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Virtual Power Plant for Interoperable and Smart isLANDS

VPP4Islands

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Deliverable Report

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REVISION AND HISTORY CHART

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
ALWA	AlgoWatt
AMU	Aix-Marseille Université
BC2050	Blockchain2050
BornholmsVarme	Bornholms Varme A/S
BoZI	Bozcaada Belediye Baskanligi
BUL	Brunuel University
CIVI	CIVIESCO srl
CSIC	Consejo Superior de Investigaciones Científicas
CU	Cardiff University
DAFNI	Network of Sustainable Greek Islands
FORM	Consell Insular de Formentera
FTK	FTK Forschungsinstitut fur Telekommunikation und Kooperation EV
GRADO	Comune di Grado
IDEA	INGENIERIA Y DISENO ESTRUCTURAL AVANZADO
IFISC	Institute for cross disciplinary physics and complex systems
INAVITAS	INAVITAS Enerji AS
LIS	Laboratoire d' Informatique et Systemes
RDIUP	RDI'UP
REGENERA	REGENERA LEVANTE
SCHN	Schneider Electric
TROYA	TROYA CEVRE DERNEGI
UIB	Universitat de les Illes Balears
UEDAS	Uludag electric dagitim

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EXECUTIVE SUMMARY

This Report has been prepared as a revision of the Requirements and Needs for Island Energy Services Report uploaded on 31.01.2021. Diagrams of the pilot region determined within the scope of the project and analyzes for operation and failure situations were prepared and attached. In addition, smart meters to be measured in the pilot region were determined and their technologies were added. In this framework, the preliminary studies for the supply of products and the facility continue in the technologies determined.

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1. VIRTUAL POWER STATIONS AND THEIR EXAMPLES IN THE WORLD

1.1. Definition of Virtual Power Plant (VPP)

Virtual Power Plant (VPP), as a software and an interface, aims at the proper integration of existing energy systems and distributed generators (DGs) and is defined as an autonomous microgrid [1]. A basic VPP structure is given in Figure 1. Virtual power plants play an active role in resource planning, load demand management, cost reduction, efficient use of distributed energy, and intervention in case of failure. Flexible loads can be managed by VPPs instead of activating or decommissioning real power plants.

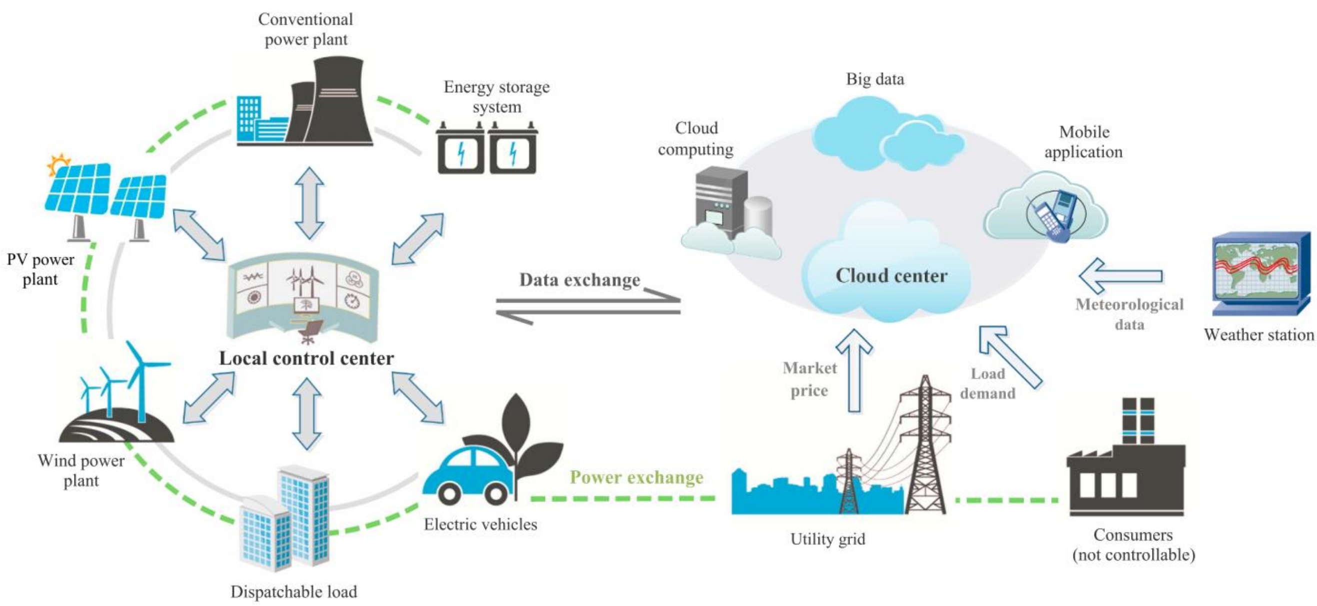

Figure 1. A basic VPP structure [1]

VPPs consist of combining various small-sized distributed production units to create a "single virtual generation unit" that can be viewed and managed as a whole. DGs' control cannot be provided centrally due to resorting to plain DGs leads instead of inefficient and costly investments in the distribution infrastructure [2]. In fact, there is often no cooperation nor communication between neighboring DGs. As a result of this, the capacity of DG is limited to respond to local needs only. One way to overcome these problems is to bring together many DG units and combining them into VPPs. A

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VPP offers the right solution for the integration of alternative energy sources into the grid. In addition, it has the benefits of reducing the load on the power grid, generating more power locally, avoiding high voltage transmission over long distances, reducing energy losses, etc. [3]. A VPP consists of an increasing number of installed, alternative energy sources from the structure point of view. The general purpose of a VPP is to manage many DG units and active elements as storage and flexibles loads from a standard central management system. In Figure 2, the operating scheme of a general VPP system is given.

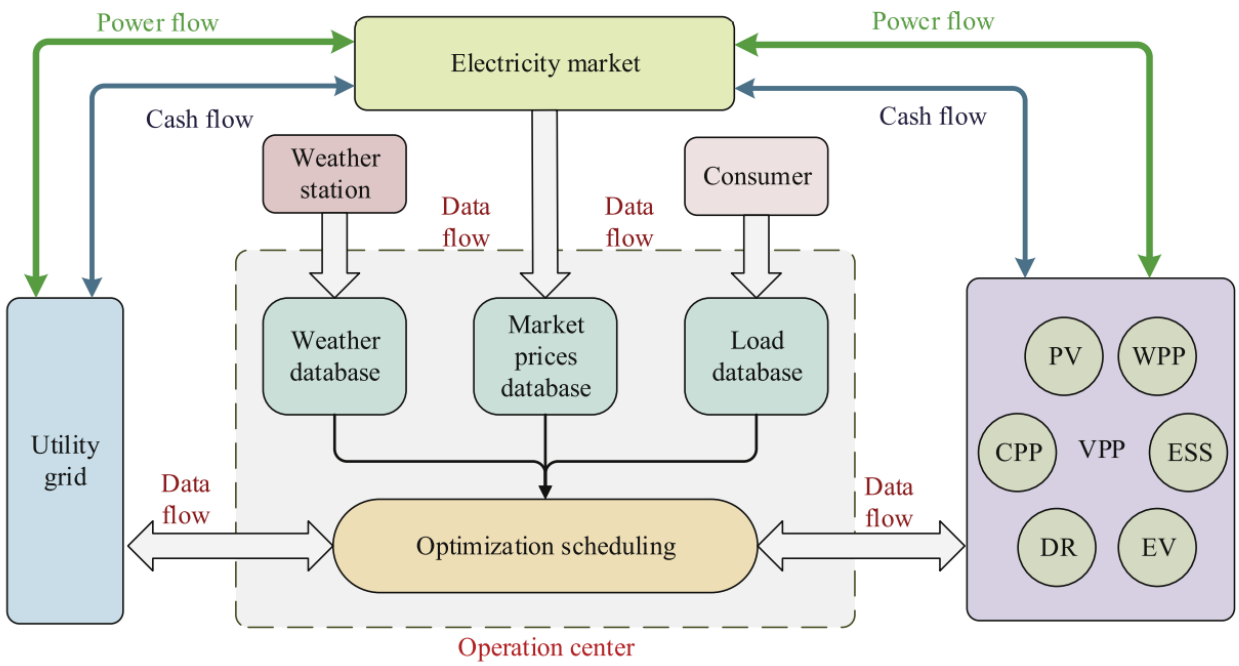

Figure 2. Operating structure of a general VPP system (PV=Photovoltaic, WPP= Wind Power Plant, ESS=Energy Storage System, EV=Electric Vehicle, DR=Demand Response, CPP= Conventional Power Plant)

Relationship between distributed power systems and VPP: VPP gathers several functional units under a central control system. Almost all energy production and storage technologies can be part of a VPP, including biogas, biomass, combined heat and power (CHP), wind, solar, hydro, diesel, and fossil fuel power plants. Distributed energy providers are established to be managed collectively and

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can be used as virtual power plants in some cases occurring in the grid. Many DGs, storage elements and flexible loads can be controlled in this approach, rather than commissioning or decommissioning real power plants. If a VPP is installed as a reliable solution, it can be seen as an alternative that can be used with confidence and comfort instead of real power plants (CPP=Coventional Power Plant).

Solutions used for distribution grids, including control and optimization through a VPP, can correlate all units' real-time load charts, forecast deviations, free capacity trading during the day, and optimized day-ahead load schedules for each balance group in the Region [4]. The VPP system architecture is scalable from a few units to thousands of units, and customers can implement their business models. It realizes real-time optimization of setpoints and provision of balancing power, taking into account current system constraints and ramp speeds. The solution handles the real-time processing of large-signal flows and data sets and manages optimum unit commitment and control of assets in a single step.

The VPP model should facilitate demand-side management and resynchronization. DG and battery systems that form the structure of VPP are shown in Table 1. Besides, power flow control and interfaces used (power electronics elements and electrical machines such as converters, generators, etc.) for DG and ESS are also shown in Table 1.

Table 1. Methods and interfaces used in DG and battery systems [5]

Primary energy source type		Typical interface	Power flow control
DG	CHP	Synchronous generator	AVR and Governor (+P, ±Q)
	Internal combustion engine	Synchronous or induction generator	
	Small hydro	Synchronous or induction generator	
	Fixed speed wind turbine	Induction generator	Stall or pitch control of turbine (+P, −Q)
	Variable speed wind turbine	Power electronic converter (AC–DC–AC)	Turbine speed and DC link voltage controls (+P, ±Q)
	Micro-turbine	Power electronic converter (AC–DC–AC)	
	Photovoltaic (PV)	Power electronic converter (DC–DC–AC)	Maximum power point tracking and DC link voltage controls (+P, ±Q)
	Fuel cell	Power electronic converter (DC–DC–AC)	
Energy storage	Battery	Power electronic converter (DC–DC–AC)	State of charge and output voltage/frequency control (±P, ±Q)
	Fly-wheel	Power electronic converter (AC–DC–AC)	Speed control (±P, ±Q)
	Super capacitor	Power electronic converter (DC–DC–AC)	State of charge (±P, ±Q)

The load condition (critical, sensitive devices, etc.) is essential for the expected operating strategy's success in micro-grid installation. The created structure must have the following properties:

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- To stabilize the voltage and frequency by automatic functions (Primary Control), it should facilitate load shedding/generation.
- The power quality and reliability of critical and sensitive loads need to be increased.
- Peak-load must be reduced in order to optimize the value of distributed generators.

VPP auctions are the sale of electricity capacity, which are "virtual" divestments by one or more dominant firms in a market, rather than "physical" divestments. Instead of selling the physical plant, the firm retains management and control of the facility but sells its electricity capacity virtually by offering contracts to maximize its production. These contracts are sold in auctions as fissile goods. The world's first and longest-running virtual power plant auctions are Electricité de France (EDF) generation capacity auctions.

Differences between micro-grid and VPP: Micrograds and VPPs share some critical features, such as the ability to integrate demand response, DG power generation, and distribution-level storage. It is estimated that some market participants share many activities with these two platforms. However, there are also differences between micro-grid and VPP [6]:

1) VPPs are always in the form connected to the grid.

2) VPP such an unexpected situation.

3) The presence or absence of archiving is possible for VPPs.

4) VPPs are highly dependent on information technology.

5) VPP in "large geographic areas."

6) VPPs can be marketed to fill the wholesale market.

7) VPPs can be marketed on existing structures.

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1.2. VPP structures and applications in the world

FENIX VPP (England): The aim of this project, which started in 2005, is to increase its contribution to integrating DG through the combination of large-scale VPP and decentralized control [7]. FENIX box (FB) features a remote monitoring-control interface; commercial VPP, timing, and energy optimization of the DG group and technical VPP; represents the production schedule and load sharing verification. In this structure, a 3 MW DG structure consisting of various generators, including a 200 kW fuel cell, is used. When a market transaction occurs, a production schedule for commercial DG is created, and this flow is transferred to all DG devices. In real-time, DG monitors programs to generate/consume energy. FENIX VPP structure is presented in Figure 3. The project aims to optimize DGs' operation by integrating the power system and managing it hierarchically, providing a sustainable solution for the future security, income, and stability of the European Union (EU) electricity supply system. The uncertainty in the system lies in renewable energy uncertainty and market price uncertainty.

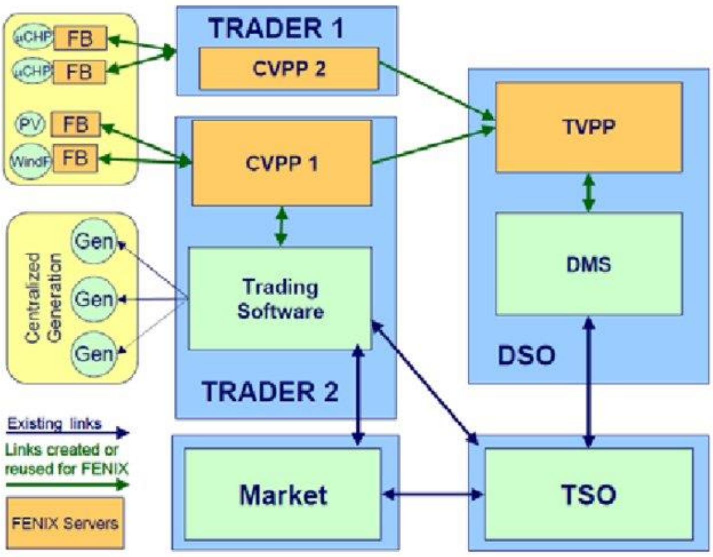

Figure 3. FENIX VPP structure (PV=Photovoltaic, CHP=Combined Heat, and Power, DMS=Data Management System, CVPP= Centralized VPP, TSO=Trading Selling Offer) [7]

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EDISON VPP (Denmark): The EDISON project [8], started in 2009, was initiated to explore the challenges of integrating electric vehicles into the power system. The platform is used on Bornholm Island, where every electric vehicle on the island can be connected to the energy system via VPP. There are 52 distributed generator units on the island, 35 of which are wind turbines. There are 27,000 electricity consumers on the island with a total capacity of 135 MW and a maximum load of 55 MW. The VPP system of the EDISON project consists of 3 main modules: control module for each DG, data acquisition module, and connectivity, collaboration, and communication module. In this project, VPP uses the electric vehicle battery's energy storage to stabilize the wind turbine's output ripple. The VPP can use battery energy storage to hold market auctions.

