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# Energy Sustainability–Survey on Technology and Control of Microgrid, Smart Grid and Virtual Power Plant

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**ABSTRACT** The idea of microgrid, smart grid, and virtual power plant (VPP) is being developed to resolve the challenges of climate change in the 21st century, to ensure the use of renewable energy in the electrical grid. For the increasing demand for electricity, raising public consciousness about reducing carbon emission, the microgrid is established which is transformed into a virtual power plant (VPP) or a smart grid with the blessing of modern communication systems, intelligence technology, and smart devices. So, to keep these systems up-to-date and to ensure security, it is important to know the details about the uses and benefits of these systems in the developed world and also to improve control methods and automation, it is important to achieve the present essence of such systems. This paper is focused to contribute to this flourishing area of energy sustainability covering microgrid, smart grid, and virtual power plant by compiling and recapping their recent advancements, technical requirements, control problems, and solutions. The paper is mainly intended to address the role of control strategies applied to the microgrid, smart grid, and virtual power plant towards future energy generation, distribution, management, and security.

**INDEX TERMS** Controllers, cyber security, microgrid, renewable energy, smart grid, system architectures, virtual power plant, world market.

## I. INTRODUCTION

Power generation is important to our modern world since it drives many electrical devices of our everyday life and powers commercial buildings, industries, the internet, and so forth. Latterly, electricity demand is growing rapidly. The next decade is projected to double electricity usage [1]. Scientists and researchers are looking for alternative energy generation and distribution systems to meet up the demand for electricity in the future. The energy that comes from renewable energies is the energy that is not in use. Water, wind, solar, biofuels, or hydropower are the most widely known renewable energy sources. The world's renewable capacity at the end of 2019 stood at 2537 GW. With a production of 1190 GW, hydropower viewed the world's biggest share. While 124 GW of biofuels and 14 GW of geothermal power and 500 MW of fuel were additional renovations [2]. A statistics on global renewable energy-based power generation is depicted in Table 1.

**TABLE 1. Global renewable energy statistics 2020 [2].**

| Country/State | Capacity | Global share |
|---|---|---|
| Central America | 16 GW | 1% |
| North America | 391 GW | 15% |
| South America | 221 GW | 9% |
| Middle East | 23 GW | 1% |
| Europe | 573 GW | 23% |
| Asia | 1119 GW | 44% |
| Africa | 48 GW | 2% |

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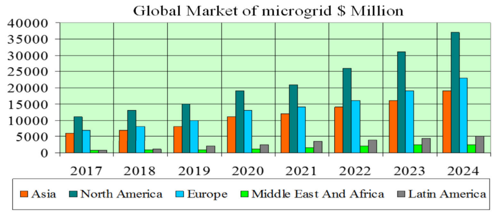

**FIGURE 1.** **Total microgrid revenue by region, world markets: 2017-2024 [3].**

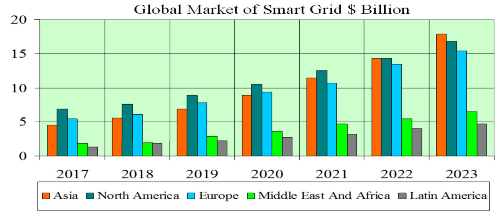

**FIGURE 2.** **Total smart grid revenue by region, world markets: 2017-2023 [6].**

To integrate the energies generated from renewable energy sources to the main grid for the sake of obtaining energy sustainability, the concept of microgrid, smart grid, and virtual power plant has been introduced. Microgrid and smart grid or virtual power plant have become the perfect application of renewable energy. The global market of the microgrid, the smart grid, and the VPP are in high demand.

Microgrids are a global phenomenon as illustrated in Fig. 1. Asia Pacific will be the dominant region with 41.3% of total microgrid revenue and North America is projected to represent 32.5% of global market share [3]. Between 2015 and 2020, the microgrid market opportunity will increase more than 3.5 times, and more than 1437 microgrid projects that represent close to 13.400 megawatts of capacity are estimated to be under construction [4]. The total revenue of 164.8 billion is expected for 2024 [3]. The global market of "smart grid" equipment and facilities has grown exponentially and is expected to continue its fast growth over the next decade which can be summarized by Fig. 2. America and Europe are the leading zones for implementing smart grid technologies. The Asia Pacific is expected to grow the most and is predicted to be the fastest-growing smart grid technology market. The retail economy of the smart grid around the world is expected to triple in size that between 2017 and 2023 to reach approximately 61 billion U.S.D and the world market size for smart grid is predicted to hit 94.7 billion U.S.D by 2025 [5].

