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TECHNICAL SPECIFICATION

colour inside

Virtual power plants –
Part 1: Architecture and functional requirements

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VIRTUAL POWER PLANTS –

Part 1: Architecture and functional requirements

FOREWORD

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IEC TS 63189-1 has been prepared by subcommittee SC 8B: Decentralized electrical energy systems, of IEC technical committee TC 8: System aspects of electrical energy supply. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
8B/124/DTS	8B/197/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63189 series, published under the general title *Virtual power plants*, can be found on the IEC website.

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- amended.

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VIRTUAL POWER PLANTS –

Part 1: Architecture and functional requirements

1 Scope

This part of IEC 63189 covers the terms and definitions, system composition and control modes of virtual power plant (VPP). It defines the functional requirements for VPPs, including power generation forecasting, load forecasting, generation and consumption scheduling, control and management of energy storage devices and loads, coordinated optimization of distributed energy resources, status monitoring and communication, data collection and analysis, and market transactions.

Since a virtual power plant is a cluster of dispersed energy converting installations, which are aggregated, it uses additional systems to achieve its objectives (e.g. regional energy meteorology forecasting, site specific energy management systems, SCADA and other communication systems).

Local regulations, the electricity market model and the corresponding manner of organising the market related to the utilisation of controllable DER affect the management, control and operation of VPPs.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60870-5-101, *Telecontrol equipment and systems – Part 5-101: Transmission protocols – Companion standard for basic telecontrol tasks*

IEC 60870-5-104, *Telecontrol equipment and systems – Part 5-104: Transmission protocols – Network access for IEC 60870-5-101 using standard transport profiles*

IEC 61000 (all parts): *Electromagnetic compatibility EMC*

IEC 61850 (all parts), *Communication networks and systems for power utility automation*

IEC 62351-3, *Power systems management and associated information exchange – Data and communications security – Part 3: Communication network and system security – Profiles including TCP/IP*

IEC TS 62351-5, *Power systems management and associated information exchange – Data and communications security – Part 5: Security for IEC 60870-5 and derivatives*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
controllable load
load of particular consumers which under contract must be increased or reduced, for a limited period of time, at the request of the distribution supply undertaking

Note 1 to entry: Controllable load can be increased as well as reduced, according to the request of the distribution supply undertaking.

[SOURCE: IEC 60050-603:1986, 603-04-42, modified – "increased or" has been added to the definition.]

3.2
distributed energy resources
DER
generating units (with their auxiliaries, protection and connection equipment), as well as load units and those units having both characteristics (such as electrical energy storage systems), connected to a low-voltage or a medium-voltage network

[SOURCE: IEC 60050-617: 2009, 617-04-20, modified: adopted for the inclusion of controllable loads]

3.3
distributed generation
DG
generation of electric energy by multiple sources which are connected to the power distribution system

[SOURCE: IEC 60050-617:2009, 617-04-09]

3.4
demand response
DR
action resulting from management of the electricity demand in response to supply conditions

[SOURCE: IEC 60050-617:2009, 617-04-16]

3.5
demand side management
DSM
process that is intended to influence the quantity or patterns of use of electric energy consumed by end-use customers

[SOURCE: IEC 60050-617:2009, 617-04-15]

3.6
electrical energy storage system
EES system
EESS
grid-connected installation with defined electrical boundaries, comprising at least one electrical energy storage, which extracts electrical energy from an electric power system, stores this energy internally in some manner and injects electrical energy into an electrical power system and which includes civil engineering works, energy conversion equipment and related ancillary equipment

Note 1 to entry: The EES system is controlled and coordinated to provide services to the electric power system operators or to the electric power system users.

Note 2 to entry: In some cases, an EES system may require an additional energy source (nonelectrical) during its discharge, providing more energy to the electric power system than the energy it stored (compressed air energy storage is a typical example where additional thermal energy is required).

Note 3 to entry: "Electric power system" is defined in IEC 60050-601:1985, 601-01-01.

[SOURCE: IEC 62933-1:2018, 3.1.2]

3.7
local control unit
LCU
device that interfaces field equipment to a control system by transmitting measurement and status data from the equipment to the control system and operating commands from the control system to the equipment

3.8
microgrid
group of interconnected loads and distributed energy resources with defined electrical boundaries forming a local electric power system at distribution voltage levels, that acts as a single controllable entity and is able to operate in either grid-connected or island mode

Note 1 to entry: This definition covers both (utility) distribution microgrids and (customer owned) facility microgrids.

[SOURCE: IEC 60050-617:2009, 617-04-22]

3.9
virtual power plant
VPP
party or system that realizes aggregation, optimization and control of distributed generation, energy storage devices and controllable loads

Note 1 to entry: The aggregated distributed generation, energy storage devices and controllable loads are not necessarily within the same geographical area.