It should be noted that the reasonable choice of robust control coefficients has a specific impact on the formulation of the VPP bidding strategy. CVaR (Conditional Value at Risk) can be adapted to measure the reserve's impact on system operation risk to reduce risk loss caused by uncertainties. The operating structure of the EDISON project is shown in Figure 4.

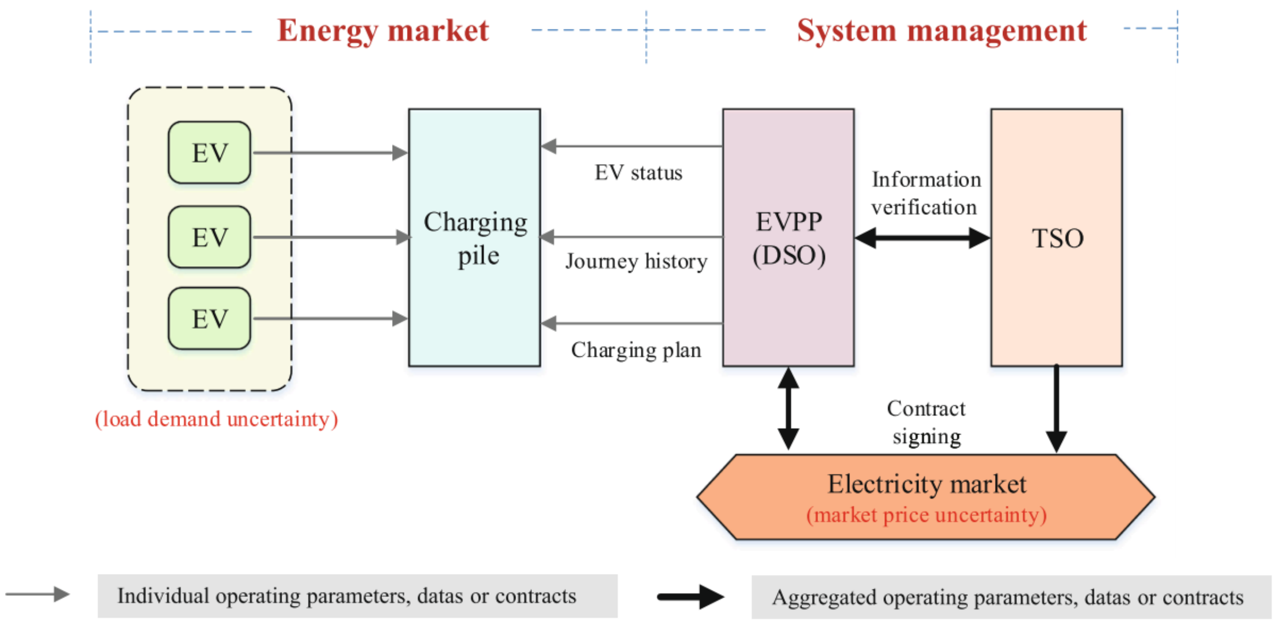

Figure 4. The operating structure of the EDISON project [8]

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KONWERS VPP [9]: Units with an individual share of the maximum power of the VPP are considered. Small units and uncontrollable units are only estimated. DG units are used to monitor network and power flow parameters. VPP structure includes CHP (which works with energy obtained by the combustion of biomass), wind turbines, photovoltaic (PV) power plants, and conventional power stations. VPP DGs meet the central part of the electricity and heat demand. If the electricity generation is insufficient, extra electricity will be provided to the VPP from external sources. This condition shows that DGs must be connected to the external electricity grid.

NEMOCS VPP: Fluctuations in the grid are increasing with renewable energy sources entering into electricity generation. A VPP can compensate for frequency variations of the grid by successfully predicting, monitoring, and controlling consumption. If the grid frequency becomes unstable, a group of flexible units step in and provide the desired power within a few seconds. Next-Kraftwerke, an experienced energy company and operator of one of Europe's largest VPPs, has developed the NEMOCS VPP [10] platform. By combining decentralized energy sources, power generation can be adjusted depending on grid requirements, thus providing a stable and low-cost power supply. This system has more than 4000 decentralized energy assets with an energy capacity of 2,800 MW. Different technologies can be connected to the VPP and controlled remotely using a standard interface with the project. The control system displays and records real-time information about resources' current capacity, storage levels, and standby status.

Shanghai Huangpu District (SHD) VPP (China): The project is a VPP pilot project implemented in China in 2016 [12]. The project aims to develop a VPP for commercial buildings in the Shanghai city area and realize automated, large-scale, and diversified demand response of commercial buildings based on the internet, smart energy, and big data technology. SHD project is located in the commercial zone, and its main component is the demand responses of commercial buildings. Demand response is heavily influenced by psychology and politics, which makes centralized control more difficult.

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Besides, uncertainty becomes more pronounced and more robust after introducing large-scale renewable energy, quickly causing power system imbalances. In this project, demand information and production information of DG on the consumer side are continuously monitored and evaluated by the demand side management center (dispatch center). In the light of these data, the critical control systems are operated in real-time over the network. In this way, the balance between production and consumption is achieved, and frequency control is realized.

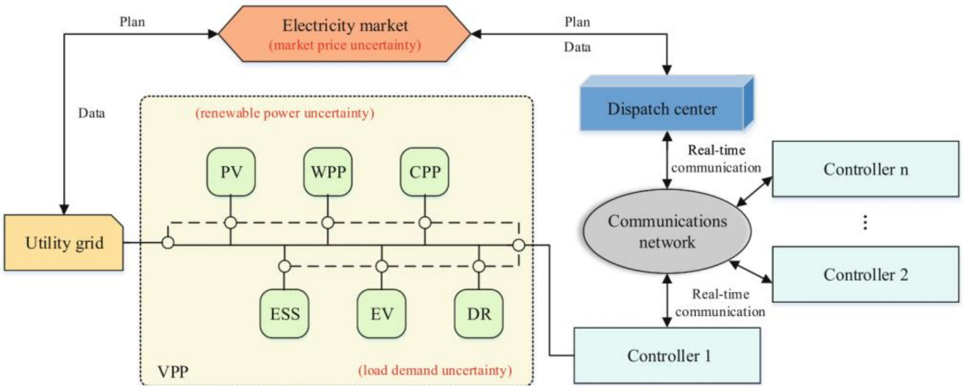

Figure 5. Operating structure of the SHD project [12]

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2. RENEWABLE ENERGY EVALUATION IN ISOLATED AREAS

2.1. The current state of energy generation on the islands

On islands, traditional energy sources are limited due to isolation, lack of space, and distance. Imported fossil fuels are still the main energy source for most of the world's islands. For example, 90% of energy demand in the Caribbean islands is based on imported fossil fuels. More than 30% of the GDP (Gross Domestic Product) is spent on fuel imports in some islands. Also, when the fuel is insufficient, the power supply will be affected or even interrupted. Therefore, the energy cost is a considerable burden for the islands [13].

Due to the deteriorating state of energy security and insufficiency, using different energy sources has become necessary for island structures. Accordingly, the Global Renewable Energy Island Network (GREIN) was established by the International Renewable Energy Agency (IRENA) to provide a platform for exchange and cooperation for the renewable energy development of islands [14]. More than 60 European islands have signed the "Islands Pact" to achieve the European Union (EU) sustainability targets for 2020.

The dominant renewable energy sources used on the islands are biomass energy, hydroelectricity, wind, and solar energy. Table 2 shows the current renewable energy use situation in selected islands around the world. It is seen that the ratio of renewable generation compared to the total electricity generation varies between 0% and 100% in different islands. Renewable energy use differs for each island.

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Table 2. Electricity generation from renewable energy on selected islands [15]

Island	Total percentage of electricity production from renewable energy (%)	Main type of renewable energy	Renewable energy plan/target (percentage of total power)	Electricity consumption per capita (kWh)	Region
Samsoe	100	Wind	100% (present)	\	The Atlantic Ocean
Pellworm	64.95	Wind, Solar	100% (present)	20,457	The North Atlantic
Fiji	59.3	Wind, Hydropower	90% (2015)	946.8	The South Pacific
Reunion	31.2	Hydropower, Biomass, Ocean	100% (2030)	3382	The Indian Ocean
Crete	26	Wind, Solar, Biomass	50% (2020)	3806	The Mediterranean
Cape Verde	21	Wind, Biomass	50% (2020)	595	The Indian Ocean
Cyprus	2.8	Wind, Solar	16% (2020)	4081	The Mediterranean
Tuvalu	2	Wind, Solar	100% (2020)	489	The South Pacific
Barbados	0.0	Solar	29% (2019)	3491	The Caribbean

In the early stages of PV systems, high investment is required, and extreme climatic events can damage PV systems. Therefore, while many islands have abundant natural resources to improve PV generation, there is little actual improvement in most islands' solar power generation. The status of renewable energy technologies in islands is discussed in Table 3. The cost and characteristics of different resources are summarized. It can be seen that the leveled electricity costs (LCOE) of PV systems are 2100–7000 $ / kW, which is relatively high across different renewable energy generations.

Table 3. State of renewable energy technologies: characteristics and costs [15]

Type of electricity generation technology	Hydropower: grid-based	Hydropower: off-grid/rural	Solar PV: ground-mounted utility-scale	Solar PV: rooftop	Solar thermal: domestic hot water systems	Geothermal power	Wind: onshore	Wind: Small-scale turbine
Plant size	1–18,000 MW	0.1–1000 kW	2.5–250 MW	3–5 kW (residential)	7–10 kW_{th} (single family)	1–100 MW	1.5–3.5 MW	< 100 kW
Capital costs ($/kW)	750–4000	1175–6000	1200–1950	2150–7000	147–2200	1900–5500	925–1950	6040 (United States)
Typical energy costs (cent/kWh)	2–23	5–40	9–40 (non-OECD)	28–55 (non-OECD)	1.5–28 (China)	4–19	4–16	15–20 (USA)

Wind energy, the most common and promising renewable energy source in island structures today, is quite rich on most islands. The average wind speed is 3–10 m/s, maximum 40–50 m/s. According to statistics, more than 50% of the islands have reached wind power generation, and 55.4% of the electricity produced from renewable energy is provided by wind energy [16]. Table 4 shows the current potential and current use of wind energy on selected islands. Besides, islands face several problems in the process of harnessing wind energy. Land ownership for wind farms is one of the most

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critical problems, and therefore, many projects have been stopped or postponed [17]. Also, location selection and accurate assessment of wind power potential are challenges in using wind energy.

Table 4. Potential and current use of wind energy on selected islands [15]

Island	Wind speed (m/s)	Current installed capacity (MW)	Electricity potential (GWh)	Existing electricity generation (GWh)
Crete	10.1	134.75	900	336.7
Samsoe	6.5–7.5	33	/	100% Power supply
Barbados	6.6	0	20	0
Cape Verde	5.75	26	/	8.33
Pellworm	5.55	5.7	91.5	15.136

Hydroelectric, a clean energy source with almost no greenhouse gas emissions, has shown prime use and development worldwide. Besides, it is an important renewable energy source in the islands, especially in the mountainous Region with abundant rainfall and storage reservoirs. Hydroelectric power accounts for 89% of installed renewable energy capacity in the Caribbean islands. In recent years, medium (25-250 MW) and small (<25 MW) power plants have been used in clean hydroelectric projects on the islands. Many small and micro-hydroelectric power plants supplied electricity to dispersed consumers in the islands' rural areas with low electricity demand and dispersed population. Although these projects' initial capital costs are high, their operation and maintenance costs are low [18].

Moreover, hydropower generation output can be flexibly and quickly controlled over a wide range. Thus hydropower generation output can balance power sags from other renewable energy. In remote island rural areas, local electricity generation and consumption can prevent long-distance transmission losses and oil-dependent energy supply. Therefore, various small hydroelectric power plants are planned and built in these areas. Most of these are small-scale hydroelectric projects, micro-HEPP projects, and ultra-HEPP projects ranging from a few kilowatts to tens of megawatts [19].

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Biomass energy is an abundant renewable energy source on earth. It accounts for 10% of the global primary energy demand. Also, biomass provides primary energy consumption on some islands and is commonly used for heating and lighting. Biomass energy can be harnessed in two ways: traditional biomass and modern biomass. Although the traditional method shows the widest spread, the yield is around 5-15% and is very low. In modern methods, it is possible to increase the efficiency between 60-90% with less damage to the environment.

Other renewable energy sources used on islands are geothermal energy sources. Geothermal energy refers to the heat from the depths of the earth, commonly found in volcanic regions. It is a non-interrupted, renewable energy source and can be used in heating and electricity generation structures. However, geothermal energy's initial capital costs are relatively high, and there are geographic constraints for its development.

2.2. Energy storage techniques in islands

Renewable energy is characterized by natural fluctuation and randomness, while island power grids must balance supply and demand in real-time. Energy storage techniques are practical approaches to dealing with renewable energy generation's stochastic and variable behavior, and excess renewable energy can be converted into mechanical energy, electromagnetic energy, and chemical energy in various energy storage systems to be used as backups. In addition, supply-demand can be met through energy storage systems in conditions where distributed generation is insufficient. In one of the studies [20], it was calculated in a comparative analysis that the penetration level of renewable energy coupled with energy storage could reach up to 70.9%. In comparison, without energy storage units, this level can only reach 45.8%. A reliable energy storage system is an essential and practical approach to improving renewable energy penetration.

Energy storage in island power grids, including pumped hydroelectric storage (PHS), battery energy storage (BES), compressed air storage (CAS), flywheel energy storage (FES), hydrogen energy

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storage (HES), supercapacitor storage (SCS), etc. techniques have been used [21]. Energy storage systems, storage capacity, charging, and discharging time can be determined by various factors such as location selection, geographical conditions of the islands, investment, and operating costs in island power grids. As seen in the studies conducted so far, BES, HES, and PHS are the main energy storage techniques used on the islands. In Table 5, different energy storage systems are compared.

