	–	√	–
[68]	–	√	√	–	–	√	–	–	–	–	√	–	–	√	–	–	–	–	–	–	√	–
[69]	–	√	√	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	–
Ref. No.	**Formulation Type**		**Solving Method**		**DER Type**										**Uncertainty**	**Reliability**	**Reactive Power**	**Control**	**Emission**	**Stability**	**Demand Response**	**Multi-objective**
	Stochastic	**Deterministic**	**Mathematical**	**Heuristic**	**WT**	**PV**	**CHP**	**HT**	**PS**	**FC**	**Th**	**EV**	**MT**	**ES**								
[70]	–	√	√	–	√	√	–	–	–	–	–	–	√	√	–	√	–	–	√	–	–	–
[71]	–	√	√	–	√	√	√	–	–	√	√	–	–	√	√	√	–	√	–	–	–	–
[72]	–	√	√	–	√	√	√	–	–	–	√	–	–	√	√	–	√	–	–	–	–	–
[73]	–	√	√	–	–	–	–		–	–	√	–	–	√	–	–	–	√	–	–	–	–
[74]	–	√	√	–	√	√	√	–	–	√	√	–	–	√	–	–	√	–	–	–	–	–
[75]	–	√	√	–	√	√	–	–	–	–	√	–	–	√	–	√	√	–	√	–	–	–

[76]	–	✓	✓	–	✓	✓	–	–	–	–	✓	✓	–	–	–	–	–	✓	–	✓	–	–
[77]	–	✓	–	✓	✓	✓	–	–	–	–	✓	–	–	✓	–	–	✓	✓	–	–	–	–
[78]	–	✓	✓	✓	✓	✓	–	–	–	–	✓	–	–	✓	–	–	–	–	–	–	–	–
[79]	–	✓	–	✓	✓	✓	–	–	–	✓	–	–	✓	✓	–	–	–	–	✓	–	–	✓
[80]	–	✓	–	✓	–	–	–	–	–	–	–	✓	–	–	–	✓	–	–	–	–	✓	–
[81]	–	✓	–	✓	–	–	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–
[82]	–	✓	–	✓	–	✓	–	–	–	✓	–	–	–	✓	–	–	✓	–	–	–	–	–
[83]	–	✓	–	✓	–	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–	–
[84]	–	✓	–	✓	✓	✓	–	–	–	✓	✓	–	–	✓	✓	✓	–	–	✓	–	–	✓
[85]	–	✓	–	✓	–	–	–	–	–	–	✓	–	–	–	–	✓	–	–	–	–	✓	–
[86]	–	✓	–	✓	✓	–	✓	–	–	–	✓	–	–	–	–	–	–	–	–	–	–	–
[87]	–	✓	–	✓	✓	✓	–	–	–	✓	✓	–	✓	✓	–	–	–	–	✓	–	–	–

Abbreviations: WT: Wind Turbine; PV: Photovoltaic; CHP: Combined Heat and Power; HT: Hydro Turbine; PS: Pumped Storage; FC: Fuel Cell; Th: Thermal; EV: Electric Vehicle; MT: Micro Turbine; ES: Energy Storage.

12. Comparison of approaches

The summary reviews and investigations performed on the cited literatures in scheduling problem using microgrid and VPP concepts are depicted in Tables 5 and 6. In these tables, the literatures are assessed from different issues and points of view and a comprehensive comparison is performed. In both concepts, the authors have focused on the uncertainty, reactive power, control and automation, and DR associated with scheduling problem.

Emission and stability issues have not been considered in more details in the VPP and microgrid concepts, respectively. In the scheduling problem through microgrid concept, researchers have concentrated more on the deterministic formulation type than on the stochastic one. The mathematical solving method is more heuristic in both concepts. Also, in DER type consideration, the use of wind and solar powers are more prevalent than in others; therefore, it can be concluded that these DERs are more pervasive. Reliability consideration in VPP concept is low and it seems that more investigation will be desirable. Considering the multi-objective problems in VPP scheduling, it seems that more consideration is needed, because it has not been investigated so much.