Note 2 to entry: The party or system is to facilitate the activities in power system operations and electricity market.

3.10
virtual power plant management system
VMS
system which can realize the dispatch management and control of different VPP units such as generators, loads and energy storage units, with the VPP participating in market trading in an orderly manner

4 System components

4.1 General

A VPP may include distributed generators, storages and controllable loads spread over a wide geographical area, equivalent to a large power plant with the function of regulation and control. A core part of a VPP is the virtual power plant management system (VMS). In VPPs, the VMS can communicate with generators, controllable loads, energy storage units and microgrids with different reserved communication interfaces to provide operational data and realize unified scheduling management and control. The communication medium can be optical fibre, cable or wireless, with OPC (Object Linking and Embedding for Process Control), IEC or other protocols. The VMS provides external interfaces and can interact with system operator and energy management/trading platform to implement external information access release, scheduling management and market trading. Figure 1 shows the VPP system components.

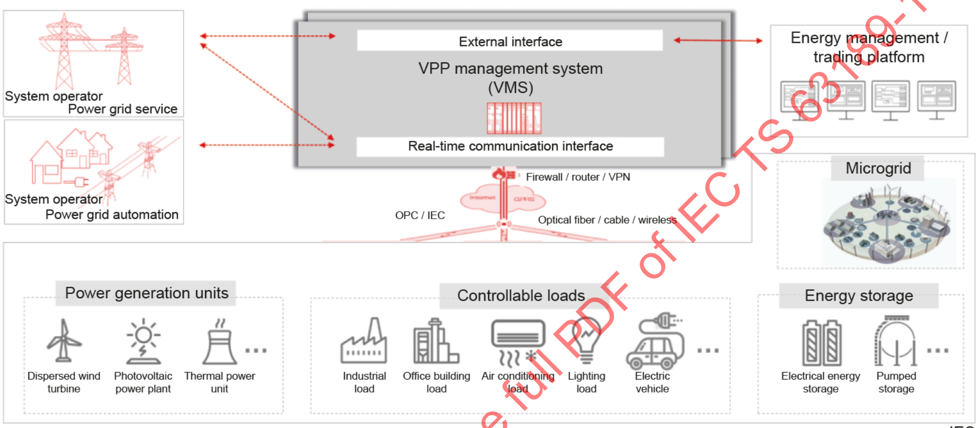

Figure 1 – VPP composition diagram

A typical virtual power plant possibly contains multiple levels, among which the subordinate level may be regarded as an integrated part for the upper level, and a VPP can also be formed by a certain amount of VPPs.

4.2 Power generation units

The power generation units of a VPP can include dispersed wind turbines, photovoltaic power plants, thermal power units and other units. The power generation unit can interact with VMS to upload the status information of the power generation unit and respond to the power generation control command of VMS. The power generation forecast function should be provided by upper layer VMS.

4.3 Controllable loads

The controllable loads of a VPP can include industrial loads, office building loads, air conditioning, lighting, electric vehicles, and other loads. The controllable loads exchange information with the VMS, upload the status information and respond to the power demand command of VMS. The controllable loads prediction function should be provided by the upper layer VMS.

4.4 Energy storage

The energy storage units of a VPP can include electric energy storage, pumped storage and other units, which have the ability to interact with the power grid in two directions, and can supply or consume power. The energy storage unit interacts with the VMS to upload the status information of the units and respond to the charge and discharge control commands of the VMS.

The energy storage units can help the upper layer VMS to realize an optimized operation control strategy.

4.5 Microgrids

A microgrid is a small power distribution system consisting of distributed generation, energy storage units, energy conversion device, load, monitoring, control, energy management and protection devices. It may operate in grid-connected or island mode. It is used to realize flexible and efficient application of distributed energy resources. The VMS communicates with the microgrid control system, and then the microgrid control system communicates with the generators, EES units, loads, etc., in microgrid.

On a basis of having the integration function for DER, microgrids and VPPs not only play the role of participating in market transactions and demand response, but also provide support for peak regulation and frequency regulation for the system.

Microgrids and VPPs have certain commonalities regarding the system components, role in aggregating DER, participating market activities including demand response, as well as providing ancillary service to the power system.

While microgrids and VPPs have a major difference regarding geographic boundary. A microgrid is a physical system composed of DER, loads, electric lines and so forth that located in the same geographic area, and is connected to the main grid as a single unit. Virtual power plants are capable to achieve geographically dispersed DER aggregation and coordination by advanced communication technologies and by software and hardware framework, taking part in the electricity market as an independent unit.

4.6 VMS

The VMS realizes the dispatch management and control of different VPP units such as generators, loads and energy storage units, with the VPP participating in market trading in an orderly manner. The VMS should include data acquisition and communication systems to realize data communication and interaction with different systems and units. According to different control methods, a VMS can function in centralized control mode or decentralized control mode. The centralized control mode is generally applicable to smaller and more centralized controllable resource aggregation, such as DER connected at the same grid point. The decentralized control mode is more suitable for large-scale, geographically distributed areas control resource aggregation.