BES is one of the most popular energy storage techniques on the market. Significant BES types include the lead-acid battery, lithium-ion battery, vanadium redox battery (VRB), nickel-cadmium battery, and sodium-sulfur (NaS) battery. Different BES structures can be applied for different island energy systems depending on the batteries' characteristics, including energy storage capacity, charge and discharge rates, lifetime, efficiency, and costs. For example, while the lead-acid battery is applicable for small scale energy storage system (<10 MW); lithium-ion batteries and VRB are commonly used in large-scale energy storage systems (>10 MW) [22]. The lead-acid battery is the most mature technique widely used on islands to provide a reliable power supply by combining diesel fuel and renewable energy.

PHSs are widely used in 2011, accounting for 98.3% of installed storage capacity for global power grids. The energy conversion efficiency of PHS can reach 70-85% and is thought to maintain a rapid growth rate for decades to come. It is widely used to improve alternative renewable energy penetration and reduce environmental pollution on the islands. The variability and predictability of wind power limit its full use in the power system. However, PHS can regulate power output to reduce this impact on system stability and frequency quality.

Table 5. Features of the different energy storage systems used in the islands

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Storage type	Specific power (W/kg)	Specific energy (Wh/kg)	Energy efficiency (%)	Cycling capability (k)	Life (year)	Capital cost ($/kWh)	Response time	Application
PHS	Low	Low	70–85	20–50	30–50	10–70	min	Spinning reserve, energy storage, peak shaving, frequency modulation, phase modulation
CAS	low	3.2–5.5	70–80	10–30	20–40	3–70	min	Spinning reserve, energy storage, peak shaving, frequency modulation
Lead-acid	180–200	30–50	70–80	0.2–1.8	5–15	50–270	s	Energy storage, voltage control, fluctuation suppression, power quality controller
Li-ion	245–500	80–200	78–88	1.5–3.5	14–16	900–1,300	ms	Energy storage, voltage control, fluctuation suppression, power quality controller
NaS	150–230	150–240	80–90%	4–40	10–15	125–250	ms	Power quality controller, black start, peak shaving, demand side management, loss reduction, area control
Vanadium redox	10–50	16–60	70–85%	2–15	5–20	350–800	ms	Spinning reserve, black start, peak shaving, demand side management, loss reduction, area control
HES	600–1200	100–1000	40–70	20	10–20	2–15	s	Energy storage, power quality controller, peak shaving
FES	11,900	5–100	85%	100–10,000	20	400–800	ms	Energy storage, power quality controller, peak shaving, spinning reserve

In some cases, energy storage systems require both relatively high energy density and power density. Therefore the hybrid energy storage system is a better solution than a single storage system specifically for VPP. In one of the studies performed [23], an energy storage system with hybrid VRB and super-capacity was installed. Here, VRB, characterized by high energy density and preferred long-term storage, is used for microgrid autonomy. In contrast, super capacity with a high power density and preferred short-term storage is used to cope with rapid power changes.

2.3. Hybrid renewable energy systems on islands

Intermittent renewable energy sources are not characterized by the continuity of service due to their seasonality and variability. As a result, hybrid energy systems can be implemented and used to mitigate the intermittent and unstable electricity supply effects. While more energy is provided from PV in the Summer, as irradiance from the Sun weakens in Winter, wind energy can be used the whole year. In the rainy season, HEPP structures can be used as primary resources. Various configurations for hybrid renewable energy systems such as wind / PV, PV / biomass, wind / hydroelectric, wind / PV / biomass are presented in the literature. Hybrid sustainable energy systems are the most important trump card in reducing the dependence on expensive fossil fuels.

As presented in Table 6, some researchers have evaluated the feasibility of hybrid renewable energy systems to reduce fossil fuel dependency and consumption of isolated areas. These studies have proven that combinations of PV, wind, diesel, and batteries are competitive, viable, and positively impact.

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Diesel-wind-PV and PV-diesel-battery systems are also popular for islands and remote villages, respectively. Moreover, the cost of renewable energy technologies such as PV and wind will decrease with technology development, expressing broad expectations for hybrid renewable energy sources. However, there are still difficulties in operating and maintaining the system, remote islands with extreme weather conditions: High involvement of renewable energy can increase the uncertainty of system operation, such as facilities' service life. PV panels and wind turbines can be affected by extreme weather conditions, and the limitations of transportation systems of geographically isolated areas can increase system maintenance costs.

Table 6. Approaches for different isolated areas in hybrid renewable energy systems

The application of various configuration of HRES for different isolated areas.

Isolated areas	HRES	Outcome	Analysis tool	Reference
Isolated island, Japan	Diesel-wind-PV-battery	The operation cost of the HRES was 10% lower than single diesel generator.	/	Senjyu et al. [7]
A remote island	solar–wind–battery	The existing diesel generator on the island could be fully replaced by a 100% RE system. The proposed hybrid system is practical and cost- effective for the island.	HOMER	Ma et al. [15]
St. Martin Island, Bangladesh	PV-wind-battery-diesel	The best configuration of HRES was proposed with a renewable fraction of 31%. About14 tons/year CO_2 emission was reduced.	HOMER	Islam et al. [56]
Off-grid residence, Greece	wind–diesel	The wind–diesel system was considered as the optimal solution among four different configurations.	HOMER	Panapakidis et al. [58]
Three off-grid islands, Hong Kong	solar–wind–diesel–battery	The investigation results of eight possible HRESs showed that the solar–wind–diesel–battery system was the optimal solution from the techno-economic perspective.	HOMER	Ma et al. [66]
Tioman Island, South China Sea	PV-hydro-diesel-battery	The HRES is the most optimal system based on current energy situations in this Island.	HOMER	Khan et al. [67]
A remote area, Ethiopian	PV-wind-diesel-battery	The availability of the HRES was confirmed. The cost of energy is in the range of 30–40 Cents/kWh.	HOMER	Bekelea and Boneya [123]
Al Hallaniyat Island	PV–wind–battery–diesel	The cost of generating energy is \$0.222 kW h^{-1} for the hybrid system (70 kW PV system, 60 kW wind turbine, batteries and 324.8 kW diesel system). The COE will increase to \$0.225 kWh^{-1} without batteries.	HOMER	Albadi [124]
Faroe Islands, Mykines	wind-hydrogen	The system is technically possible and a positive development.	/	Enevoldsen and Sovacool [125]
Grimsey island, Iceland	wind-hydrogen-diesel	The operational cost of the HRES was the lowest among three investigated configurations.	HOMER	Chade et al. [126]
Aegean Sea islands	wind-diesel-battery	The hybrid system might be the most cost-effective solution for isolated consumers in the regions with average wind speed exceed 6.0 m/s.	/	Kaldellis and Kavadias [127]
Three islands, Maldives	PV-wind-diesel	The system will provide good opportunities for high RE penetration.	HOMER	Nayar et al., [128]
A remote village, Saudi Arabia	PV-diesel-battery	The hybrid system would be more economical than diesel only system with the increasing fuel price, the hybrid system with 20% solar PV penetration was recommended.	HOMER	Rehman and Al-Hadhrami [129]
St. Martin's Island	PV-wind–diesel-battery	The greenhouse gas produced by the proposed system can be minimized. The CO_2 emission produced by this system is approximately 12,000 kg/year whereas 413 kg/h is produced by 700 kW diesel generator.	HOMER	Amin and Hasan [130]
Karpathos island, Greece	PV-wind-hydrogen	The high profitability of wind make them the highest priority addition to the energy system of this island, supported by PV for maximum RES penetration.	HOMER	Giatrakos et al. [131]
Kinmen Island	wind-solar-ESS	A new unit commitment scheduling was proposed to cope with the high penetration of RE.	/	Wu et al. [132]
An isolated island in South China Sea	PV-wind-ESS	The carbon reduction rates of the proposed HRESs are between 87.7% and 95.1% compared with a fossil-based power system.	HOMER	Ye et al. [133]
An isolated island, Madeira archipelago	PV-wind-hydrogen	It is possible to increase the RE penetration by introducing the hydrogen storage.	H_2RES	Duić et al. [134]
Tioman Island, Malaysia	PV-wind-diesel-battery	The HRES results to the reduction of net present cost, cost of energy and CO_2 were \$3.94 million, \$0.064/kWh and 2,861,113 kg/year respectively.	HOMER	Hossaina et al. [135]
An astronomical Center in Atacama desert, Chile	PV-wind-pumped hydro	When the coverage factor is larger than 64%, a storage system must be introduced.	/	Abos et al. [136]

2.4. Demand-side management on islands

Electricity generation on the islands is mainly used for commercial and residential purposes. With the emergence of advanced communication and information infrastructures, responsive demand-side management can be used to coordinate residential energy consumption with changing electricity generation from renewable energy sources. Demand-side management refers to the coordination

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between power supply and demand through end-user device management. On the islands, end users can power appliances when renewable energy generates sufficient electricity and reduce or even turn them off in the event of insufficient electricity supply. Therefore, demand-side management can plan end-users' device usage to offset the erratic electricity generation from the island's renewable energy. While looking at the islands' examples, in the study conducted in Reunion, the annual average growth rate of electricity generation was reduced from 5.3% to 3.6% thanks to demand-side management [41].

3. INTEGRATION CRITERIA AND POWER QUALITY

Microgrids are an issue that has been studied and tested around the world in the recent past. Standards related to microgrid structure are reflected by IEEE Std P1547.4 (IEEE Std P1547.4 on Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems) [25]. These standards have been developed specifically to address missing information in IEEE Std 1547-2008 on isolated island micro-grid structures [26].

Power quality events such as island mode operation, current, and voltage total harmonics distortion (THD), frequency drop / rise, voltage drop / rise, flicker, notch, etc., are the main factors affecting energy quality in isolated microgrids. The IEEE-1547 standard specifies the requirements for total demand distortion (TDD) and amplitude of harmonic currents transmitted to the grid by grid-connected PV systems. The IEEE-519 standard [27] requires to determine the voltage and current harmonic limits. TS EN 50438 standard is used for single-phase and three-phase connected PV plants, and phase current to be realized in Turkey for PV installations of less than 16 kW.

3.1. Island mode operation

Island mode operation is when a distribution system is electrically isolated from the remainder of the power system. The energy flow is maintained exclusively by the distributed generation sources connected to it. In Island operation, the distributed generator system feeds the load even though it is

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disconnected from the grid. Island mode brings with it working security problems. Island mode operation can have various effects on power system stability due to the loss of synchronization. As a result, this situation often causes the system to remain outside the specified voltage and frequency values, and in turn, this can damage electrical devices and systems. Grid connection principles determined by IEEE 929-2008 [28] are given in Table 7. There are many studies in the literature regarding the detection of island mode [29,30].

Table 7. Grid connection principles determined by IEEE 929-2008 std. [6]

No	Frequency	Voltage	Breaker Opening Time
1	f_{nom}	$0{,}5V_{nom.}$	6 period
2	f_{nom}	$0{,}5V_{nom} < V < 0{,}88V_{nom}$	2 sn / 120 period
3	f_{nom}	$0{,}88V_{nom} \leq V \leq 1{,}10V_{nom}$	Normal Working
4	f_{nom}	$1{,}10V_{nom} < V < 1{,}37V_{nom}$	2 sn / 120 period
5	f_{nom}	$1{,}37V_{nom} \leq V$	2 period
6	$(f_{nom}-0{,}7) \leq f \leq (f_{nom}+0{,}5)$ Hz	V_{nom}	Normal Working
7	$f < (f_{nom}-0{,}7)$ Hz	V_{nom}	6 period
8	$f > (f_{nom}+0{,}5)$ Hz	V_{nom}	6 period

3.2. Power quality disturbances

Voltage sag, swell, and interruption: Voltage sag is defined as the decrease in voltage between 10% and 90% in a system operating at the grid frequency, with a time interval of 10ms to 60s. Motors cause it with inrush currents, and other causes are overloads, failures occurring along the line, intermittent operations in the DG, etc. Voltage swell event is defined as the increase in voltage allowed range is 110%..180% of the nominal voltage, which is equivalent to an increase of +10%..+80% providing that it is limited to 10ms to 60s in a system operating at grid frequency. These are the voltage spikes that occur when high power loads are switched off, during malfunctions, or commissioning large capacity groups. Depending on the topological and physical location and system conditions, a fault may lead to transient voltage sag, swell, or interruption [31, 32] (Figure 6).

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Voltage fluctuations and unbalances: When the DG units are switched on and off, the voltage may drop or rise. These values are limited to ± 3.3% V according to IEC 61000-3-3 standards, as shown in Table 8 [33]. Besides, it should be within ± 10% V of the nominal value as required by the standards in 95% of the time it is active. Analysis should be made at the limit values that the system can withstand, especially when analyzing the voltage, such as minimum production-maximum consumption. The imbalance in 95% of the measurement period should not exceed 2% according to EN 50160 standards, which was created considering only the voltage's negative component for the LV network. An equal amount of DG power plant power should be distributed to each phase to prevent voltage unbalance.

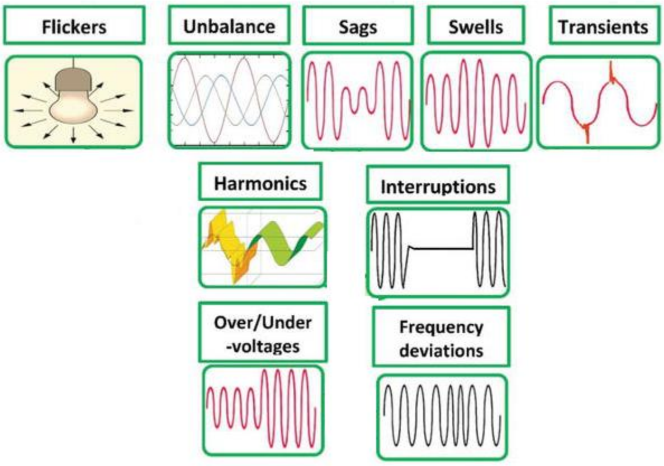

Figure 6. Power quality disturbances

Table 8. Voltage ripple limit values [8]

PV System Operation Status	Maximum Value
When the PV System is connected	± %3,3 V
When the PV System is disconnected	± %3,3 V
As long as it is active (95%)	± %10

Harmonics: Based on IEEE 519 standards, the total harmonic distortion amount of the voltage in the power system is limited to 8% in low voltage grids and less than 5% of each harmonic value. These limits are shown in Table 9.