13. Conclusion

In this paper, the recently published papers were evaluated and investigated as a comprehensive review. The subject is DER scheduling problem in both microgrid and VPP concepts concerning different issues and points of view. The papers cited suggest that DER scheduling problems must be carried out to perform a reliable, optimal, and suitable operation from the view of customer and generator. In addition, to obtain a proper and better scheduling, the problems should be associated with different important factors such as uncertainty, reliability, reactive power, control, emission, stability, and demand response. The scheduling problem study can be different when comparing the systems with each other. The present review can help to the development of future researches in this field to open new windows for further and important investigations. On the whole, the DER scheduling models presented and developed have some of the following drawbacks:

- In the microgrid scheduling, some DERs such as pump-storage and hydro-power have attracted limited attention. These kinds of generations should be taken into consideration due to their beneficial aspects like environmental ones, cost, and efficiency.
- In the microgrid concept, stability consideration has not been properly studied. These kinds of dynamic studies are very important and they should be analyzed from various views in new research activities.
- Demand response consideration in microgrid concept related to the scheduling problem can be investigated in the form of different program types. In this regard, it seems that considering any types of DR such as direct load control programs, demand bidding/buyback programs, emergency DR program, capacity market programs, and real-time pricing rates are very interesting.
- In the VPP scheduling problem, reliability consideration has not been suitably investigated. Due to the importance of assessment in this field, different indices can be introduced and with their penetration in the objective function or as constraints, the reliable scheduling can be achieved.
- Emission problem associated with VPP scheduling has not been considered so much. Therefore, minimization of various pollutants like what have been considered in the microgrid concept is relevant and important criteria which can be investigated in the future.

Table 6
Comparative review of the cited literatures related to VPP concept.

Ref. No.	Formulation type		Solving method		DER type										Uncertainty	Reliability	Reactive power	Control	Emission	Stability	Demand Response	Multi-objective
	Stochastic	Deterministic	Mathematical	Heuristic	WT	PV	CHP	HT	PS	FC	Th	EV	MT	ES								
[88]	√	–	√	–	√	√	–	√	–	–	√	–	–	√	–	–	–	√	–	√	–	–
[89]	√	–	√	–	√	–	–	√	–	–	√	–	–	√	√	–	–	–	–	–	√	–
[90]	√	–	√	–	√	√	–	–	–	–	–	–	–	√	√	–	–	–	–	–	√	–
[91]	√	–	√	–	–	–	–	–	–	–	–	–	–	–	√	–	–	√	–	–	√	–
[92]	√	–	√	–	√	√	√	–	–	√	–	–	√	√	√	–	–	√	–	–	√	–
[93]	√	–	√	–	√	√	–	–	–	–	–	–	√	√	–	–	–	–	–	–	√	–
[94]	√	–	√	–	√	√	–	–	–	√	√	–	–	–	√	–	–	–	–	–	–	–
[95]	√	–	√	–	√	–	–	√	–	–	–	–	–	–	–	–	–	–	–	–	–	–
[96]	√	–	√	–	–	√	√	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
[97]	√	–	√	–	√	–	–	–	–	–	–	–	√	√	√	–	–	–	–	–	√	–
[98]	√	–	√	–	–	–	–	–	–	–	–	–	–	–	√	–	–	–	–	–	√	–
[99]	√	–	√	–	–	–	–	–	–	–	√	√	–	–	√	–	–	–	–	–	–	–
[100]	√	–	√	–	√		–	–	√	–	√	–	–	√	√	–	–	–	–	–	–	–
[101]	√	–	√	–	√	–	–	–	–	–	–	–	–	√	√	–	–	–	–	–	–	–
[102]	√	–	√	–	√	√	–	–	–	–	√	–	–	–	–	–	–	–	–	–	–	–
[103]	√	–	√	–	√	√	–	–	–	–	√	–	–	–	√	–	–	–	–	–	–	–
[104]	√	–	√	–	√	√	√	–	–	–	–	√	–	√	√	–	–	–	–	–	√	–
[105]	√	–	√	–	√	√	–	–	–	–	√	–	√	–	–	–	–	–	–	–	–	–
[106]	√	–	√	–	√	√	√	–	–	√	–	–	–	–	√	–	–	√	–	√	–	–
[107]	√	–	√	–	√	√	√	√	–	√	√	–	–	√	–	–	√	√	–	√	√	–
[108]	√	–	√	–	–	√	–	√	–	–	–	–	–	√	–	–	√	√	–	√	–	–
[109]	√	–	–	√	√	–	–	–	–	–	–	–	–	–	√	–	–	–	–	–	–	–
[110]	√	–	–	√	√	√	–	√	–	–	√	–	–	√	–	–	–	–	–	–	–	–
[111]	√	–	√	–	√	√	–	–	–	–	√	–	√	√	√	–	–	√	–	–	–	–
[112]	√	–	√	–	√	√	–	–	√	–	√	–	–	√	√	–	–	–	–	–	√	–
[113]	–	√	√	–	√	√	√	–	–	–	√	–	–	√	–	–	–	–	√	–	√	√
[114]	–	√	√	–	√	–	–	√	–	–	√	–	–	–	–	–	–	√	–	–	–	–
[115]	–	√	√	–	–	–	–	–	–	–	√	–	–	–	–	–	–	√	–	–	–	–
[116]	–	√	√	–	√	√	–	√	–	–	√	–	–	–	–	–	–	–	–	–	√	–
[117]	–	√	√	–	–	–	√	–	–	–	–	–	–	√	–	–	–	–	–	–	–	–
[118]	–	√	√	–	√	√	√	–	–	–	–	–	–	√	–	–	–	√	–	–	–	–
[119]	–	√	√	–	√	√	√	–	–	√	√	–	√	√	–	–	–	√	√	–	–	–
[120]	–	√	√	–	√	–	–	–	–	–	–	√	–	–	–	–	–	–	–	–	–	–
[121]	–	√	√	–	√	√	–	–	–	–	√	–	–	–	–	√	–	–	–	–	–	–
[122]	–	√	√	–	√	√	–	√	–	√	√	√	√	–	–	–	–	–	√	–	–	–
[123]	–	√	√	–	√	√	–	–	√	–	√	–	–	–	–	–	–	–	–	–	–	–
[124]	–	√	√	–	–	–	√	–	–	–	–	–	–	–	–	–	–	√	–	–	–	–
[125]	–	√	√	–	–	–	–	–	–	–	√	–	–	–	–	–	√	√	–	–	–	–
[126]	–	√	√	–	–	–	√	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
[127]	–	√	√	–	–	–	–	–	–	–	√	–	–	–	–	–	–	√	–	–	–	–