5 Control mode

5.1 Centralized control mode

5.1.1 General

In the centralized control mode, the VMS determines the optimization objectives according to the grid state, and then directly controls and schedules the LCUs (local control unit) according to the analysis and calculation of the optimal scheduling strategy according to the optimization objectives. LCU converts the operational state or signal into a data format that can be sent via communication channels. It also converts the data/information sent from the VMS into commands to realize the functional control of the remote equipment. See Figure 2.

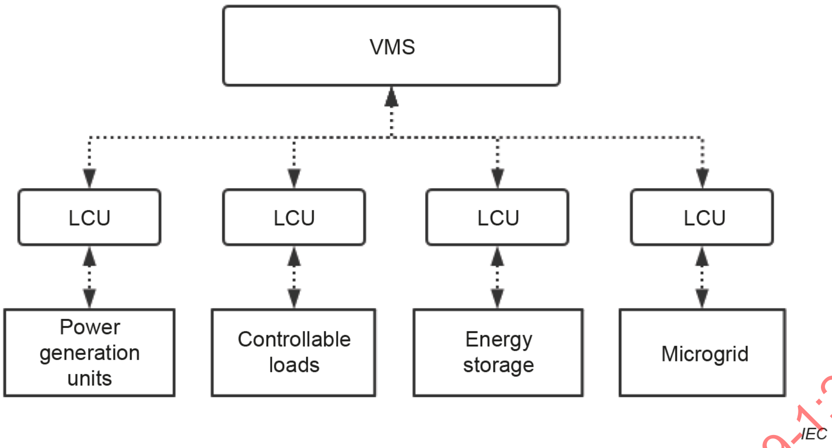

Figure 2 – Centralized control mode architecture

5.1.2 Dispatch and control architecture

In the centralized control mode, all kinds of measurement variables, state variables and control variables are collected by the LCU and uploaded directly to the VMS. The VMS analyses and calculates the optimal dispatch and control strategy according to the given optimization objectives and sends the dispatch commands to the LCU. The LCU forwards the dispatch command to the control systems of DER and controllable load for implementation.

The time interval for the LCU to upload data to the VMS shall be suitable for the type of business in which the VPP participates. When the VPP participates in real-time business, it should be transmitted frequently. While when participating in non-real-time business, it can be transmitted less frequently.

When a certain regulated resource is out of operation due to failure or maintenance, offline status information needs to be uploaded to the LCU. The LCU then uploads the information to the VMS, and the VMS will re-optimize the objective function and determine set points of the other regulated resources.

5.1.3 Communication system

Communication system should be implemented to enable the data and information exchange amongst different layers of VPP, i.e. the DER and LCU, controllable and LCU, LCU and VMS, VMS with system operator and energy market. The communication system shall consider the real engineering conditions and allow to use consistently multiple communication technologies and protocols.

The communication system shall be specified by the following technical parameters:

- Quality of the communication network
- Communications technology and protocols for communications networks
- Access rate requirements for different control scenarios
- Information model[1]
- Security requirements

[1] IEC 61850-7-420:2021, *Communication networks and systems for power utility automation – Part 7-420: Basic communication structure – Distributed energy resources and distribution automation logical nodes* is an eligible data model for supporting VPPs (independently from the communication protocol).

The first four requirements are detailed in 6.1, the establishment of security protection capability should be considered from the aspects of potential malicious attacker's capability, natural disasters, other external threats, internal system vulnerabilities, and recovery capability after damage. The security protection plan shall include physical environment protection, security area division, terminal protection, communication control, security equipment and protection system selection, security policy and process, etc.

5.1.4 Application scenario

The central control mode is suitable for a single operator to build a small VPP. The controllable resources are few in number, variety and total amount in a small scope (for example, contiguous urban areas), which mainly provides services for local power grid or power users.

5.2 Decentralized control mode

5.2.1 General

In decentralized control mode, Central VPP Management System (CVMS) and Local VPP Management System (LVMS) coordinate the control and dispatch of LCUs. LVMS may also have lower-level LVMS nested within it. Among them, according to the different division of functions between CVMS and LVMS, decentralized control mode can be classified into decentralized control-centralized assessment and decentralized control-local assessment. In the decentralized control-centralized assessment, calculation is performed by the CVMS and implemented by the LVMS. In the decentralized control-local assessment, calculation and implementation are performed by the LVMS, and the CVMS is only used as the data exchange and management system for interactive electricity price information, meteorological information, etc., and decomposes and distributes the power grid dispatching or power market demand to the LVMS.

The communication system between CVMS and LVMS shall consider the real engineering conditions and allow to use consistently multiple communication technologies and protocols. See Figure 3.