Table 9. Voltage waveform distortion limits

PCC Point Voltage (V)	Internal Harmonic Value	Total Harmonic Distortion

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V ≤ 1.0 kV	5.0	8.0
1 kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161 kV	1.5	2.5
161 kV < V	1.0	1.5

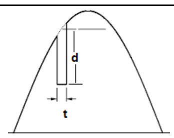
Flicker: The flicker caused by voltage fluctuations is a power quality deterioration event caused by consumer loads independently from the distribution grid. The effect size of the flicker depends on the voltage variation and the frequency of this change. Flicker limit values must comply with IEEE Std.1453-2004 and IEC 61000-2-2 standards [34]. In the Electricity Grid Regulation of the Energy Market Regulatory Authority, rapid voltage changes occurring more than 10 times in 1 hour are considered flickering. Long-term and short-term flicker limit values are given in Table 10, according to IEC 61000-2-2 and IEC 6100-3-3 standards.

Table 10. Flicker limit values

IEC 61000	PV Plant (IEC 6100-3-3)	Consumer (IEC 6100-2-2)
P_{ST} (Short Term)	≤ 1.00	≤1.00
P_{LT} (Long Term)	≤ 0.65	≤ 0.80

Notch: In a system operating at the grid frequency, the voltage waveform distortion occurs as the converter's number of pulses in one period. Also, the voltage is short-term for half a period. Since the frequency components created by the notch effect are very high, they cannot be defined with classical harmonic measuring devices. According to this IEEE 519-2014 standard, the limit values depending on the notch area and depth are as in Table 11.

Table 11. Notch limit values in voltage

	Special Applications (Hospital, Airport, etc.)	General System	Systems with Converters
Notch Depth	%10	%20	%50
Notch Area (A_N)	16400	22800	36500
Notch Field and Depth Definition (IEEE 519-2014)		% Notch depth = d/V×100 A_N = t•d = µsec × ∆volt	

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Noise: Noise can originate from power electronics devices, loads with switched power supply, high arc devices. It damages sensitive devices such as microprocessors and PLCs.

DC current injection: Inverters in the PV production plant connected to the LV grid can sometimes misbehave and inject DC current into the system. DC current injection drives the distribution transformer to saturation, causing the waveform to be out of nominal conditions. According to IEEE Std 929-2008 standards, this DC current supplied to the system via inverters needs to be limited to 0.5% of the nominal current.

Frequency deviations: The deviation of the power system's frequency value is out from its nominal value. It is caused by the mismatch between the amount of load in the system and the amount of power generated. The frequency change's size and duration depend on the response of the control system against the load. Under normal operating conditions, the limit ranges of the average values of the operating frequency measured in the grid-connected PV system and the grid according to the operating periods during the year are given in Table 12.

Table 12. Frequency average value limits

TS EN 50160	Percent Limit	Value Range	Working Time
Frequency	50 Hz ± %1	49,5 Hz-50,5 Hz	%99,5
	50 Hz +%4/ -%6	47 Hz-52 Hz	%100

3.3. Inverter standards in terms of power quality

Inverters differ from the existing electrical power system due to their bidirectional nature. While the power quality in the current electricity distribution system is affected only by the load, both the production and consumption sides in a PV system determine factors. Plants generating electricity from solar energy must comply with the criteria for connection to the grid (current harmonic values, voltage fluctuation limits and allowed flickering amount, etc.) determined by IEC standards in Turkey. In addition, the power quality parameters of the energy produced in grid-connected PV systems must be within the range specified in the TS EN 50160 standard. Inverters used in PV systems are standardized

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in terms of electromagnetic compatibility (EMC), grid frequency monitoring, grid voltage monitoring, and grid loss. These tolerances are determined by IEC 61727. Mains voltage and frequency monitoring limits and breaker opening time, according to IEC 61727, are shown in Table 13.

Table 13. Breaker Trip Time Limits for Voltage and Frequency

IEC 61727	Lower Limit	Upper Limit	Trip Time
Voltage	%50	%135	0,1 / 0,05s
	%85	%110	2s
Frequency	-1 Hz	+1 Hz	0,2 s

4. PLANNING PARAMETERS IN VPP SYSTEMS

4.1. Defining the formulation type and objective function

Generally, there are two types of formulation or modeling to discuss optimal scheduling problems. These are stochastic or probabilistic and deterministic or robust models. A stochastic procedure for formulation planning, followed by the achievement of optimal bidding in a microgrid or VPP, is shown in Figure 7 [6]. In this method, after taking all the scenarios and reducing them to a lower number, stochastic optimization is performed, and optimum energy bids are finalized.

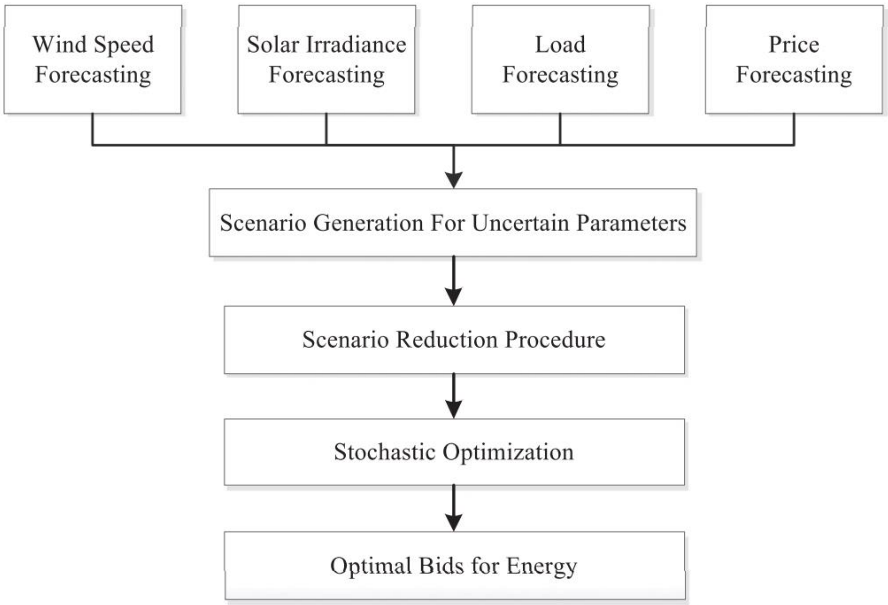

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Figure 7. The procedure of bidding strategy in VPP

One of the main goals of a microgrid is to provide power at the minimum possible cost. Therefore, with this objective in mind, an optimization problem can be proposed that considers different mandatory and optional constraints. The output is the optimum power generated by different sources in the microgrid. Minimum cost (depending on optional or mandatory constraints) is considered in the scheduling of distributed generation resources in the microgrid. Unlike micro-grid structures, the main purpose of VPP systems is to maximize profit or benefit. When a VPP partially reduces load demand, this reduced load is a virtual production. Some of the energy resources, while in standalone operation, it lacks capacity, flexibility, and adequate controls for system management and marketing activities. These problems can be solved by creating a VPP through a group of energy sources and flexible loads. In VPP systems, maximum profit (depending on optional or mandatory constraints) is considered in the the scheduling distributed generation resources.

4.2. Planning associated with the solving method

If an optimization model is defined as a scheduling problem, there are some issues with its solution. First of all, some different input data should be prepared, and then a suitable method should be chosen for the expression and solution of the optimization model. In this context, many different methods have been implemented to solve optimal timing problems proposed in microgrids and VPPs. These solving methods can be divided into two main and important methods: mathematical and heuristic optimization methods.

VPP related mathematical optimization can be categorized in detail as linear programming, nonlinear programming, mixed-integer linear programming, mixed-integer nonlinear programming, inner point method, and first-binary sub-gradient algorithm point estimation method. Decision tree, event-oriented service-oriented framework, hierarchical structure, dynamic programming, quadratic

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programming, game theory, area-based observation & focus algorithm, fuzzy simulation, and net equivalent solution methods are also among the solution methods [6].

4.3. Uncertainties

The uncertainty statement is used for predicting future events and any unexplained or physical measurements that have already taken place. Uncertainty arises in part in observable or random environments and also due to omissions. There are some main approaches to examine the effect of uncertainty in a technical classification, such as Monte Carlo Simulation (MCS), analytical methods, and embedded methods.

The most critical components of a microgrid or VPP planning that may be uncertain are wind power, solar power, load, and market price. Therefore, to get real results in examining the scheduling problem in both frames, it is indispensable to assume that these parameters are uncertain and choose an appropriate method to analyze their behavior.

4.4. Reliability

Reliability in a power system describes the system component's ability to operate under specified electrical conditions for a specified period. This aspect of the system is expressed as the probability of failure, the frequency of failure, or expressed as a probability derived from reliability, availability, and sustainability. It plays an essential role in the cost-effectiveness of power systems, so any power system programming such as timing problem should be associated with a reliable solution. So if there is no analysis on this, there is no reliable supply guarantee for claims. In scheduling renewable energy sources in microgrid and VPP concepts, different forms of reliability have been considered. The power system's reliability can be established as part of the objective function or as a constraint with some indices used. Table 14 shows the indices that evaluate the reliability in both micro-grid and VPP concepts for the scheduling problem and the methods used to solve them [6].

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Table 14. Reliability assessment of microgrid and VPP timing problem

Index	Calculation method	Time horizon
EENS	MCS Method	Daily
Load Not Supplied	–	–
NDE (Non-delivered energy)	Failure Probability of Elements	Seasonal
Maintenance Cost	Maintenance Plans with Different Priorities	Daily
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
EENS, COST (annual interruption energy and interruption cost), SAIFI, SAIDI and MAIFI (annual average values of all customers)	MCS and Analytical Technique	–
Reliability improvement index as a constraint	–	Daily
Loss of Power Supply Probability	Analytical Technique	Daily
Reliability Constraint	–	–
Reliability improvement index	–	Daily
SAIFI, SAIDI and ENS	Analytical Technique	Daily
EUE (Expected Unserved Energy), LOLP (Loss of Load Probability)	Analytical Technique	Daily
Maintenance Cost, LOEE (Loss of Energy Expected), LPSP (Total Loss of Load Probability)	Mathematical	Monthly
Probability of Interruption and Average Duration of Interruption	Analytical Technique	Daily
ASUI, ASAI, EENS, SAIDI, and SAIFI	MCS	–
Reliability Worth Index (hourly interruption cost)	Analytical Method and MCS	Daily
EENS	MCS	Daily
EENS	Analytical Method	Daily

4.5. Reactive power planning

In a power system, reactive power control is one of the main aspects of programming. Sometimes this problem can be thought of as a system-wide constraint, and sometimes it can be the outcome of the timing problem in both concepts mentioned. Therefore, reactive power associated with microgrid and VPP concepts should be studied in detail.

4.6. Emission problem

Emission and environmental issues in a power system are significant issues to be considered due to environmental constraints. Some energy sources, especially conventional ones, have unfavorable impacts on the environment due to greenhouse gases. In the scheduling problem in both concepts studied, the literature has considered the emission problem as a function that should be minimized.

4.7. Stability

Power system stability is expressed as the system's ability to remain in an operational equilibrium state under normal conditions and recover an acceptable equilibrium state after suffering a breakdown. In power system dynamics, there are two main stability categories: voltage and frequency stability. Some articles have addressed these phenomena in scheduling in microgrids and VPP [35-37].

4.8. Demand response

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Demand Response (DR) programs can be divided into two basic categories: time-based programs and incentive-based programs. Each method includes some programs, as shown in Figure 8.

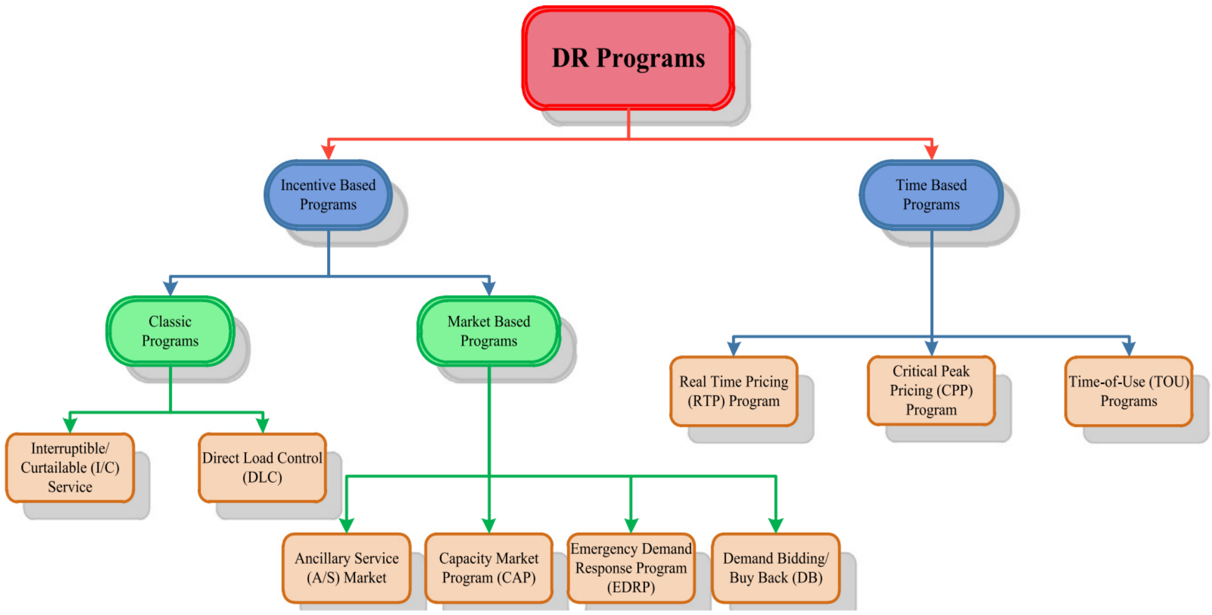

Figure 8. Classification of demand response programs [6]

Table 15 summarizes the demand response applications in microgrids and related to VPP for the planning problem. The type, functions, and descriptions of the request-response program are provided for each reference.

Table 15. Type and functions of demand response programs for microgrid and VPP planning

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Type	Function
DLC	–
TOU	Costs of demand response measures
incentive-based	The consumers have the option of foregoing, reducing or shifting their load
incentive-based	The load reduction costs of DRPs and the option to use DR programs in reserve scheduling for distribution systems
incentive-based	Demand response programs are treated as virtual generation units.
incentive-based	Include Adjustable Loads (Shiftable and Curtailable)
TOU	–
(I/C) service rates	–
TOU	–
incentive-based	The incentives which are paid to consumers in order to reduce their demands
TOU	The interruptible loads are fixed intervals loads or any short duration loads in a day.
TOU	–
incentive-based	–
I/C service rates	–
DLC	Controllable loads must be on continuously for some hours when they turn on
DLC	Load curtailment and load reduction
DLC	Load curtailment and load reduction
TOU	Using flexible demand in the energy balance constraint
DLC	Demand side management is provided on non-interruptible or interruptible loads
TOU	The load model is modified to obtain flexible load participation cost in offering procedure
DB Program	The VPP is buying the reductions from internal consumers on a day-ahead basis
DLC	The controllable loads have been prioritized in three categories
I/C service rates	A penalty is paid to each interruptible consumer for curtailing its consumption
DLC	Controllable loads

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5. ELECTRICAL INFRASTRUCTURE AND PHYSICAL EVALUATION FOR GÖKÇEADA

5.1. *The wind energy potential of Gökçeada:* The daily average and maximum wind direction and speed for Gökçeada are shown in Tables 16 and 17, respectively. It is observed that the most suitable renewable energy type in terms of return on investment is wind.