Renewable energy applications in microgrid, smart grid, or virtual power plant have some major challenges. As time progresses the scientist and researchers are finding new challenges with the advancement of technologies. Fortunately, researchers are working restlessly to overcome those challenges and make the electrical grid more customer-friendly. While distributed energy resources(DER's) have been revolutionary in consumer choice, their development provides the energy industry with a variety of unexpected problems, including implications for consumers, companies, providers, and the whole grid unless they are proactively and effectively regulated. Those challenges are broken down into three broad categories: complexity, safety, and efficiency. If the amount of DERs rises, electricity providers, networks, and aggregators will strive to improve DER's collective ability. This is to resolve grid related challenges and potential market prospects some of which arise as a result of the high DER penetration. Standardizing control of heterogeneous devices, differentiating between machines and nodes, establishing common language across standards & protocols, grid interface requirements and operating systems constraints, managing different network configurations, coping with diverse digital energy business markets, etc are complexity-based challenges.

The efficiency challenge is to maximize the value of what will eventually be thousands of DERs of various combinations and capabilities, connected to the electricity grid at different locations with different functions. Security is an indicator of the capacity of the power grid to continue to function, except in the case of a failure such as the sudden loss of generation or payment [7].

A large number of studies on various aspects of the microgrid, smart grid, and virtual power plants, such as control procedures, integration problems, management, security, design, operation, and planning were carried out. The use of control strategies has an important role in the energy sustainability of the microgrid, the smart grid, and the virtual power plants. These concepts were incepted with the aim to integrate low inertia renewable energies to the high inertia synchronous generation based traditional power grid. Most renewables are intermittent in nature and the integration of them to the main grid is not so straight-forward. It necessitates a great deal of attention from various perspective and certainly, control is a major area that needs to be look-up deeply in order to guarantee the stability and sustainability of such systems.

Control strategies are able to control, monitor, manage, and direct the flow of energy among various sources to ensure the effective use of such resources which provide energy sustainability which can be seen from Fig. 3. Renewable energy sources are specifically connected to local distribution systems or host facilities within local distribution systems. The adoption of DERs changes the manner of energy transmission through utility power grids, which provide flexibility and stability in energy consumption. A high penetration of DG (Distributed generation) into grids brings challenges to the operation and stability of power systems. The EMS (Energy management system), ESSs (Energy storage systems) are the vital supervisory controllers, play multiple roles in MG, SG and VPP system with high penetrations of renewable energy sources with effective ancillary services to the power utility with updated operation methodologies which is used to manage the power and energy between sources and loads and to provide high quality, reliable, sustainable, and

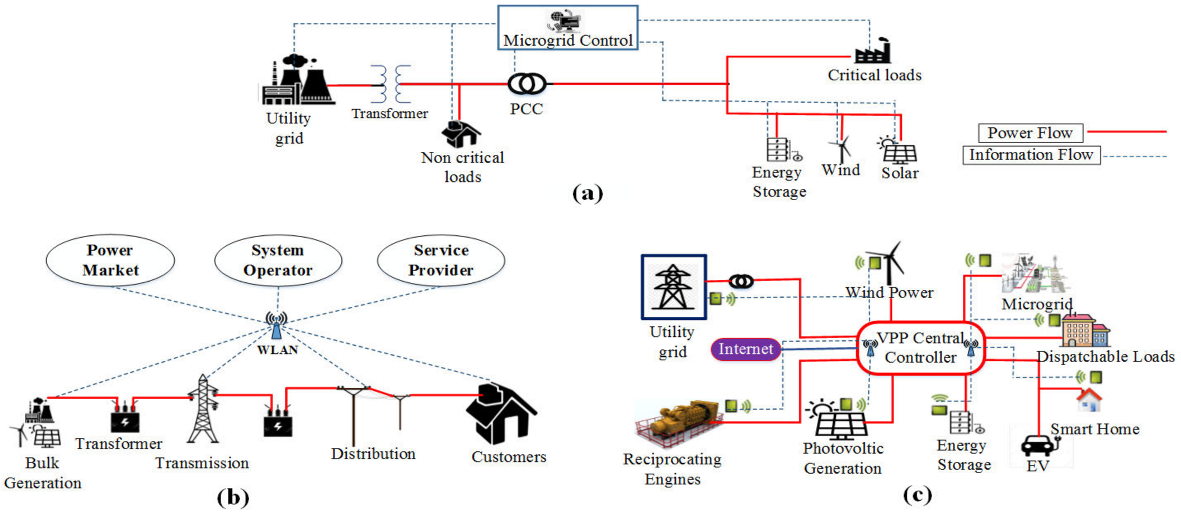

**FIGURE 3.** Architecture of (a) microgrid (b) smart grid (c) virtual power plant.

environment-friendly energy to the consumers. Hence, proper control techniques for DERs are important to ensure the stability, safety, efficiency and energy sustainability of power systems [8]–[10]. Therefore, the role of control towards next generation MG, SG and VPP cannot be ignored for sustainability [11]–[13].