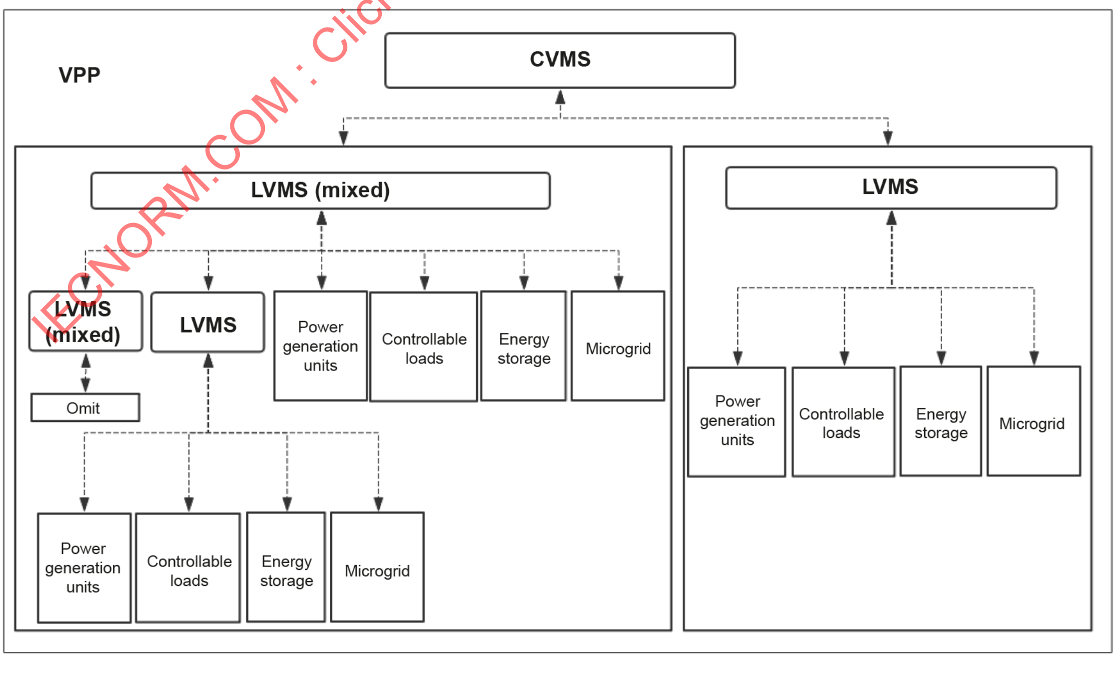

Figure 3 – Decentralized control mode architecture

In both cases, the time interval between LCU uploading data to LVMS depends on the needs of the distribution network operator and should be appropriate for the type of business in which VPP participates. In both cases, the time interval for the LCU to upload data to the LVMS should be suitable for the type of business in which the VPP participates. When the VPP participates in real-time business, it should be transmitted frequently, while when participating in non-real-time business, it can be transmitted at less frequently. See 6.1 for specific requirements.

5.2.2 Decentralized control-centralized assessment

5.2.2.1 Dispatch and control architecture

In the decentralized control mode, the dispatch and control are performed jointly by the CVMS and the LVMSs. Among them, LVMSs will aggregate controllable components based on electrical location, network operational limits, geographical location or energy type into VPP units, and accept the dispatch and control of CVMS.

The general consideration on the decentralized control mode architecture includes:

a) dispatch and control priority of CVMS and LVMSs under different controllable resources aggregation modes. For example, for the aggregation mode based on energy type, when the controllable components of the same feeder but different energy types need to be scheduled and controlled, they are controlled by CVMS or LVMSs respectively according to their energy types;
b) dispatch and control boundary of CVMS and LVMSs. For example, whether the controllable resources in the VPP unit controlled by LVMSs should be transparent to the CVMS. If so, the CVMS needs to send accurate scheduling commands to dispatch geographically or electrically interconnected components in different VPP units;
c) functional division of CVMS and LVMS;
d) recommend fault tolerance and synchronization mechanisms, including:
   - Failure of one or more LVMSs due to delayed communication or system failure;
   - The LVMSs cannot execute or delay the execution of dispatch and control instructions from the CVMS;
   - One or more components within a VPP unit do not respond or fail to respond.

Asset owner is allowed to opt out. VPP systems assure that the required flexibility is still available.

In the above case, offline status information needs to be uploaded to LCU, which will upload the information to the main station, which will re-optimize the calculation and select other regulated resources.

5.2.2.2 Communication system

The requirements are the same as 5.1.3.

5.2.2.3 Application scenario

This control mode is suitable for the single operator or a group of VPP operators in a wide geographical area (for example, a large city or agglomeration) to build large-scale VPP (the controllable resources are large in number, variety and total amount), and is especially suitable for the sub-regional (including electrical and geographical) or classified management of resources. Such VPPs can serve a wide area grid, local grid or power users.