Table 16. Daily average windy direction and speed

Daily Average Windy Direction and Speed (m/s)												
Day/Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	NNE 8.0	SSW 4.4	S 5.6	NNE 4.1	S 6.5	N 3.2	NNE 4.2	NNE 2.4	NNE 4.7	NNE 1.6	NNE 6.3	NNE 6.5
2	NNE 5.3	S 5.7	ESE 3.4	NE 4.4	NNE 2.6	ENE 2.6	NNE 4.3	NNE 3.4	NNE 5.0	W 1.8	ENE 4.3	ENE 2.5
3	NNE 5.5	SSE 5.6	NE 5.5	NE 6.7	S 3.1	S 4.3	N 3.1	NNE 1.8	NNE 5.2	S 6.1	SSE 2.5	ESE 3.0
4	NE 9.2	NNE 1.2	ENE 1.5	NNE 4.3	S 5.1	S 3.5	NNE 4.7	NE 4.4	NNE 5.5	S 5.9	S 7.8	NNE 8.0
5	NNE 8.1	N 2.4	N 4.9	N 1.7	S 5.8	SSW 2.0	NNE 3.7	NNE 3.9	NNE 6.0	ENE 2.8	S 5.9	NNE 6.2
6	NE 3.3	NNE 7.3	S 5.4	NNE 2.4	S 6.6	NNE 1.5	NNE 2.0	NNE 3.4	NNE 5.6	NE 2.5	S 7.2	NE 4.0
7	NNE 6.0	NNE 8.4	SE 2.2	E 2.7	ENE 3.3	N 1.7	NNE 2.0	NNE 3.8	NNE 4.0	NE 3.6	N 7.2	ESE 1.6
8	NNE 6.5	NNE 6.6	S 3.3	SE 3.2	NNE 3.4	NNE 1.7	N 1.6	NNE 3.8	NNE 4.2	NNE 6.6	S 5.1	NNE 1.3
9	SSE 4.0	NE 4.6	S 5.9	ESE 3.3	S 1.9	NNE 3.2	N 1.9	NNE 3.3	NNE 4.9	NNE 2.7	S 4.4	ESE 1.1
10	S 12.7	ENE 0.9	S 2.9	NNE 2.4	S 5.7	NNE 4.8	NNE 2.6	NNE 4.4	NNE 4.2	S 2.2	S 3.9	ENE 1.3
11	NW 5.9	S 5.1	S 7.0	S 4.0	NW 1.7	NNE 3.3	NNE 5.2	NNE 5.9	NNE 5.5	NE 2.7	SSE 2.1	NE 6.0
12	NNE 6.4	WSW 6.8	ENE 8.1	S 7.4	NNE 1.7	N 1.9	NNE 1.2	NNE 7.0	NNE 5.4	NNE 4.5	SSE 1.1	NE 1.9
13	NE 4.7	NNE 9.6	NNE 9.1	N 3.3	N 2.5	N 1.7	NNE 1.4	NNE 6.4	NNE 7.1	N 3.5	S 2.7	SSE 2.4
14	SW 2.1	NNE 11.0	NNE 4.0	NNE 2.4	ENE 2.8	NNE 2.2	NE 1.5	NNE 4.8	NNE 5.8	N 3.1	SSE 2.9	SE 5.4
15	NNE 5.7	NNE 9.9	NNE 2.2	NE 5.5	S 2.0	NNE 4.0	N 2.0	NNE 2.7	NNE 5.3	N 2.3	SSE 3.9	ENE 1.5
16	SSE 3.6	NNE 9.8	S 2.3	NNE 5.3	SSW 2.3	NNE 3.4	NNE 2.7	NNE 3.4	NNE 3.7	N 3.0	NNE 1.5	NNE 1.0
17	S 3.1	NE 5.1	S 5.5	N 1.7	N 2.1	N 3.0	NNE 5.3	NNE 3.8	NNE 1.2	NNE 2.7	NNE 2.4	SSE 1.3
18	S 5.0	NNE 1.7	S 4.3	NNE 3.8	N 2.1	NNE 3.2	N 2.1	NNE 2.0	S 3.1	N 1.3	SE 2.3	NNE 0.8
19	SSE 3.4	NNE 2.0	S 4.2	N 4.7	S 3.7	N 2.5	NNE 3.5	NNE 3.3	NNE 3.8	N 1.0	NNE 1.4	N 0.9
20	SSE 4.3	N 1.1	NNE 2.7	NE 4.5	S 5.6	NNE 1.8	NNE 5.2	NNE 4.9	NNE 6.1	NNE 1.6	SSE 1.7	SSW 3.7
21	ENE 3.2	NE 2.2	NE 7.9	NNE 2.0	S 5.5	NNE 2.3	NNE 4.4	NNE 3.8	NE 5.2	NNE 2.6	ESE 3.7	SSW 7.2
22	ENE 2.3	NNE 1.2	NE 6.3	NNE 1.4	SE 3.0	N 1.9	NNE 3.5	NNE 2.8	NNE 4.2	NNE 4.7	E 3.2	S 11.1
23	SSE 7.4	NNE 9.2	NE 4.8	NE 1.8	NNW 1.8	N 1.8	NNE 3.8	NNE 5.0	NE 1.4	NNE 4.8	E 3.2	S 7.4
24	SE 6.5	NNE 11.0	NE 4.9	E 1.5	N 2.8	NE 2.6	NNE 4.4	NNE 4.8	SSE 1.7	NNE 4.0	NE 2.4	ENE 0.3
25	ESE 5.8	NNE 9.4	NNE 2.0	N 1.2	S 3.0	NNE 6.5	NNE 3.4	NNE 5.6	NE 3.2	NNE 3.7	E 3.2	
26	SE 5.7	NNE 6.0	NNE 1.2	N 1.6	N 1.9	NNE 6.0	N 3.0	NNE 5.4	S 1.6	NNE 4.0	NE 2.5	
27	NE 3.0	NNE 6.1	NE 4.2	NNE 0.9	N 1.5	NNE 5.7	NNE 2.4	NNE 6.4	NE 2.4	NNE 3.1	NE 3.2	
28	S 3.2	SW 2.9	NE 6.1	S 3.1	S 2.8	NNE 2.9	NNE 3.6	NNE 6.0	NNE 1.8	NNE 1.9	S 4.3	
29	SSE 7.1		NNE 9.1	S 4.7	S 5.6	NNE 5.6	NNE 1.7	NNE 5.7	N 1.5	NE 1.2	SSW 6.5	
30	SSE 6.4		NNE 10.5	S 7.6	SSW 3.4	NNE 4.0	NNE 2.2	NNE 4.9	N 1.3	NNE 1.6	S 3.8	
31	SSW 3.6		NNE 8.5		N 1.9		N 2.1	NNE 5.7		NNE 4.3		

Table 17. Daily maximum windy direction and speed

Daily Maximum Windy Direction and Speed (m/s)												
Day/Mont	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	NNE 16.8	WSW 9.8	S 14.2	NNE 9.7	SSE 11.9	N 9.5	NNE 11.6	NNE 8.6	NNE 10.6	NE 5.7	N 13.3	NNE 16.6
2	N 11.5	SSW 14.3	NE 12.6	NNE 13.5	NW 5.5	NNE 7.8	NNW 11.0	NNE 9.3	NNE 11.7	SSE 7.3	ENE 9.5	NNE 5.9
3	N 26.7	SSE 13.0	NNE 11.2	NNE 13.1	SW 8.3	S 15.3	NE 12.4	N 8.0	NNE 12.0	SSE 15.9	SSE 13.0	NNE 14.6
4	SW 20.5	NNE 5.7	NW 5.7	NNE 9.1	SSW 15.0	NW 9.3	NNE 11.7	NE 12.7	ENE 12.9	SW 16.5	S 17.8	NNE 16.7
5	NE 19.0	NE 17.9	S 14.0	NNW 5.2	S 16.3	NNW 5.3	NNW 10.8	N 9.6	NNE 14.7	NNE 8.9	SSW 12.4	NE 12.2
6	NNE 12.2	NNE 17.0	S 13.2	NNE 8.9	S 12.8	NNW 5.6	NNE 6.9	NE 10.6	NNE 11.4	NE 8.5	S 15.5	NNE 7.9
7	NE 16.9	NE 16.5	SSE 6.9	SE 13.1	N 10.9	NNW 5.6	NE 7.0	NNE 9.9	NE 9.3	ENE 11.3	SSW 15.7	SSE 6.0
8	NNE 15.8	NNE 13.2	SSW 12.7	S 13.2	NE 8.8	NNE 5.6	N 9.1	NNE 9.5	NNE 10.5	NNE 15.1	SSE 10.0	NNE 5.7
9	SSE 28.1	NNE 10.0	S 14.2	ESE 11.0	SSE 11.0	NNE 13.7	NNE 6.7	NE 10.5	NE 12.4	NW 5.8	S 9.5	NE 3.9
10	SSE 25.8	N 4.5	SSW 12.2	SSE 6.4	S 13.1	NNE 11.8	N 11.5	N 10.1	NNE 10.2	S 8.3	S 12.5	NE 9.8
11	S 14.3	SSE 17.1	SSW 17.7	S 13.6	N 5.9	NNE 11.6	NNE 14.8	N 13.5	N 12.8	NE 11.8	S 5.5	NNE 14.8
12	NNE 14.3	S 23.3	NNE 19.0	S 18.0	NE 5.5	WNW 5.6	NNE 5.8	NE 15.3	NNE 13.0	N 10.7	SSE 4.2	N 6.9
13	NNE 11.8	NNE 23.3	NE 19.3	SE 11.4	NNE 8.8	NNW 5.6	NW 5.8	NE 15.0	N 17.0	NNE 10.9	SW 9.2	SE 9.8
14	SSW 8.4	NNE 21.9	NNE 9.6	NNE 7.9	ENE 7.9	NNE 8.8	N 6.8	N 11.2	NE 15.6	NNE 8.5	SE 8.8	SE 13.0
15	NNE 18.5	N 21.3	NE 8.8	NE 12.8	SSE 6.8	N 10.3	NW 6.0	NE 9.4	N 14.8	NNE 8.8	S 8.9	NE 7.0
16	WSW 8.7	NNE 18.2	S 10.2	NNE 11.7	SSW 7.3	NNE 8.5	ENE 10.3	NNE 10.1	NNE 9.8	N 8.7	ENE 7.4	SSE 3.6
17	SSE 9.6	NNE 10.6	SSW 10.3	N 5.4	N 7.9	NE 9.0	NNE 12.3	NE 15.5	N 5.0	NNE 8.4	NNE 6.3	SSW 4.8
18	SSE 12.1	NNE 6.5	S 12.2	NE 13.4	ENE 8.2	NNE 9.4	NNE 5.8	NW 6.2	SSW 8.4	N 3.9	S 11.7	NNE 3.5
19	SE 10.2	NNE 7.5	SSW 10.1	NNE 11.9	S 8.5	N 10.5	NNE 11.1	NNE 10.5	NNE 10.8	N 3.8	NNE 4.8	NW 3.4
20	SE 10.2	N 4.9	NE 15.4	NE 13.3	S 13.0	NE 6.0	N 12.5	NNE 12.1	NNE 15.4	NE 6.6	SE 7.9	SSW 12.7
21	SSE 9.1	NE 11.3	NNE 16.7	NNE 6.5	SSW 12.5	NNE 7.1	NNE 10.3	NE 8.4	NNE 12.9	NNE 10.5	NE 9.6	SSE 17.1
22	SSE 16.1	ENE 8.7	NNE 13.6	SSW 6.5	SSE 9.1	NNW 6.8	NE 10.1	NE 10.4	N 11.0	NNE 13.5	NE 11.6	S 29.8
23	SSE 19.4	NNE 24.8	NE 12.1	NNE 6.3	NNE 6.6	N 5.6	NNE 9.6	NNE 12.1	NW 5.2	NE 14.1	SE 6.7	S 15.7
24	SE 17.3	NE 21.0	NE 10.1	S 8.1	NNE 9.0	NE 13.0	N 11.7	NE 13.5	S 6.9	NNE 13.0	NE 7.1	
25	SSE 21.7	NNE 18.0	NW 6.3	NNW 4.9	SE 10.1	NNE 14.5	NNE 8.2	NNE 12.3	NNE 10.0	NNE 11.8	NE 10.5	
26	SSE 11.6	NNE 14.0	NE 8.8	N 6.6	SSE 6.0	N 13.2	NNE 9.4	NE 12.5	S 6.6	NNE 10.0	NE 10.9	
27	NNE 9.2	NNE 15.2	NNE 9.9	NNW 4.9	NNE 6.1	NNE 12.6	NNE 8.6	NNE 15.0	NE 10.5	NNE 7.8	NE 8.5	
28	S 15.1	S 9.5	NE 17.9	S 9.9	SSW 12.3	N 12.6	N 8.5	NNE 13.5	NNW 6.0	N 6.2	SSW 12.4	
29	SSW 14.7		NNE 22.2	SSW 15.4	S 11.7	NNE 12.0	NNW 6.7	NE 12.7	NNE 5.3	NNE 4.8	SW 14.5	
30	S 16.3		NNE 21.3	SSW 17.0	S 9.9	NNE 9.1	N 7.2	NE 10.9	N 5.7	NE 7.7	NE 13.4	
31	W 13.6		NNE 18.3		WNW 13.6		W 6.7	NNE 13.6		NNE 14.4		

NOTES: **1-** (N)North, (NNE)North-Northeast, (NE)Northeast, (ENE)East-Northeast, (E) East, (ESE) East-Southeast, (SE)Southeast, (SSE) South-Southeast, (S)South, (SSW)South-Southwest, (SW)Southwest, (WSW)West-Southwest, (W)West, (WNW)West-Northwest, (NW)Northwest, (NNW)North-Northwest, (C) Calm. **2-** In the wind chart; Calm (C): 0.0-0.2 m / s (0 Bofor), Breeze: 0.3-1.5 m / s (1 Bofor), Light Wind: 1.6-3.3 m / s (2 Bofor), Fresh Wind: 3.4-5.4 m / sec (3 Bofors), Medium Wind: 5.5-7.9 m / sec (4 Bofors), Strong Wind: 8.0-10.7 m / s (5 Bofors), Strong Wind: 10.8-13.8 m / sec (6 Bofors), Stormy Wind: 13.9-17.1 m / sec (7 Bofor), Storm: 17.2-20.7 m / sec (8 Bofor), Strong Storm: 20.8-24.4 m / sec (9 Bofor), Full Storm: 24.5 - 28.4 m / sec (10 Bofor), Very Violent Storm: 28.5-32.6 m / sec (11 Bofor), Harikeyn (Orkan): 32.7 m / sec (12 Bofor) and more. **3-** (Automatic Meteorology Observation Station) works unmanned and observation observations are not made.