In this paper, we first going to present a picture of the recent advancement on the microgrid, the smart grid, and the virtual power plant projects around the world by stating their current status with regards to the location and the capacity. Secondly, we provide a brief overview of the microgrid discussing its class, major components, integration challenges with the main grid, and the control requirements for its successful operation with the main grid. Next, we introduce a detailed investigation of the control issues and applied mechanisms of the solar-powered, battery-powered, and wind-powered microgrid. After that, we put forward a synopsis of the smart grid stating the differences between the traditional grid and smart grid with its major components along with the control requirements and the issues including its cybersecurity consciousness. Then we move forward to define VPP, the differences between the VPP and the microgrid. The key components of the VPP and its classification are discussed next. After that, the challenges of the VPP, requirements, control issues, and prospects of the VPP are presented in a detail.

The remaining paper is organized accordingly: Section II reviews the worldwide existing projects of the microgrid, the smart grid, and the virtual power plant and their functionality. Section III is based on reviewing different types of microgrids with renewable DGs and other components, integration issues, and control methods applied to the microgrid. Section IV discusses smart grid components, the control methods of smart grid, and cybersecurity. Section V reviews the virtual power plant in a brief. The paper is concluded in Section VI.

## II. CURRENT ADVANCEMENT STATUS OF MICROGRID, SMART GRID AND VIRTUAL POWER PLANT

### *A. MICROGRID PROJECTS*

North America accounts for 66% of global electricity in microgrids. It is therefore expected that by the middle of this century North America will have a major impact on distributed generation research, including renewable resources [14]. The technology of the microgrid in China is rapidly evolving. More than 100, including in-grid and isolated microgrids, have been deployed there by the end of 2016. Chinese microgrid policies demonstrate that optimum microgrid capacity preparation, energy storage, and incentive policy are key factors for fostering microgrid deployment in China [15]. In the European Union, microgrids have reached mature technology to participate in the utility grid. Europe has already progressed in the production and utilization of renewable energy. Moreover, Europe has many islands around, where power transmission will be incredibly costly, microgrid might be a possible solution [16]. India has recently accelerated its growth rate as its government promotes international investment reforms and develops its 1.2 billion citizens. But in the form of grid losses, India is losing revenue. A summary of the microgrid projects has been depicted in Table 2.

### *B. SMART GRID PROJECTS*

Over the coming 20 years, the smart grid-related infrastructure demand in the United States would reach around $13 billion in a year. In recent years, the smart grid industry has spent $20 billion a year in new spending and it will increase to over $100 billion a year by 2030 [17]. In Europe, almost 527 projects are established until 2017. The policy history begins with the Europe 2020 plan, which is to be followed by 2030 on the environment and electricity [18]. China smart grid also called "Strong Smart Grid. At first, the smart grid

**TABLE 2.** Some microgrid projects in the world.

| Name of the projects | Country | Location | Capacity |
|---|---|---|---|
| Mad River Park Microgrid, Vermont [22] | USA | Waitsfield, VT | 500 KW |
| RIT Microgrid [22] | | New York | 600 KW |
| Alaska Power Plant [22] | | Wales, Alaska | 500 KW |
| California Santa Cruz Island [22] | | California | 300 KW |
| Hawii Hydrogen Power Park [22] | | Hawaii | 200 KW |
| The Ilhavo Municipal Plant [16] | Europe | Portugal | 300 KW |
| LABEIN's Commercial Feeder [16] | | Spain | 200 KW |
| Continuon's MV/LV Plant [16] | | Netherlands | 315 KW |
| University of Nottingham Testbed [16] | | United Kingdom | 500 KW |
| Bronsbergen Park Microgrid, Zutphen [16] | | Netherlands | 300 KW |
| Sino Danish Microgrid Collaboration [23] | China | Shanghai | 200KW |
| Hangzhou [23] | | Zhejiang | 120 KW |
| Goldwind Demonstration Microgrid [23] | | Beijing | 3,730KW |
| Xiamen University DC Microgrid [23] | | Fujian | 150KW |
| Hefei University of Technology Microgrid [23] | | Anhui | 1000 KW |
| CM Official Residence Microgrid [24] | India | Bihar | 125 KW |
| Chhattisgarh RE Development Agency [24] | | Chhattisgarh, Raipur | 500 KW |
| Dharnai Microgrid [24] | | Dharnai, Bihar | 100 KW |
| Andaman Island Coast Guard Microgrid [24] | | Andaman Islands | 75 KW |
| Sundarbans Village Microgrids [24] | | West Bengal | 120 KW |
| Agnew Hybrid Renewable Microgrid [25] | Australia | Leinstar, Weatern Australia | 56000 KW |
| ATCO Hydrogen Microgrid [26] | | Jandakot, Western Australia | 300 kW |
| Garden Island Microgrid [26] | | Perth, Western Australia | 2000 KW |
| Latrobe Valley Microgrid [26] | | Victoria | 7500 KW |
| Royella Solar Firm [26] | | Canberra | 240000 KW |