5.2.3 Decentralized control-local assessment

5.2.3.1 Dispatch and control architecture

The CVMSs only serve as data exchange and processing centres, which are used to exchange price information, weather information, etc., and to decompose and distribute power grid dispatching or power market demand to each VPP unit. LVMS is responsible for dispatching and controlling the VPP units to ensure the optimal operation of the local power grid. Dispatching information, provided by the distribution grid operator shall be processed by the LVMS directly.

Therefore, the dispatch and control architecture within the VPP units can be referred to as the decentralized control mode of the VPP control architecture. In addition, fault tolerance and synchronization mechanisms need to be considered, mainly including:

– Failure of one or more LVMSs due to delayed communication or system failure;
– The LVMSs cannot execute or delay the execution of scheduling control instructions from the CVMS;
– One or more components within a VPP unit do not respond.

Asset owner is allowed to opt out. VPP systems assure that the required flexibility is still available.

In the above case, offline status information needs to be uploaded to the LCU, which will upload the information to the main station, which will re-optimize the calculation and be replaced by other adjustable resources.

5.2.3.2 Communication system

The requirements are the same as 5.1.3.

5.2.3.3 Application scenario

This control mode is suitable for large-scale controllable resources with various types of DER which can be controlled by different LVMS. Through the cooperation between different LVMS, it can provide services for a wide area grid, local grid or power users.

6 Functional requirements

6.1 Status monitoring and communication

6.1.1 Status monitoring and data collection

When connecting various DER and controllable loads to a VPP system, LCU is recommended to be placed to carry out the functions of status monitoring, data collection and processing, communication and control.

The general functional requirements of an LCU are listed below:

LCU should have the functions of data collection and control to the connected DER. The data type and data accuracy to be collected should meet the requirements of different data analysis functions. For example, for the function of participating in power trading, the data to be collected includes the active power, the on/off status, the cost, etc. The sampling period depends on the requirement of different trading platform, e.g. every 5 min or 15 min. For the function of providing the frequency regulation or reserve, the data to be collected includes the active power, the on/off status, the cost, etc. The sampling period depends on the requirement of the system operation, e.g. every minute for secondary frequency regulation.

LCU should be able to send data remotely to VMS, CVMS, and LVMS, and be able to receive control command or set-point command remotely from VPP central platform or sub-platform.

LCU should have the interface and communication functions, see 6.1.2 in detail.

LCU should have time synchronization function.

LCU should have the self-testing and diagnostic function.

LCU may have the encryption functions for data privacy, e.g. cyber security in accordance with IEC 62351-3, IEC 62351-5, etc.

6.1.2 Communication and interface specification

LCU shall have communications with the DER/controllable loads and the VMS. The communication scheme can be selected according to actual engineering conditions.

Carrier and optical fibre communication scheme should be in accordance to any standard of IEC 61850 series, IEC 60870-5-101, IEC 60870-5-104, DNP3.0 and other appropriate IEC series, OpenADR, OPC, Modbus, MQTT, etc.

Wireless communication scheme should meet the power specific level. Electromagnetic compatibility (EMC) should be in accordance to IEC 61000 series. The operating temperature, the power supply voltage and the protection level should be adequate values for the equipment. The wireless transmission equipment should have the function of router and firewall. The channel should be compatible with 5G/4G/3G/GPRS.

The availability of the channel should be greater than 99 %, which is defined as the time that the channel is available for normal communication compared with the whole year time. The private network communication is preferred. Wireless public network communication is recommended as the main mechanism while other communication schemes are considered as supplementary mechanisms.

LCU should have any of RS232, RS485, Ethernet, optical fibre communication interface.

In practical application, in terms of information security, secure communication devices, one-way communication devices, VPN links, etc., are necessary. Considering the reliability of the communication scheme, redundant communication methods should be adopted.

In addition, VPP should have an interface with the smart metering system for data exchange.

6.1.3 Data analysis functional requirements

VPP status monitoring and data collection shall support VPP to achieve the following functions:

– Data storage function should include historical database and process database.
– Registration function should support the registration and management of DER, controllable loads, and microgrids.
– Billing function should support the energy settlement of DER and controllable loads.
– Diagnostic function should evaluate the operating status and availability of DER in the VPP.

6.2 Prediction

6.2.1 Power generation forecast

6.2.1.1 Objective requirement

a) Power generation in VPPs includes conventional power plants and renewable power plants (such as photovoltaic power stations, wind farms and biomass power generation).

b) The time scale of power generation forecast includes ultra-short-term forecast (time scale from minutes to hour) and short term forecast (time scale from hour to day), and the detail requirements should be in accordance with the technical specifications in each VPP project.

c) The spatial scale of power generation forecast should vary with the optimization.