5.2. *Gökçeada interruption details:* Interruptions in Gökçeada are usually long-term period. These interruptions are caused by bird touching, box dislocation, overcurrents, voltage transformer, falling trees, disconnections cause by damage, LV box problem, LV connector damage, LV cable damage, MV insulator damage, surge arrester damages, and MV overhead line maintenance. The most extended interruption recorded was 13.77 hours. The shortest interruption recorder lasted 0.01 hours. The faults occurred at a similar rate on both the LV and MV sides. Users most affected by malfunctions are LV customers both in the center and in rural areas. The reasons and durations of some of the faults in Gökçeada are given in Table 18.

Table 18. Interruptions

Interruption Reason	Source LV/MV	Interruption Time Short/Long	Planned/Unplanned	Interruption Duration(hour)	MV Customer in Center	LV Customer in Center	MV Customer in Rural Area	LV Customer in Rural Area
LV Box Problem	LV	Long	Unplanned	0,06	0	0	0	29
LV Connector Damage	LV	Long	Unplanned	0,35	0	0	0	1
LV Connector Damage	LV	Long	Unplanned	0,52	0	0	0	53
LV Overhead Conductor Damage	LV	Long	Unplanned	0,55	0	1	0	0
LV Cable Damage	LV	Long	Unplanned	0,58	0	138	0	0
LV Connector Damage	LV	Long	Unplanned	0,64	0	0	0	81
LV Box Problem	LV	Long	Unplanned	0,66	0	0	0	137
LV Customer Cable	LV	Long	Unplanned	0,82	0	1	0	0
LV Box Problem	LV	Long	Unplanned	0,97	0	0	0	104
MV Others	MV	Short	Unplanned	0,01	10	3794	18	1516
MV Others	MV	Short	Unplanned	0,05	10	3729	17	1460
MV Others	MV	Short	Unplanned	0,05	10	3758	18	1502
MV Others	MV	Long	Unplanned	0,49	10	3716	17	1455
Birds Touch	MV	Long	Unplanned	0,5	0	0	32	709
MV Insulator Damage	MV	Long	Unplanned	0,63	0	1	33	722

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Transformer Maintenance	MV	Long	Planned	0,63	0	374	1	193
Birds Touch	MV	Long	Unplanned	0,64	0	0	3	206
MV Insulator Damage	MV	Long	Unplanned	0,65	0	1	26	721
MV Cable Damage	MV	Long	Unplanned	0,68	10	3716	17	1455
MV Others	MV	Long	Unplanned	0,68	0	0	31	704
MV Others	MV	Long	Unplanned	0,77	8	2	22	689
Birds Touch	MV	Long	Unplanned	0,85	0	213	0	0
Average				0,54	2,6	883,8	10,7	533,5
Total				11,78	58	19.444	235	11.737

5.3. Gökçeada Load Profile, Solar and Wind Energy Potential

Within the project's scope, two wind turbines of 900 kW installed power in Gökçeada, a 210 kW solar power plant, and a 4x770 kVA diesel generator of UEDAŞ will be connected to the VPP system to be installed. Approximately 100 smart counters will be installed in a transformer area. Also, an energy storage facility with a storage capacity of 100 kWh and an output power of 50 kW will be established on the island. Figure 9 shows the total active power consumption profile of Gökçeada between 2017 and 2020 years.

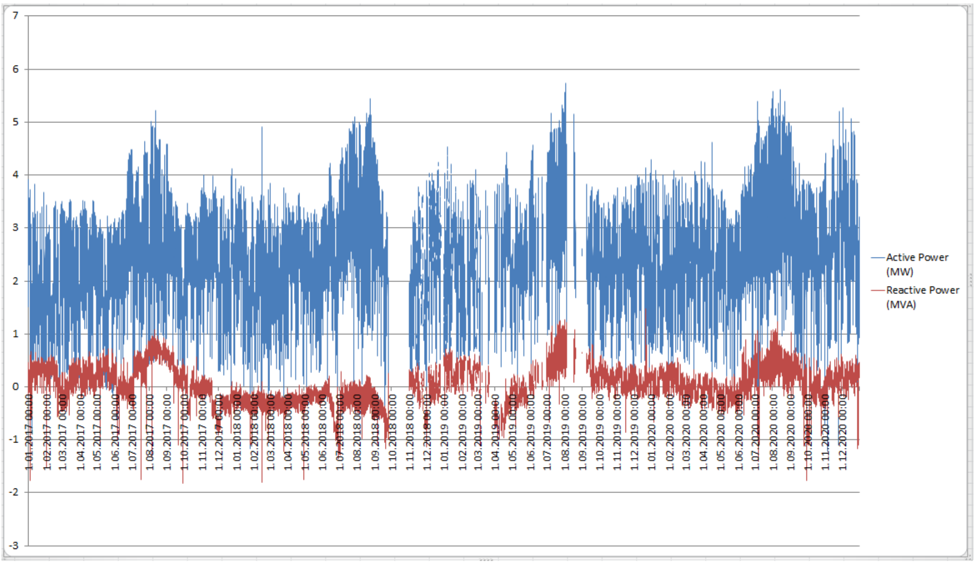

Figure 9. Total active power consumption profile of Gökçeada between 2017 and 2020

The load profile indicates that the energy consumption increases in Summer, especially from June to September. Besides, the island's energy consumption is related to the attendees

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in the island's overall year. Maximum energy consumption is 5 MW on the island. Thus, the renewable energy-based power plants are more suitable for the electrical energy requirements of the island.

Total active energy generation of solar power plant (SPP) installed in Gökçeada comparing to active energy consumption is shown in Figure 10. The amount of power generated by a solar power plant is considerably higher than the amount of power consumed. It is seen here that it would be appropriate to use the solar energy potential for the island.

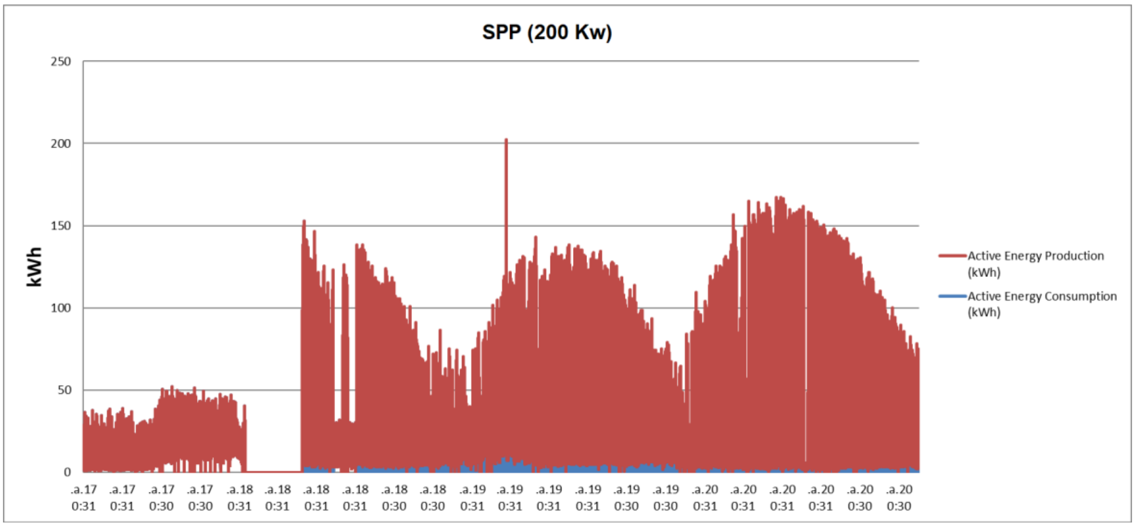

Figure 10. Total active energy generation of solar power plant (SPP) installed in Gökçeada comparing to active energy consumption

The total active energy generation of wind turbines installed in Gökçeada compared to active energy consumption is shown in Figure 11. The amount of power generated by wind turbines is considerably higher than the amount of power consumed. It is seen here that it would be appropriate to use the wind energy potential for the island.

In the island where the wind energy potential is quite high, and it is seen that two wind power plants (WPP=Wind Power Plant) with 900 kWp power are considered to be very suitable for the VPP system that is planned to be established. Thus, the photovoltaic-based

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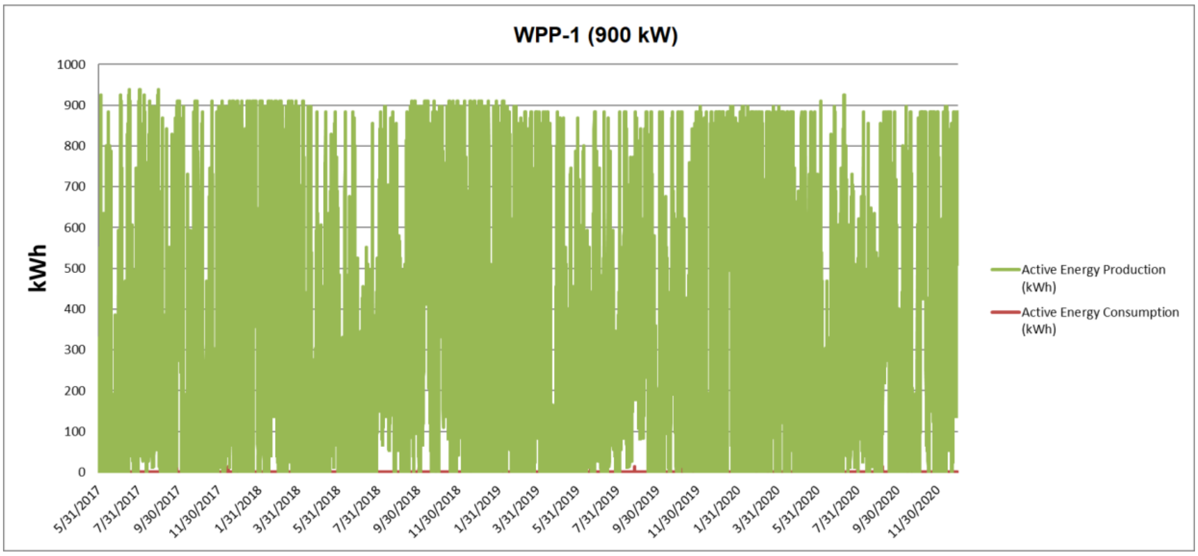
power generation kind of renewable energy-based power plants are more suitable for the island's electrical energy requirements.



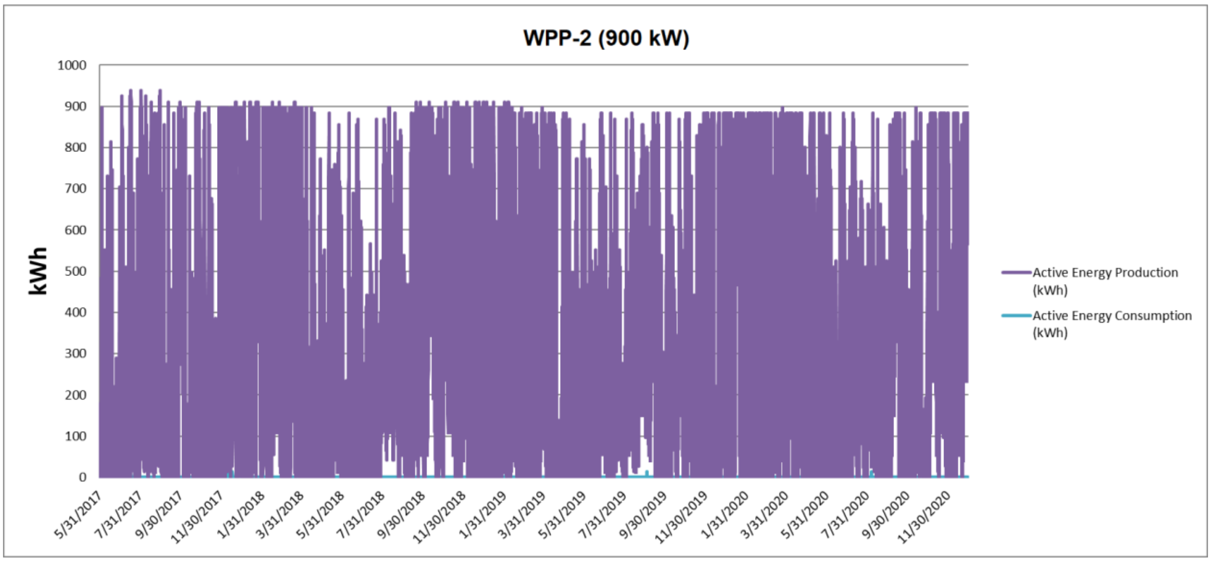


Figure 11. Total active energy generation of WPPs in Gökçeada comparing to active energy consumption

5.4. Required Auxiliary Services for Installation of Wind and Solar Energy Plants in Turkey

The PV plant owners must follow "The Guidelines for Generating Unlicenced Electricity In Turkish Electricity Market" [31] to install a PV plant in Turkey. The most recent form of

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the rules was reformed in 2013. This law has paved the way for integrating DGs into the electrical distribution system from Low Voltage levels. The PV installations defined as licensed and unlicensed power generation plants with this renewable energy law and the power capacity of the PV plants identified as follows:

Unlicensed Power Generation Plants: < 1 MWp.

The PV power plants installing under the power of 1MWp in Turkey are defined as "Unlicensed Power Generation Plants." These plants are generally connected to the grid from the low voltage (LV) level.

Licensed Power Generation Plants: > 1 MWp

The PV power plants installing over the power of 1MWp in Turkey are defined as "Licensed Power Generation Plants." These PV plants are big-scaled solar energy plants, and they are also installed from the medium voltage (MV) level to the grid.

Natural and legal people can take advantage of the governments' promotional prices listed in Table 19 for over ten years. Providing that selling the excess generated energy to the electricity distribution companies is supported by the current renewable energy law [31,32].

The electricity distribution companies, which have a retail sales license, are legally bound to purchase excess energy provided to the electricity distribution companies within this scope. The purchase of electrical power from the electricity distribution companies within this clause is expected to comply with promotional prices.