**TABLE 3.** Smart grid projects in the world.

| Name of the projects | Country | Location | Capacity |
|---|---|---|---|
| AEP Ohio [27] | USA | Ohio | 2954030 KW |
| Detroit Edison's (DTE's) [27] | | Michigan | 11084000 KW |
| Pacific Northwest Smart Grid Project [27] | | Washington | 112000 KW |
| Energy Storage with Staying Power [27] | | Pennsylvania | 1000000 KW |
| CCET [27] | | Texas | 8500000 KW |
| ADELE [28] | Europe | Germany | 200000 KW |
| C2C [28] | | United Kingdom | 152000 KW |
| Orkney Smart Grid [28] | | UK | 26000 KW |
| DECOS [28] | | Italy | 345000 KW |
| EDGE [28] | | Denmark | 213000 KW |
| Hebei Electric Power Company [29] | China | Handan, Hebei | 4590000 KW |
| Xianjiaba Shanghai Power Company [29] | | Shanghai | 64000000 KW |
| Jiangsu Electric Power Company [29] | | Nanjing, Jiangsu | 12700000000 KW |
| Fujian Electric Power Company [29] | | Fuzhou, Fujian | 6000000000 KW |
| Hunan Electric Power Company [29] | | Changsha, Hunan | 4500000000 KW |
| CESC [30] | India | Mysore | 151890000 KW |
| UHBVN [30] | | Hatyana | 131800000 KW |
| MSEDCL [30] | | Maharastra | 261600000 KW |
| APDCL [30] | | Assam | 90000000 KW |
| UGVCL [30] | | Gujarat | 1700000000 KW |
| TSECL [30] | | Tripura | 128630000 KW |
| HPSEB [30] | | Himachal Pradesh | 533000000 KW |
| Narara Ecovillage Smart Grid [31] | Australia | Narara, New South Wales | 471 KW |
| Berrimal Wind Farm [32] | | Western Victoria | 72000 KW |
| Mortlake South Wind Firm [32] | | Victoria | 157500 KW |
| Aldoga Solar Firm [32] | | Queensland | 480000 KW |
| Lilyvale Solar PV Plant [32] | | Queensland | 118000 KW |

in China was introduced by the State Grid Corporation of China (SGCC). China the largest power utility in the world consists of 1.86 million employees, 2352.7 billion yuan total assets, and serves over 1.1 billion population [19]. The annual electricity sales in China 3253.9 Twh in 2012 [19]. In India, the total estimated cost for all the projects and NSGM (National Smart Grid Mission) activities for the 12th plan (ending March 2017) is 980 cr rupee [20]. India is only able

**TABLE 4.** **The virtual power plant projects in the world.**

| Name of the projects | Country | Location | Capacity |
|---|---|---|---|
| Pennsylvania American Water VPP [34] | USA | North America | 400 kW |
| Detroit VPP [35] | USA | State of Michigan | 300000 KW |
| Wasatch energy and Sonnen VPP [36] | USA | California | 60000 KW |
| Swell VPP [36] | USA | Southern California | 300000 KW |
| FENIX [37] | Europe | UK, Spain, France | 150000 KW |
| VPP of Siemens Company [38] | Europe | Germany | 1450000 KW |
| Gresham House energy storage VPP [36] | Europe | UK | 265000 KW |
| UK SMS VPP [39] | Europe | Uk | 90000 KW |
| ENGIE and Kiwi Power VPP [36] | Europe | UK | 3000 KW |
| Sonnen VPP [39] | Europe | Itely | 1000000 KW |
| Shizen energy VPP [40] | Asia | Japan | 5300 KW |
| Hitachi ABB VPP [39] | Asia | Singapore | 2400 KW |
| Stategrids VPP [41] | China | Jiangsu | 10000000 KW |
| Ausgrid and Reposit unveil VPP [42] | Australia | New South Wales | 1000 KW |
| SEA(Smart energy Australia) VPP [39] | Australia | Victoria | 1000000 KW |
| AGL Virtual Power Plant [43] | Australia | Adelaide | 5000 KW |

to build a secure climate for investments in electrical infrastructure with a trustworthy, financially sustainable smart grid that will address the fundamental problems of grid [21]. A summary of the smart grid projects has been depicted in Table 3.

### C. VIRTUAL POWER PLANT (VPP) PROJECTS

The global VPP is reported by polls and surveys (P&S), In 2016, the VPP market was anticipated to grow from USD 191.5 million to US$ 1.1875 billion in 2023 [33]. A list of some worldwide VPP projects has been depicted in Table 4.