The spatial characteristics of the forecasts should be adapted to the multiple combinations of renewable power plants in VPPs.

d) The outputs of the power generation forecast should be online corrected with actual power data, and the accuracy should meet the operation requirements.

6.2.1.2 Data preparation

a) Actual power data

Actual power data is necessary but not sufficient for power generation forecast, which is also indispensable to the mathematical model of uncertainty forecast.

All actual power data of photovoltaic power stations, wind farms or biomass power generation with not less than one year of commissioning should be collected since operation.

b) Generation unit information

Generation unit information includes unit type, unit capacity, normal generation state, curtailment state, stand-by state.

c) For wind farms, the wind speed, wind direction, air temperature and atmospheric pressure at the altitude of 10 m, 70 m and above for at least one year should be collected.

d) For photovoltaic power plants, the global horizontal radiation, direct normal radiation, ambient temperature and sunshine time for at least one year should be collected.

e) Topographic data should be collected.

6.2.1.3 Data analysis and processing

a) All data should be collected automatically and more data can be added manually.

b) Data of wind farms and photovoltaic power forecasting system should be transmitted by reliable wireless or fibre transmission.

c) All data should be tested for integrity and rationality before storage in the database, and any missing or abnormal data should be supplemented and corrected, and use log files to record the operations on that abnormal data.

6.2.1.4 Multi-scale forecast

Considering the climate and historical data of the wind farm, the photovoltaic power plant or biomass power station, the appropriate method should be used to construct a specific model for power generation forecast. According to predictable time scale and specific requirements of a practical application, ensemble method should be adopted to achieve an optimal prediction strategy. Generally, predictable time scale for power generation forecast should include short term forecast and ultra-short-term forecast, with high-resolution time series processing.

6.2.2 Controllable load forecast

Controllable loads in the virtual power plant system need to participate in the optimal scheduling of the system. Load forecasting can be divided into two types: short term and ultra-short term. The influencing factors need to be considered in load forecasting, including:

a) Economic factors: economic factors have influence to the load size.
b) Time factors: the load level on weekends is usually below that on workdays. The load amplitude declines significantly and the load curve has obvious changes in major holidays. In addition, it differs distinctly from seasons.
c) Meteorological factors: temperature is the main factor affecting the short-term load. Humidity, clouds, rainfall and comfort requirement may also influence the load, especially in summer.
d) Other factors: there are many other factors that may affect the accuracy of load forecasting, such as consumption pattern changes of large electric power consumers. The electricity price variation may also influence the load demand.

Analyse statistically the present load condition within the planning, rebuilding or expansion area of the virtual power plant, including:

– Types of the main power load.
– Peak load demand.
– Typical daily load curves in every month.

Forecast the load demand in the planning period, according to the historical load data and the total programming requirement of power development within the covering area of the virtual power plant, including:

– The growth trend of peak load.
– Types and levels of additional load.
– Total annual load demand forecasting data.
– The typical daily load demand forecast (with hourly interval data).
– Dynamic load (e.g., motor) characteristics forecasting data (with minute or second level data).

6.3 Aggregation and optimization

6.3.1 Aggregation

Aggregation is one of the most important features of virtual power plants. For a virtual power plant with multiple distributed energy resources, the output volatility of multiple distributed power sources is high due to the uncertainty output of wind/sunlight, which affects the quality of VPP ancillary services to the public grid and makes it difficult to meet electricity market trading standards as well. With advanced information communication technology and software, the controllable units such as distributed generators, controllable loads, energy storage systems, and microgrids could be aggregated to provide more stable electrical power to the public network, fast-response ancillary services, and join the power market. This would reduce the unbalanced risk of distributed generators, controllable loads and energy storage systems running alone in the market, and could obtain the benefits of economies of scale.

The aggregation function should establish capacity configuration and regulation method, by which the VMS can regulate the output of combined distributed power sources to conform to expected values.

The aggregation function should take into account the backup costs and deviation penalties for the contribution of renewable energy, to better weigh the expectations and risks of investment returns, and to quantitatively analyse the approved electricity price, risk preference, reserve price, and renewable energy for renewable energy generation.

6.3.2 Optimization

The optimization of the virtual power plant refers to the integration and packaging of distributed generators and controllable loads with fine control methods and energy management methods. Controlling the output through mutual complement between multi-power supplies and multi-time-space coordinated scheduling method, thereby achieving the standards for participation in the electricity market transactions, which means a power sales agreement is similar to a conventional unit can be signed.

Different control architectures, operating modes, market factors, and other factors will directly affect the results of the virtual power plant’s portfolio optimization.