Table 19. Supported Prices from Turkish Government for Renewables

Renewables	Supported Prices (cent/kWh)

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Hydropower	7,3
Wind Energy	7,3
Geothermal Energy	10,5
Biomass	13,3
Solar Energy	13,3

The renewable energy law has some restrictions to prevent misuse of the capacity rate of renewable energy generation. Table 20 shows one of these restrictions to specify the capacity of power plants connected with the LV level to the electricity companies' distribution generators.

This restriction's primary purpose is to take advantage of the power plant owners without causing any adverse effects on power quality and the continuous power supply of other consumers. There is no obligation for the power plant owners who want to connect the PV system to the grid with their distribution transformers. The connections realized with special distribution transformers are accepted as medium voltage level connection by the electricity distribution companies.

A PV power plant with a 1000 kWp installed power can be connected to the grid from medium voltage level with plant owners' 1250 kVA special distribution transformer.

Table 20. The allowed capacity of power plants connected from the LV level to the distribution transformers

Transformer Power (kVA)	The Total Capacity Connected from LV (kW)	The Total Annual Capacity for a Person Connected from LV (kW)

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50	15	7,5
100	30	10
160	48	16
250	75	25
400	120	40
630	189	63
800	240	80
1,000	300	100
1,250	375	100
1,600	480	100
2,000	600	100
2,500	750	100

The other connection rules for unlicensed PV power plants are explained below [31,32].

a) The power generation plant must be matched with the frequency (50 Hz) and voltage level (220 V RMS) of the distribution system from the electricity meter point. It must not affect the other distribution system consumers with the harmonic distortion and flicker effects of the voltages and currents.

b) The power generation plant must be designed and operated to disconnect the PV power plant from the grid reliably and not supply electrical energy in the conditions of islanding, short circuit fault, and abnormal grid operations. The power generation plant must disconnect from the grid in any faults without causing an islanding condition.

c) The power generation plant's connection to the distribution system must perform, according to the type of the ground system of the distribution network and the related technical standards.

d) The residential power generation plants constituted a part of a building that must realize the domestic installation and column line instructions without exceeding the current-

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carrying capacity when the power generation plant constitutes the same place as the consumers.

e) The potential short circuit current of the power generation plant must not exceed the withstand short circuit current of the distribution system equipment.

f) The PV plant is connected to the distribution network from the LV level when the plant's installed power is under 11 kWp. The PV plant is connected to the distribution system with the MV / HV level when the plant's installed power is over 11 kWp.

g) The power generation plants' total capacity connected to the distribution system with the LV level must not exceed 30% of the connected distribution transformer power.

h) The total annual capacity shared from a distribution transformer is defined as a person who owns a PV plant connected from the LV level, according to Table 20.

i) The stiffness ratio is defined as the short circuit current rate of the distribution system / the nominal current of the distribution network. It must be over 30 for the co-generation plants, that the installed power is over 1 MWp, and it must be over 70 for other power generation plants. The distribution company can offer a new connection point when the stiffness ratio is not in acceptable values.

j) The power generation plant is connected to the distribution system from the LV level and single-phase when the PV plant's installed power is under 5 kWp.

- The power generation plant is connected to the distribution network from the LV level and three-phases. When the PV plant is installed, power is over five kWp. Thus, the phase current is under 16 A (11 kWp).

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- The power generation plant is connected to the distribution system with the LV / HV level and three-phases when the phase current is over 16 A. The distribution company defines the voltage level decision. Table 21 summarizes this concept.

Table 21. The voltage levels of PV plants according to the installed power

Installed Power (kW)	Phase Number	Voltage Level	License Status
$0 < P_{plant} \leq 5$	1	LV	Unlicensed
$5 < P_{plant} \leq 11$	3	LV	Unlicensed
$11 < P_{plant} \leq 1000$	3	LV / MV	Unlicensed
$1000 < P_{plant}$	3	MV feeder / MV busbar	Licensed

k) The unlicensed power generation plants must be designed, constituted, tested, and operated according to some standards:

- The power generation plant is connected to the distribution system with a single-phase and must consider the TS EN 50438 standard.
- The power generation plant is connected to the distribution system with three-phase, and the phase current is under 16 A must consider the TS EN 50438 standard.
- The power generation plant is connected to the distribution system with the LV level, and the phase current is over16 A must consider the TSE K 191 standard.
- The power generation plant is connected to the distribution system with an HV level, and the phase current is over16 A must consider the TSE K 192 standard.

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The interface protection provides the reliable and parallel operation of the PV power generation plant with the grid. The interface protection prevents the reverse supplying condition and increases the reliability of the system. The interface protection is required in small and medium-scaled PV power generation plants. However, it is allowed to be used in the inverter or the generator in micro-scaled PV power generation plants.

The selection of the internal or external interface protection is under the authority of electricity distribution companies. The inverters' internal interface protection is sufficient under 11 kWp power for the connections from the LV level in Turkey. However, today many distribution companies require external protection between 11 kWp-1 MWp.

The under/over voltage protection and the under/over-frequency protection functions are the fundamental protection for the PV power generation plants and obligated worldwide [32]. Some distribution companies find this protection constituted in the inverter as internal protection sufficient for micro-scaled PV power generation plants operating under 50 kWp power. However, this condition is not available in Turkey. The inverters usually have over-current protection relays with a subjective concept, but the over-current protection is implemented with separate fuses and circuit breakers. The residual current device is requested to provide the security of life and property in Turkey's applications.

5.5. Fault Ride Through Capability and Reactive Power Support for Wind Turbines

The fault ride-through indicated in Figure 12, active and reactive power control, and the dynamic grid support is also presented in Figure 12. These functions are additional issues for the electrical protection of the wind turbines connected at the transmission level.

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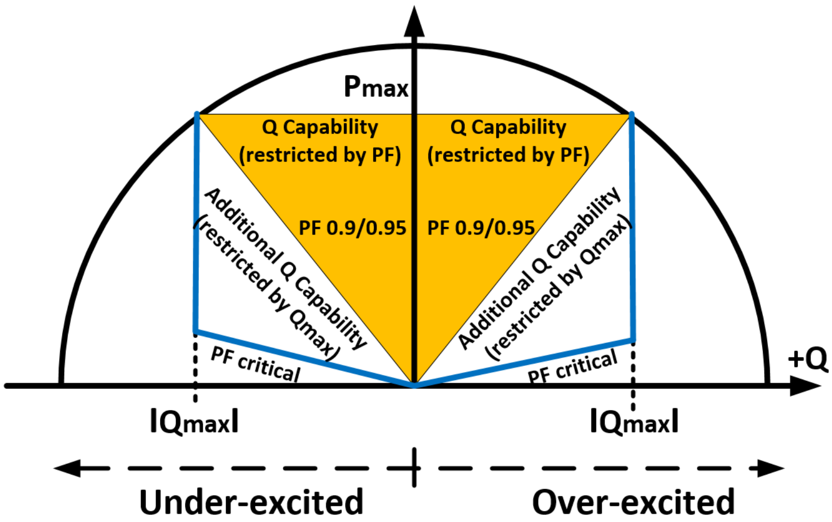

Figure 12. Fault ride-through support

The increasing share of wind power generation is gradually changing the dynamics of modern power systems. Installed wind turbines must provide auxiliary services to maintain the transient stability of a power system. As is the case in most countries, grid codes require wind power plants to stay connected to the grid for a short time during a voltage drop. This is the failure driving ability of wind turbines. If the turbine fails immediately after the voltage drop, the grid voltage will drop further. Also, the system frequency will drop due to power imbalance. Subsequently, the power system may be subject to power failure due to the generators' series of faults. Wind turbines must be equipped with a breakdown feature to prevent system interruptions. In Turkey, the grid code has been declared in the Electricity Market Grid Code, with the Grid Connection Criteria of Wind Energy Based Generation Plants. The requirements for the fault ride-through capabilities of wind turbines are shown in Figure 13. Reactive power support criteria for wind turbines are regulated by the Turkish Electricity Transmission Corporation (TEIAS) [38].

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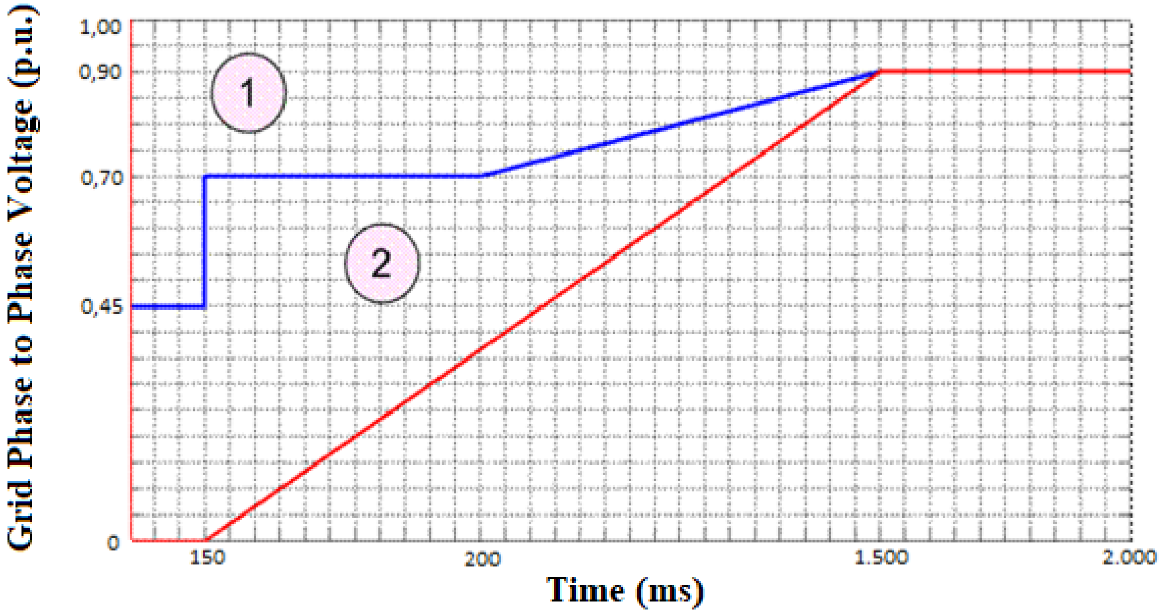

Figure 13. Reactive power support criteria for wind turbines according to TEIAS

5.6. Simulation Studies

5.6.1. Short Circuit Fault Analysis

The generalized electrical single-line diagram of Gökçeada is shown in Figure 14.a. In order to observe the short circuit power and current contribution of the integrated DGs in the power system, single line-to-ground (L-G), double line-to-ground (L-L-G), and line-to-line (L-L) asymmetric fault and three-phase symmetrical fault (L-L-L) were realized. In this part of the study, the results of the faults generated in the Santral DM (bus fault), and the faults formed in the 25%th km of the Santral DM-Özlüce Kök lines (in line fault) are presented. Figure 14.b depicts the simulated model in which the analyses are performed.

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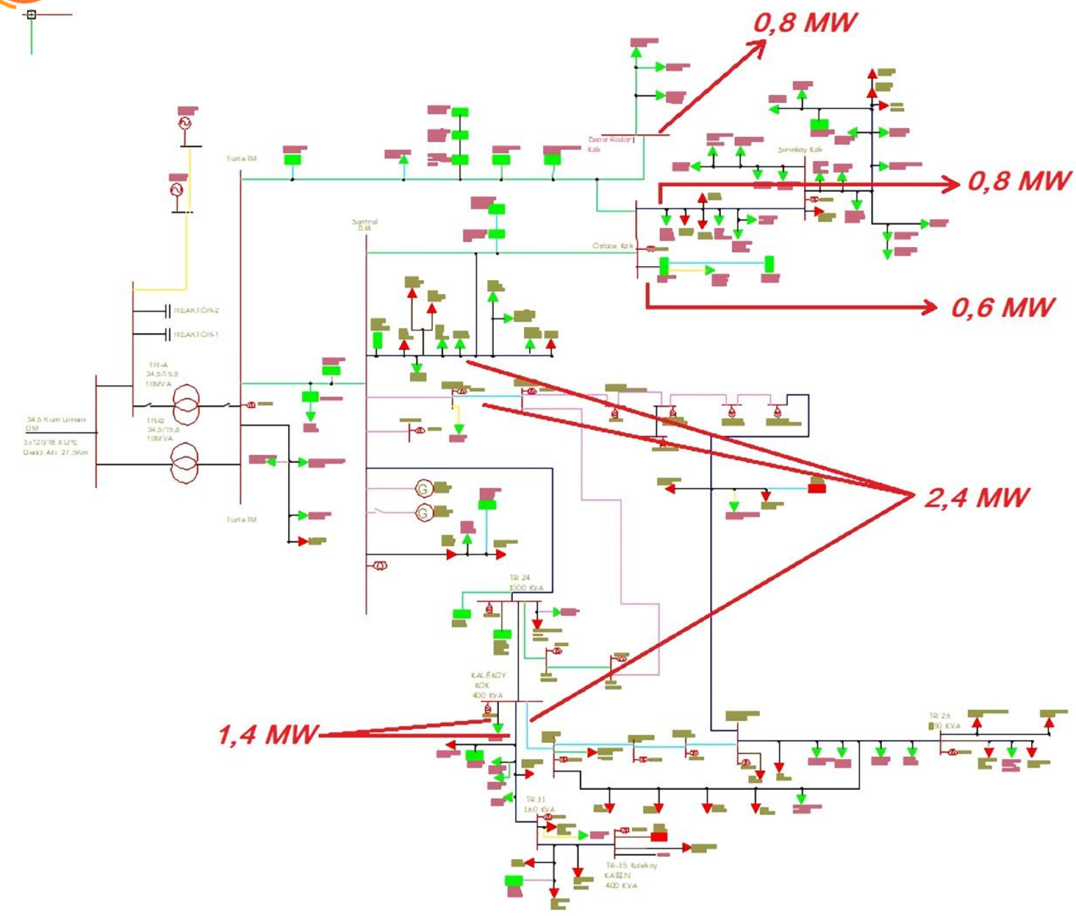
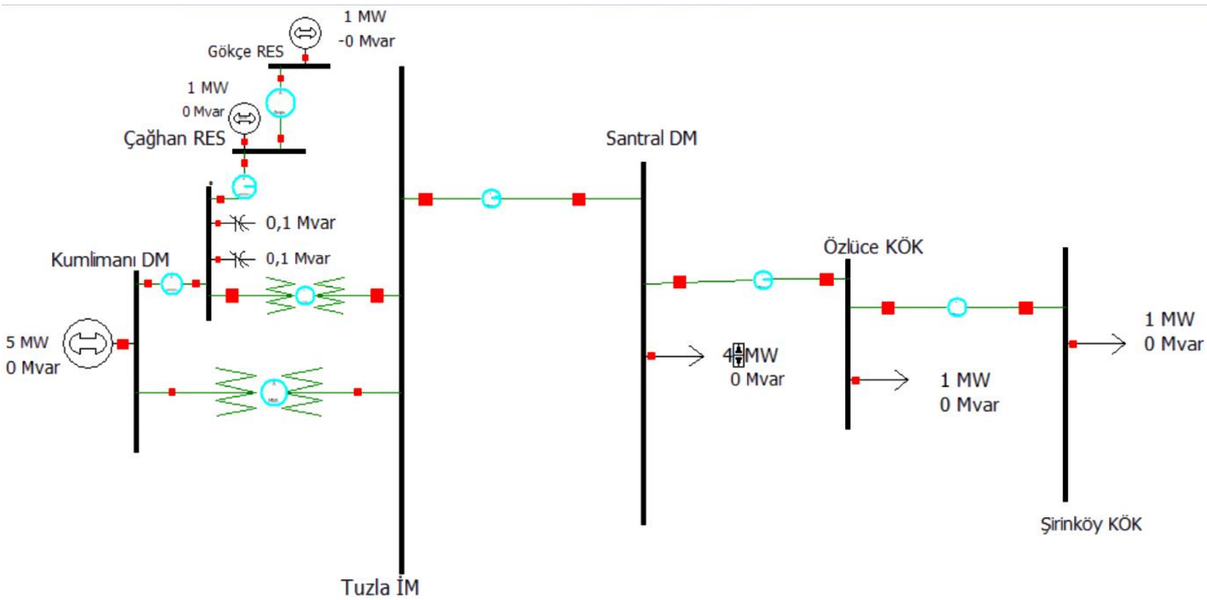


(a)



(b)

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Figure 14. (a) Generalized power distribution in Gökçeada, **(b)** Simulated model

5.6.1.1. Bus fault analysis results

Table 22 shows the values of voltage and phase angle after L-G fault at Santral DM bus. In this case, the fault impedance values are R=0.01 ohm and X=0.07 ohm. Voltage values are given in per unit (pu).