## III. MICROGRID - ARCHITECTURE AND CONTROL

Microgrid is a small-scale power system located near the consumers. It is an interconnected charge group with clearly specified electrical boundaries and distributed energy resources (DERs). It is a separate energy network, composed of the electricity source and the loads that are transmitted and that can be operated in combination with or without the central power plant. A microgrid can be called any small-scale, decentralized power station that has its generation and storage capacity and definable limits. It is a low or medium-voltage supply network that includes a variety of distributed generations, storage devices, and controllable loads. Microgrids are capable of operating either on the primary utility grid (grid-connected mode) or they can work without an isolated or autonomous utility grid without sacrificing the quality of the electricity. Microgrid shares electricity with the power grid in grid-connected mode. However, in an isolated mode, the microgrid operates independently without the power grid connection. Renewable sources of energy such as solar panels or wind turbines can be easily incorporated into a microgrid to cater to the rapid growth of power supply demand. Local generators are called micro sources, and they can be either traditional or renewable power generators. Such generators are primarily near the sources. Microgrid approaches allow providers to take advantage of the local, renewable, and cheaper resources that provide more reliable, closer primary source protection. Microgrid methods will enable the provider to take advantage of local, renewable, and less expensive resources that afford the security of more consistent, closer primary source [44]. Microgrid offers a broad range of benefits and even it is more adaptable than the backup system. Microgrid loads are typically broken down into two types: Flexible and fixed. Under normal operating terms, fixed loads cannot be changed and must be fulfilled while flexible loads respond to signal monitoring. Microgrid DGs are typically divided into two types: dispatchable or non-dispatchable. Depending on the unit type, the microgrid controller can control the units and is under technical restrictions. Non-dispatchable units are primarily renewable DGs, which generate unpredictable and intermittent electricity, usually, solar panels and wind turbines [45]. The point of common coupling (PCC) switch converts the microgrid to islanding mode by disconnecting the microgrid from the main power grid. The isolated capacity of a microgrid enables it to disconnect from the main grid and it is one of the most significant elements of the microgrid. The microgrid convert to island mode during utility grid fluctuations and the local DERs provide a stable and uninterrupted supply of customer loads. When the disturbance has been removed, the islanded microgrid would be re-synchronized to the grid. The ultimate purpose of a microgrid is to ensure that different distributed power supplies are installed seamlessly. A profound impact will have on the microgrid, therefore some challenges in the development of microgrids need to address like: reliability and stability, programming and designing, controlling, protection, scheduling operation [46]. Microgrid provides essential customer and utility grids, such as power reliability by local distribution system, carbon emissions mitigation through the diversification of energy sources, economic development through the mitigation of transmission and distribution costs, use of the lower cost of renewable energy DGs and the implementation of energy efficiency [47]. Research on microgrid is advancing to a new level day by day. The research trends of the microgrid in the last five years

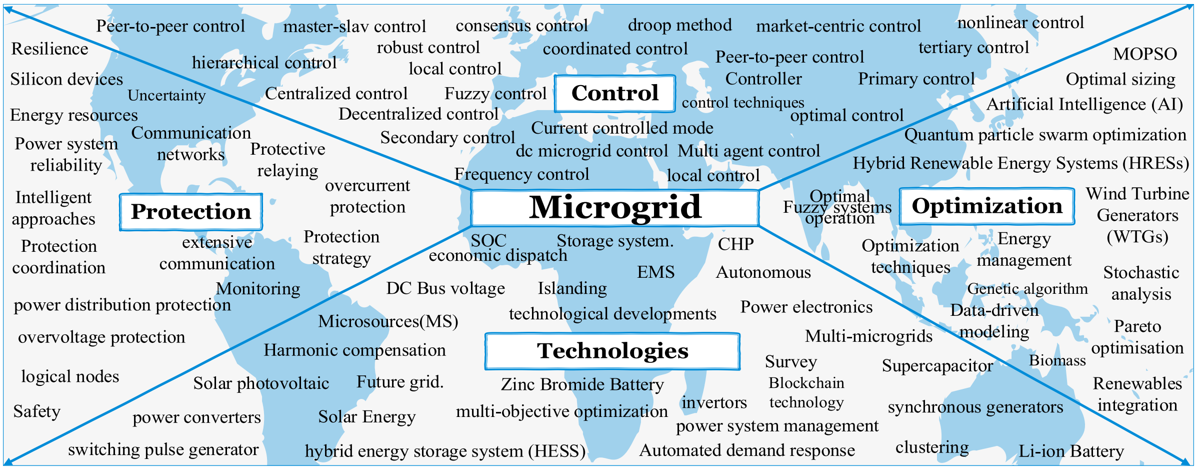

**FIGURE 4.** Keywords used in research article of microgrid from (2016 - August 2020).

(2016 to August 2020) in terms of their keywords are shown in Fig. 4.