From the perspective of controlling range, the virtual power plant’s optimization can be divided into internal controllable units optimization and optimization in market transactions.

a) The optimization of the virtual power plant’s internal controllable units

Distributed generators’ output has volatility and intermittency, such as wind power, photostatic, etc., which means accurate prediction is difficult. However, different types of distributed power supplies are space-time complementary to each other, so distributed power combinations can effectively reduce their respective uncertainties.

The optimization of the virtual power plant’s internal controllable units refers to the efficient and economic aggregation of various power generation units in the virtual power plant through algorithms such as combinatorial optimization, according to different optimization objectives, such as the highest renewable energy consumption rate, the highest reliability of power supply, etc., and cooperative scheduling with energy storage, electric vehicles and interruptible load, to achieve multi-objective optimization scheduling within the virtual power plant.

b) The optimization of the virtual power plant participating in market transactions

Optimization of participating in market transactions refers to the virtual power plant combining all distributed energy resources flexibly and dynamically, with the goal of maximizing revenue and adopting a combination algorithm or game theory, according to the type of transaction, such as electricity, ancillary service, etc. The real-time and flexibility of dynamic combination can reduce the cost of real-time balance of energy networks and the bias caused by power plant downtime, load and renewable energy output prediction errors.

6.3.3 Generation and load schedule development

A VPP that participates in the day-ahead operation process of electricity market is summarized in Figure 4, and the operation process of short-term market is similar to the day-ahead operation process. The virtual power plant can achieve peak load regulating of power system through the day-ahead market or the daily plan. The participation of VPP in the day-ahead operation can include the following steps:

a) Predict the load of the next day, and estimate the response capacity and cost. Participate in the electricity market bidding based on the predicted and estimated results.
b) Release the load shedding time and the amount to be reduced to the user, according to the load reserve or reduction plan obtained from the electricity market bidding.
c) The user conducts bidding on the demand side based on his own load-loss cost.
d) The optimization decision model based on demand side bidding and multi-energy complementation is solved, and the user's load shedding amount and output increase amount are obtained, and the dispatching instruction is sent to the user.
e) The VPP optimal scheduling process.

Declaration: Before the end of the energy market transaction, the VPP operation and dispatch centre will declare the bidding information of day D+1 to System Operator (SO) according to its own economic characteristics, which mainly includes the overall declared power generation capacity of VPP and its corresponding power generation cost curve. At the end of each dispatching cycle, System Operator will assess the actual power generation and power generation efficiency of new energy units, and punish the phenomenon of wind abandonment and light abandonment accordingly. When VPP declares in the reserve market, it not only needs to meet the upper limit of unit output, but also can optimize the internal power generation plan by allocating the reserve capacity of units reasonably, and economically compensate the unit whose power generation is reduced according to its reserve capacity share.