Table 22. L-G short circuit fault voltage and phase angle values

Bus name	Phase A	Phase B	Phase C	Angle A	Angle B	Angle C
Kum limanı DM	1,00000	1,00000	1,00000	-0,01	-120,01	119,99
Tuzla İM	0,01029	1,72418	1,73413	74,64	-150,46	149,45
Çağhan RES	1,00000	1,00000	1,00000	0,00	-120,00	120,00
Gökçe RES	1,00000	1,00000	1,00000	0,04	-119,96	120,04
Özlüce KÖK	0,00226	1,72739	1,72523	-108,09	-150,87	149,16
Şirinköy KÖK	0,00309	172756	1,72462	-108,35	-150,89	149,14
Santral DM	0,00000	1,72689	1,72689	-3,20	-150,79	149,21

Table 23 depicts the values of voltage and phase angle after L-L short circuit fault at Santral DM bus. In this case, the Fault impedance values are R=0.01 ohm and X=0.07 ohm. Voltage values are given in (pu).

Table 23. L-L short circuit fault voltage and phase angle values

Bus name	Phase A	Phase B	Phase C	Angle A	Angle B	Angle C
Kum limanı DM	1,00000	0,61885	0,58316	-0,01	-147,43	145,13
Tuzla İM	0,99966	0,59050	0,54687	-0,22	-152,91	150,07
Çağhan RES	1,00000	0,69146	0,65940	0,00	-138,98	136,50
Gökçe RES	1,00000	0,71205	0,68204	0,04	-136,98	134,66
Özlüce KÖK	0,99635	0,50238	0,49840	-0,92	-175,54	173,67
Şirinköy KÖK	0,99610	0,50225	0,49827	-0,96	-175,59	173,62

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Santral DM	0,99702	0,50272	0,49874	-0,79	-175,42	173,79

After an L-L-L three-phase symmetrical fault on the Santral DM bus, Table 24 shows the voltage and phase angle at system buses. The Fault impedance values in this scenario are R=0.01 ohm and X=0.07 ohm. The voltage values are reported in pu.

Table 24. L-L-L balanced short circuit fault voltage and phase angle values

Bus name	Phase A	Phase B	Phase C	Angle A	Angle B	Angle C
Kum limanı DM	0,41742	0,41742	0,41742	-3,41	-123,41	116,59
Tuzla İM	0,34965	0,34965	0,34965	-4,92	-124,92	115,08
Çağhan RES	0,54929	0,54929	0,54929	-2,58	-122,58	117,42
Gökçe RES	0,58381	0,58381	0,58381	-2,30	-122,30	117,70
Özlüce KÖK	0,10313	0,10313	0,10313	-3,23	-123,23	116,27
Şirinköy KÖK	0,10310	0,10310	0,10310	-3,27	-123,27	116,73
Santral DM	0,10320	0,10320	0,10320	-3,10	-123,10	116,90

Table 25 shows the values of fault currents and, degrees after short circuit faults at Santral DM bus. The I_{kss} value given in the table shows the value of the short circuit current.

Table 4. Simulated system L-L and L-L-L short circuit current values

	Line-to-line fault (L-L)		**Balanced fault (L-L-L)**	
Fault location	I_{kss}	Angle	I_{kss}	Angle
Santral DM Bus	4,8702	-175,10	5,3329	-84,97

5.6.1.2. Line fault analysis results

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Table 26 depicts the values of voltage and phase angle after L-L fault at the 2.45th km (%25) of the Sentral DM-Özlüce Kök line. In this case, the fault impedance values are R=0.01 ohm and X=0.07 ohm. Voltage values are given in per unit (pu).

Table 26. Voltage and phase angle values for L-L line fault

Bus name	Phase A	Phase B	Phase C	Angle A	Angle B	Angle C
Kum limanı DM	1,00000	0,63070	0,59416	-0,01	-145,93	143,49
Tuzla İM	0,99966	0,60203	0,55751	-0,22	-151,05	148,01
Çağhan RES	1,00000	0,70219	0,66987	0,00	-138,04	135,50
Gökçe RES	1,00000	0,72228	0,69206	0,04	-136,17	133,80
Özlüce KÖK	0,99635	0,50195	0,49852	-0,92	-175,74	173,87
Fault point location	0,99685	0,50220	0,49877	-0,83	-175,65	173,96
Şirinköy KÖK	0,99610	0,50182	0,49839	-0,96	-175,79	173,82
Santral DM	0,99702	0,50909	0,50003	-0,79	-172,00	170,25

Table 27 shows the values of voltage and phase angle after double line-to-ground (L-L-G) at the 2.45th km (%25) of the Sentral DM-Özlüce Kök line. In this case, the fault impedance values are R=0.01 ohm and X=0.07 ohm. Voltage values are given in pu. After an L-L-L three-phase symmetrical fault in the 2.45th km (%25) of the Santral DM-Özlüce Kök line, Table 28 depicts the voltage and phase angle on the system buses for same fault location.

Table 27. Voltage and phase angle values for L-L-G line fault

Bus name	Phase A	Phase B	Phase C	Angle A	Angle B	Angle C
Kum limanı DM	1,00000	0,61530	0,57761	-0,01	-148,13	145,75
Tuzla İM	1,59762	0,34127	0,22567	-2,81	-78,30	56,91
Çağhan RES	1,00000	0,68793	0,65437	0,00	-139,43	136,86
Gökçe RES	1,00000	0,70864	0,67726	0,04	-137,38	134,96

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Özlüce KÖK	1,59484	0,11839	0,11839	-0,09	-147,64	-34,19
Fault point location	1,59527	0,11863	0,11863	-3,19	-34,58	-34,58
Şirinköy KÖK	1,59461	0,11828	0,11828	-3,28	-33,90	-33,90
Santral DM	1,59542	0,13864	0,10649	-3,17	-47,30	-18,23

Table 28. Voltage and phase angle values for L-L-L symmetrical line fault

Bus name	Phase A	Phase B	Phase C	Angle A	Angle B	Angle C
Kum limanı DM	0,43842	0,43842	0,43842	-3,36	-123,36	116,64
Tuzla İM	0,37307	0,37307	0,37307	-4,76	-124,76	115,224
Çağhan RES	0,56555	0,56555	0,56555	-2,55	-122,55	117,45
Gökçe RES	0,59882	0,59882	0,59882	-2,28	-122,28	117,72
Özlüce KÖK	0,09946	0,09946	0,09946	-2,99	-122,99	117,01
Fault point location	0,09951	0,09951	0,09951	-2,89	-122,89	117,11
Şirinköy KÖK	0,09944	0,09944	0,09944	-3,03	-123,03	116,97
Santral DM	0,13533	0,13533	0,13533	-3,62	-123,62	116,38

Table 29 shows the values of fault currents and, degrees after short circuit faults at the 2.45th km (%25) of the Sentral DM-Özlüce Kök line.

Table 29. Simulated system L-L and L-L-L short circuit current values

	Line-to-line fault (L-L)		**Balanced fault (L-L-L)**	
Fault location	I_{kss}	Angle	I_{kss}	Angle
Santral DM Bus	4,68745	-174,87	5,14262	-84,97

The amount of power provides, the point at which they are linked, and the point at which the fault occurs in the system all influence the size of the short circuit fault current. As shown in tables, in the event of a fault, distributed energy sources such as WT and PV systems

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connected to the main grid cause increased short-circuit currents. In the case where generator power is distributed by spreading to buses, the short circuit current flowing from the fault point is the lowest level except the case of feeding on the grid. The results show that DG contribution to short-circuit fault analysis is within acceptable bounds.

5.7. Smart Residential Meter Selection

Any smart metering system must have communication technology. It not only has a big impact on the overall solution's performance, but it also has a big impact on the Total Cost of Ownership. Customers of energy utilities make a long-term commitment when they invest in smart grid technology. Furthermore, because technology is continually evolving, it is critical to establish a structure that allows for the implementation of other scenarios beyond the typical AMI. Therefore, Landis+Gyr's new E360 Series residential meter was chosen as the smart meter within the scope of the project. E360 Series 1 LTE 1-phase device in single-phase systems and E360 Series 1 LTE 3-phase device in three-phase systems will be used as smart meters in Gökçeada. These devices are a Gridstream® Connect smart endpoint and, supporting CAT M1 and NB-IoT. For the IoT (Internet of Things) environment, it allows flexible local and remote communications. It is possible to ensure that many distinct devices are connected to a single network in this manner. E360 is a forward-thinking instrument with advanced multi-energy, e-metering, consumer information, and network monitoring. It also has improved power quality capabilities for better network stability monitoring. The Traditional PULL architecture used in data transfer and the Smart Push architecture used in the E360 are shown in Fig. 2.

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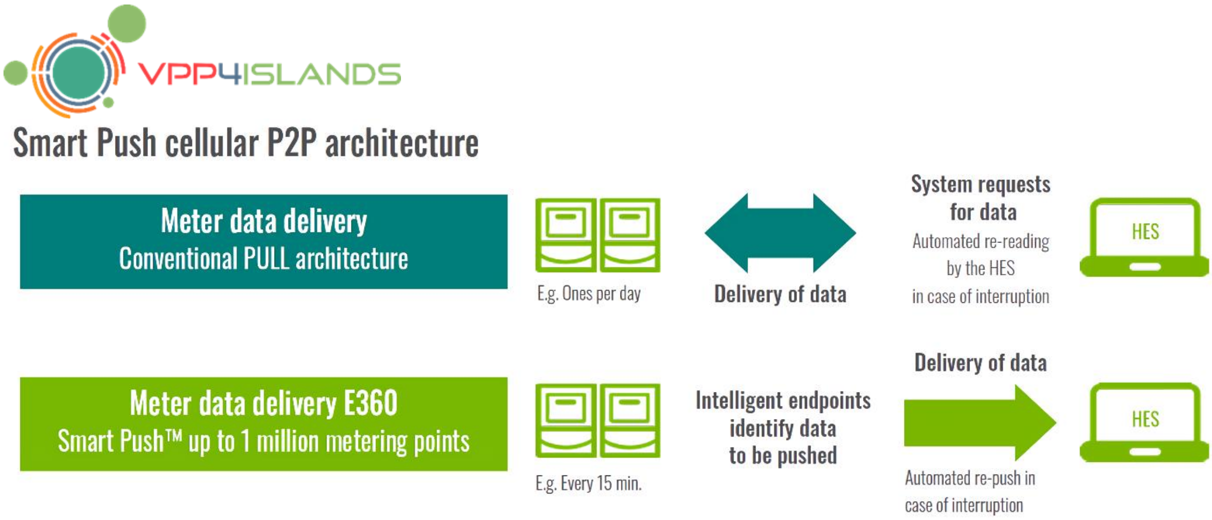

Figure 15. The Traditional PULL architecture and, Smart Push architecture used in the E360

6. OPINIONS RECEIVED FOR GÖKÇEADA FROM PRIVATE SECTOR AND PUBLIC INSTITUTIONS

Gökçeada is Turkey's largest island. It consists of volcanic masses with a rugged structure where hills and plains are lined up. 77% of Gökçeada is mountainous, 12% is rugged, and 11% is plains. It is the Region of Turkey with the most potential in terms of wind energy. However, Gökçeada is in the 6th Region, the least developed region class in terms of development index.

The island population is 9440 people, according to 2019 data, and it reaches a very crowded population due to tourism in the summer season. For this reason, it will be beneficial to design a VPP system by observing the tourism season and other periods separately. Designing a VPP system where island residents can access energy without interruption will be very beneficial for consumers. Providing uninterrupted energy to the island residents, especially when the transportation with the mainland and energy flow is interrupted, has been evaluated by the relevant authorities as essential.

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When the studies conducted for Gökçeada are examined, it is observed that the most suitable renewable energy type in terms of return on investment is wind. Following this purpose, two 900 kW wind turbines installed on the island can be connected to the VPP system, the 210 kW solar power plant, and the 4x770 kVA diesel generator UEDAŞ.

As of today, there is no hydroelectric power plant and regulator for electricity generation in Gökçeada. However, there are four ponds and one dam lake in Gökçeada. Regulators, also known as river-type hydroelectric power plants, can be established on these ponds and dam lakes. Thus, these power plants will be used for power generation. The potential power generation of these systems depends on many factors, and it is estimated that these plants can be considered pico/micro-hydropower plants.

Considering the literature review and geothermal resource studies today, we could not find any information about the geothermal resource in Gökçeada. Oil seeds that can be used in biofuel energy are not produced. Since waste is not collected regularly, it does not seem possible to use biomass energy.

Wave energy estimation has not been made around Gökçeada. It is thought that the island has potential in terms of wave energy, considering that it is one of the most intense regions in terms of wind energy. For this, the wave energy potential could be indirectly determined using wind data.

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