## *A. BASIC COMPONENTS OF MICROGRID*

### 1) DISTRIBUTED GENERATION (DG)

The most important part of the microgrid is distributed generation which is generally used for islanding mode. Distributed generation refers to electricity produced locally. Typically speaking, distributed generation happens near to where the power is currently being utilized. DGs are not centrally planned and run primarily by local energy producers or users. It is usually less than 50 MW and linked to the distribution network of electricity which can differ by region, typically referring to the part of the system which has an operating voltage of 240/400 V up to 110 kV [48]. Conventional energy sources such as synchronous generators and AC generators can be regarded as generators of distribution. Many renewable energy projects are generation systems that are distributed. The networks of renewable energies allow these energy sources to be properly used. It is feasible to utilize green energy sources such as hydropower, biomass, wind, nuclear, geothermal, wave and tidal energy, etc as microgrid distributed generation. In addition to the environmental advantages, other technological and economic benefits may be achieved by allowing DGs to run microgrid.

### 2) DISTRIBUTED STORAGE (DS)

Battery, flywheels, and capacitor is the most commonly deployed microgrid storage system for energy transmission. Energy storage is capable of performing many functions in the microgrid, such as retaining power efficiency, voltage regulation, etc. In a microgrid with different capacities, when several energy storages are available, their loading and discharge should be coordinated so that smaller power storage is not discharged faster than those of greater capacity. Also, smaller than those with higher capacity are likely to not be fully charged. This can be done based on their charging position under centralized management of energy storages [49]. If a single monitoring device needs and handles multiple energy storage systems the system ensures efficient operation, especially in the autonomous mode it is built on a master-slave structure.

### 3) INTERCONNECTION SWITCH (PCC)

It is the stage in which a microgrid acts as an electric circuit associated with the primary grid. Separated microgrids have no PCC and they are commonly found in rural areas where due to technical or economical constraints the central grid is not incorporated.

## *B. CLASSIFICATION OF MICROGRID*

A microgrid can be AC microgrid, DC microgrid, Hybrid microgrid, Community microgrid, Virtual microgrid, Military microgrid, Industrial microgrid, Residential microgrid, Networked microgrid, and so forth. Table 5 highlights the characteristics of various microgrids. Microgrids are mainly divided into three main classes, i.e. AC microgrid, DC microgrid, and hybrid microgrid. A standard AC microgrid device connected with the MV system at the PCC. At certain points within the distribution networks, DG units and ESS are related. In most cases, the operations of the AC microgrid device follow the voltage and frequency requirements implemented in most traditional systems of distribution [50].

The microgrid based on the DC hub is called the DC microgrid. Power electronics devices are generally operated by DC power. The advantages of AC and DC architectures can be combined to create a highly interesting hybrid microgrid configuration. This feature offers an effective way to incorporate potential RES or electric vehicle units (EVs) with limited adjustments to the existing distribution grid and decreases the overall cost. The most important advantages of hybrid microgrids are: integration, synchronization, voltage transformation, economic feasibility, protection, and reliability [52]. Virtual microgrids are organized into larger

**TABLE 5.** **Different types of microgrid.**

| Types | Properties |
|---|---|
| DC Microgrid [51] | • Use DC bus.<br>• Reduces the rate of dissipation of energy and building by AC/DC transformation.<br>• It is commonly used in the application of electrical vehicles, telecommunications networks, and shipboard control systems. |
| AC Microgrid [50] | • AC bus is used to connect all DERs and loads.<br>• DC generation units are connected to the AC bus through DC to AC inverters and AC-to-DC rectifiers are often used to supply DC loads.<br>• Low-frequency AC Microgrids are commonly used in many fields of science, remote settlements and testing. |
| Hybrid Microgrid [52] | • Separate AC and DC sources and loads link to the respective AC and DC networks.<br>• The AC and DC connections are connected via transformers and converters. |
| Utility or Community Microgrid [53] | • Provide a controlled grid section.<br>• They are not distinct from Microgrid. They are fundamental from the point of view of the regulatory and business model since they require a conventional utility system.<br>• The center of this function is the far more important regulatory services. |
| Virtual Microgrid [54] | • Cover DERs in many places, but organized to be delivered in a single managed entity to the grid.<br>• There are very few virtual grid demonstrations.<br>• The system must act as an insulator regulated or multiple islands organized. |
| Military Microgrid [55] | • The military's most important requirements are among many advantages of a microgrid, island capability, trustworthiness and defense.<br>• A more important factor in military applications naturally is reliability and security.<br>• As it is, a base is located in volatile territory and can be an easy target for attacks if it depends on a central power grid. |
| Commercial and Industrial Microgrid [56] | • Critical or responsive charging groups requiring a high level of power quality and dependability are normally classified as commercial and industrial electricity users.<br>• Industrial microgrid may be used to meet the demands of a multi-commercial or industrial area such as a university campus, shopping center, or manufacturing facility. |
| Residential Microgrid [57] | • A microgrid may also supply a limited multi-facility residential customers. For example: in urban areas, a variety of city buildings or high or low-rise condominiums.<br>• The residential microgrid provides a convenient and efficient energy supply network, customized to consumer needs when multiple DER units are used.<br>• Solar PV generation and CHP microturbine generation plants represent attractive DER technology on a small scale for both residential and commercial construction applications. |
| Remote Microgrid [58] | • The need to provide full load and appropriate level of contingency management reserve power in a remote microgrid is a key component of the distance microgrid architecture.<br>• The remote microgrid architecture method offers an autonomous healing mechanism with adequate urgency for a rational degree of availability and protection. |
| Networked Microgrid [57] | • Networked MG's are the connection of two or more MG's with the ability to connect DS in the traditional coupling (PCC) to share power between MG's and DS.<br>• All MGs can be run together as a network, depending on the storage capacities and support capability of different sync generating systems in each MG, which can feed the global grid for some time.<br>• It maintains the stability of frequency-voltage and overall economic energy supply.<br>• Improve the durability of the network. |