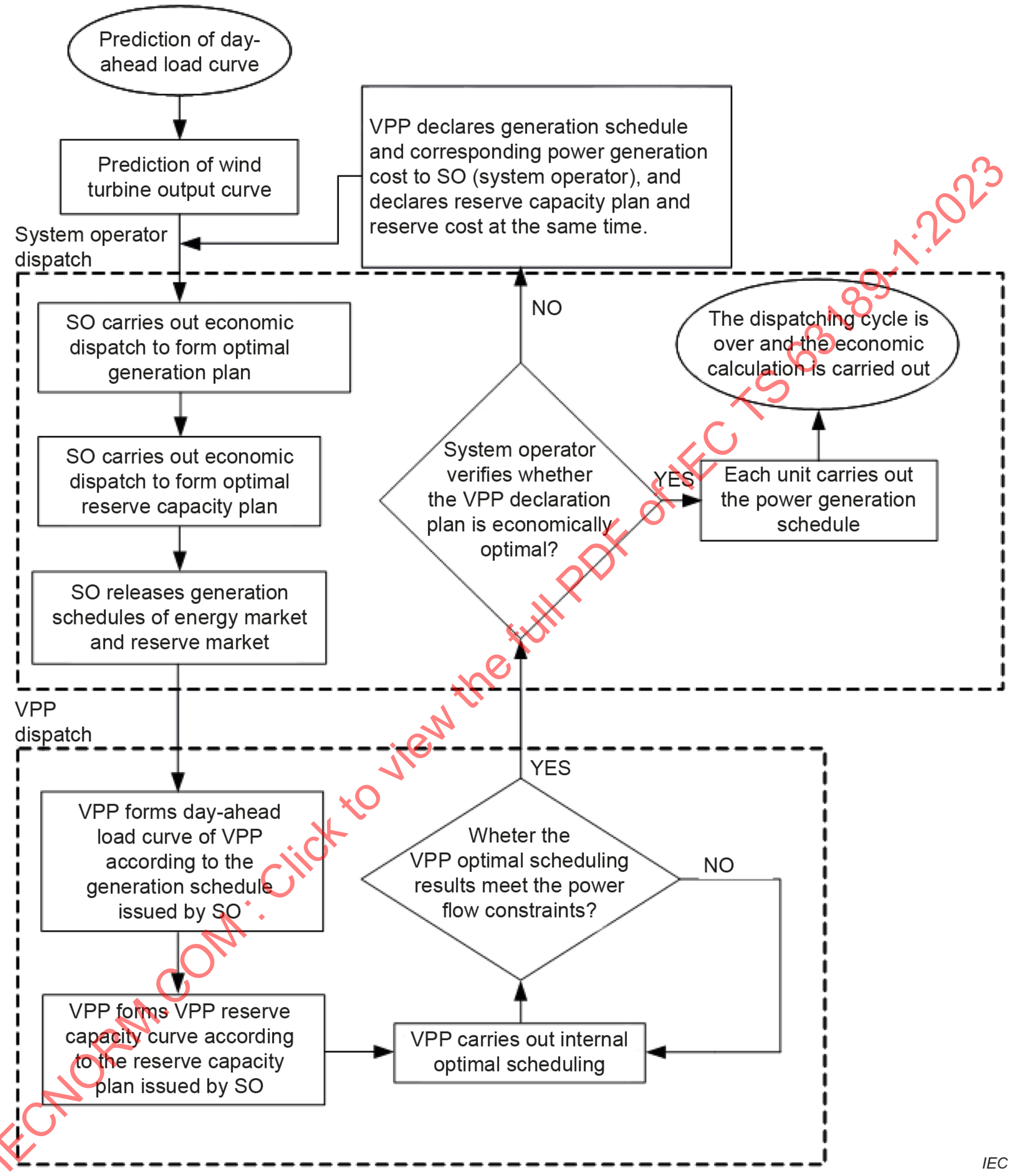

Figure 4 – VPP participates in the day-ahead operation process of electricity market

Scheduling process: Before performing SO dispatching, it is necessary to forecast the load distribution of the system in the next day and the output of new energy power plants. At the same time, the cost curve of VPP generating cost and reserve capacity is equivalent to a generator set, which is substituted by SO dispatching model for optimization analysis. SO economic dispatch takes the minimization of generation cost as the objective function. It needs to satisfy the constraints of power balance, capacity of generating units and climbing rate, capacity of energy storage equipment and charging and discharging rate, power flow and node voltage. Costs in SO economic dispatch can be divided into unit generation cost, new energy generation cost (including self-generation cost and penalty cost of abandoning wind and light), energy storage operation cost and reserve capacity cost.

6.4 Ancillary services

A VPP that participates in the ancillary service of the power system, may have the functions of frequency regulation, reserve capacity, congestion management, voltage control, etc.

a) Frequency regulation

VPP utilizes aggregate resources (mainly including DG, EES, controllable loads, etc.) to participate in power system frequency regulation ancillary service. VPP mainly provides services in the form of active power. The technical indexes that need to be specified include: response time, adjustment rate, adjustment accuracy, service capacity, service duration, resource distribution (for example, the frequency control area where the resource is located), etc.

b) Reserve capacity

A VPP can optimize and combine various controllable resources to participate in different types of reserve capacity ancillary services (including load reserve, accident reserve, maintenance reserve). A VPP mainly provides services in the form of active power. The technical indexes that need to be specified include: response time, adjustment rate, adjustment accuracy, service capacity, service duration, etc.

c) Congestion management

VPP influences the distribution of power flow by utilizing the widely distributed controllable resources in the network topology to solve or alleviate the congestion problem in power transmission. VPPs mainly provides services in the form of active power. The technical indexes that need to be specified include: response time, adjustment rate, adjustment accuracy, resource distribution (for example, the grid topology location of the resource junction), service capacity, service duration, etc.

d) Voltage control

VPP can control the voltage at the end of a line by utilizing the converged line-controlled resources distributed in specific distribution feeders. The technical indexes that need to be specified include: response time, adjustment rate, adjustment accuracy, resource distribution (for example, the access location of resources in the distribution network), service capacity, service duration, etc.

The definitions and reference ranges of the above technical indexes are shown in Annex A, among which the response time, adjustment rate, adjustment accuracy are the general technical indexes that need to be specified when VPP participates in ancillary services. The recommended values of these three general technical indexes in various ancillary services are shown in Table A.1. These technical indexes highly depend on the regional market rules and power system characteristics, so that the values are examples given for illustrative purposes.

6.5 Electricity market transaction function

6.5.1 Participate in the electricity market or aggregate ancillary services

The VPP should have the function of participating in electricity market or aggregate ancillary services transaction, including:

a) Participating in electricity transaction.

The VPP should be able to provide the range of input power of power grid (output power of the VPP) and its corresponding available time. It also should be able to provide the ramp rate required to participate market transaction of output power, as well as the minimum continuous operation and outage time of the VPP.

b) Participating in aggregate ancillary services transaction.