Ref. No.	Formulation Type		Solving Method		DER Type										Uncertainty	Reliability	Reactive Power	Control	Emission	Stability	Demand Response	Multi-objective
	Stochastic	Deterministic	Mathematical	Heuristic	WT	PV	CHP	HT	PS	FC	Th	EV	MT	ES								
[128]	–	√	√	–	√	√	–	√	–	–	–	–	–	√	–	–	√	√	–	–	–	–
[129]	–	√	√	–	–	–	–	–	–	–	–	√	–	–	–	–	–	√	–	–	–	–
[130]	–	√	√	–	√	–	–	–	–	–	√	–	–	–	–	–	–	√	–	–	–	–
[131]	–	√	√	–	–	–	–	√	–	–	–	–	–	–	–	–	√	√	–	√	–	–
[132]	–	√	√	–	√	–	–	–	–	–	–	–	–	–	√	–	–	–	–	–	√	–
[133]	–	√	√	–	√	√	–	–	–	–	√	–	–	–	–	–	–	–	–	–	√	–
[134]	–	√	√	–	√	√	√	–	√	–	–	–	–	√	–	–	–	–	√	–	√	–
[135]	–	√	√	–	–	–	–	–	–	–	–	–	–	√	–	√	–	–	–	–	–	–

[136]	–	√	–	√	√	–	–	–	√	–	–	–	–	–	–	–	–	–	–	–	–	√
[137]	–	√	–	√	–	–	–	–	–	–	–	–	–	√	–	–	–	–	–	–	√	–
[138]	–	√	–	√	–	–	–	–	–	–	–	–	–	√	–	–	–	–	–	–	√	–
[139]	–	√	√	–	–	–	√	–	–	–	–	–	–	√	√	–	–	–	–	–	–	–
[140]	–	√	√	–	–	√	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	–
[141]	–	√	–	√	–	–	–	–	–	–	√	–	–	–	–	–	–	–	–	–	√	–
[142]	–	√	√	√	√	–	–	–	–	–	–	–	–	–	–	√	–	–	–	–	√	√
[143]	–	√	√	–	–	√	–	–	–	–	–	–	–	–	–	–	–	–	–	√	√	–
[144]	–	√	√	–	–	–	–	–	–	–	√	–	–	√	–	–	–	–	–	–	–	–

Abbreviations: WT: Wind Turbine; PV: Photovoltaic; CHP: Combined Heat and Power; HT: Hydro Turbine; PS: Pumped Storage; FC: Fuel Cell; Th: Thermal; EV: Electric Vehicle; MT: Micro Turbine; ES: Energy Storage.

- Multi-objective consideration is another aspect that has not been considered appropriately. So, this type of formulation with different goals like those in the microgrid concept can help to have useful results to manage the whole power system.

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