associations to optimize the benefits of associations by multiple energy prosumers [54]. Military microgrid which main purpose is to ensure security and reliability. It is generally installed in army camps or islands for defense support [55]. Industrial microgrids are being developed with the increase of DERs installed onsite. The strategy is to establish a more efficient and constructive microgrid that enables energy effectiveness strategies to be defined, planned, and implemented at supply, management, and energy use levels. The microgrid which supplies a limited multi-facility to residential customers in urban areas, a variety of city buildings, or high or low-rise condominiums is called residential microgrid [57]. The remote microgrid architecture provides an autonomous process of healing with ample urgency for a reasonable degree of availability and security. Thus, it provides low-cost, reliable, renewable power to remote communities [58]. Networked microgrids have become a starting function in grid design that provides many advantages to local distribution networks and consumers which include economic optimization, efficiency, sustainability, and recovery. The key point of a networked microgrid is its communication. It is an advanced model of microgrid technology that interconnects multiple microgrids [57].

### *C. INTEGRATION ISSUES OF MICROGRID*

In implementing DERs in the power grid, multiple variables and limitations are involved. Most small-scale DG sources on the load side are connected to the medium or low-voltage system. Power electronics is used for interfaces between the grid and the microgrid. So, there are no adverse impacts on reliability and efficiency when the DERs are connected to the grid. The implementation of a series of variable renewable sources such as the conversion of the solar and wind grid will help to provide technological relief by reducing delays, reducing network fluctuations, and voltage decreases. Integration techniques of the microgrid can be classified into three types [59]: 1. Low penetration with existing grid 2. High penetration with existing grid 3. High penetration with smart grid concept.

There are many challenges in integrating, controlling, and operating microgrids into the entire distribution system. The microgrid is not designed to monitor the huge power supplied to the feeders [60]. Many kinds of technical and economic problems will arise. Because of the atmosphere, adequate light cannot fall on the solar panel, which reduces electricity output. Rain is another downside to the solar system's energy output. Again, electricity production is associated with the everyday situation, the seasonal state, and the characteristics of the environment. Such complexities and solar system instability pose a problem in managing the power grid [61]. Wind motion over the day or season is not permanent. At night and in winter, the wind blows hard. If the supply exceeds the requirements, the current flows in the opposite direction, which reduces the load safety. To overcome these issues, the voltage is to be moved down by an extra control. Capacitors storing energy and filtering of the reactive power are used in the central grid. The current load is reduced and the voltage of the pack is increased. Any wind variance causes voltage fluctuation. The condenser bank alone cannot overcome the change. It can be replaced with a static var compensator (SVR) [62].

Biomass power generation faces some difficulty throughout its service. The issues connected with biomass processing are gas development, gas washing, pre-treatment, etc. The area that generates biomass is often far from the units that generate electricity. This reduces the cost of energy supply. This lengthy migration often influences the properties of biomass by moisture absorption and reduction of bulk densities. Although the moisture of the biomass, which serves as an agent for gasification, is an obstacle to the regulation of electricity generation. Excess moisture in the biomass increases heat absorption and reduces thermal efficiency. The biomass will provide sufficient humidity as dry biomass raises production costs because the balance of output gas needs additional water [61].

Excessive humidity is dried from both sunshine and plant heat. Sunlight is a long-term method that relies on moisture for biomass drying. In contrast to the sunshine, the drying cycle using power from the plant is expensive and the output rate of bio-gas changes for these challenges. The energy produced by the gas turbine is not set. Such differences allow the microgrid voltage to fluctuate. The microgrid is related to a large number of DG units. For improved microgrid performance, the connection between them should be necessary. The microgrid is more costly with small-scale DG units. The microgrid is rendered by a set of paired DG units. Those device controls allow the machine more complicated. Regulation of microgrid voltage and current requires a good communication network between the DG devices. Microgrid voltage is regulated by the power converter where the microgrid is wired into two loops. Power movement within a fault can be minimal. The power electronics can control the amount of electricity and the active and reactive power on the grid side.

### *D. CONTROL REQUIREMENTS OF MICROGRID*

Microgrid requires extensive use of modern control techniques at all stages. The secure operation of microgrid and efficient interconnection or re-connection processes in connected and isolating operations is subject to microgrid control. The microgrid will be able to not only function autonomously but also communicate with the central grid [63]. So, use appropriate control loops to deal with those changes, respond to grid fluctuations, and conduct active power or frequency management, as well as reactive power or voltage regulation is required [64].

A microgrid control system is needed to assess dispatchable quantities based on various potential goals and constraints to handle and monitor microgrid dispatchable assets. Microgrid and DERs integration in general, introduce several operational problems that need. Some of these difficulties emerge from invalid assumptions, which usually extend to modern delivery networks, while others emerge from problems of reliability traditionally seen only at the level of transmission systems. Some challenges for microgrid control are: [65]: 1. Bidirectional power flows 2. Stability issues 3. Modeling 4. Low inertia 5. Uncertainty.

The control system of the microgrid will be able to ensure that the microgrid works efficiently and cost-effectively when addressing the above challenges. The desirable control system features are 1. Output control 2. Power balance 3. DSM 4. Economic dispatch 5. The transition between modes of operation.

The robustness and adaptability of controls are needed in the microgrid setting that is marked by regular and numerous changes in topology. With all the above requirements, the efficiency of measuring, connectivity, and high-speed devices are additional challenges. So, an effort must be made to eliminate the need for high-speed communications and processing in essential activities. In consideration of the various time constants involved, including fast dynamics in production controls and slower dynamics in an economic dispatch, the implementation of a hierarchical control system is very desirable. If the systems are built for use in isolated or grid-connected mode depends heavily on the nature and flexibility of the microgrid controller specifications [66].

## *E. CONTROL ISSUES OF MICROGRID*

The main goal of the control structure is: voltage and frequency control, optimization of maintenance cost for microgrid, obtaining the best combination between the microgrid and main grid, control of the line voltage, etc. Table 6 summarizes the functions and limitations of different control methods of the microgrid.

### 1) CENTRALIZED CONTROL OF MICROGRID

Centralized management's basic goal is to monitor output voltage amplitude and phase, to control the active and reactive power of the microgrid, as well as to monitor the microgrid load [61]. It is based on hierarchical control. The central controller collects information from all units so that all calculations are done and monitors all groups connected at a single stage. The central controller controls DG's electricity generation and matches criteria to maintain system balance. It senses the PCC power level and determines whether or not to disconnect the grid [11]. Local micro-source controller (MC) with load controller (LC), microgrid central controller (MGCC), distributed management system (DMS) are the three control elements of the centralized control system.

### 2) DECENTRALIZED CONTROL OF MICROGRID

The decentralized control is a hierarchical control where every single unit has a local controller. Every unit has its local control unit run independently in decentralized control. The local controller gets local data and helps to maintain local units. The control is focused on the peer-to-peer method. Without adjusting controller settings, it can integrate multiple DG units with the microgrid. Broad communication and computing in an expanded geographical area are essential for centralized control. In the case of decentralized power, it requires the function of units to be very carefully combined. The local variables cannot have a sufficient synchronization standard for the units. The hierarchical approach to management is split into three stages to solve these problems [61]: 1) Primary control 2) Secondary Control 3) Tertiary Control.

### 3) HIERARCHICAL CONTROL OF MICROGRID

Primary control is the first stage of the hierarchical control structure which is based on local measurement. The primary control protocol regulates the voltage and frequency of the reference voltage supplied to the loops of the internal current and voltage power. The necessity of external reference to stability and power control is not needed. It includes the points of reference for the DERs voltage and current control loops. Control of production and power-sharing is the key objective of this system [67]. The secondary control level is also regarded as the energy management system (EMS) and it tracks and collects microgrid control information from DG devices. The primary level produces any deviation of voltage and frequency, offset by the secondary stage of control. It syncs the central grid microgrid until it begins with the grid-connected mode in private mode [68]. The final stage of hierarchical control is tertiary control. In a matter of seconds, the tertiary control method sends information to the secondary control level that controls the basic control level and the subsystems of the microgrid, so that the central control system responds instantly to local events in a predefined fashion. If multiple microgrids need interconnection between them, the tertiary control approach makes the right combination of them. Tertiary control level is regarded simply as part of the primary grid, not the microgrid itself [69].

## *F. CONTROL ISSUES OF NETWORKED MICROGRID*

Networked microgrid is the connection of two or more microgrids with the ability to connect distribution sources in the traditional coupling (PCC) to share power between microgrids and distribution sources [70]. The simplest way to use DERs is potentially by using clusters of microgrids in the form of networked microgrids. Each microgrid alone can provide critical loads on its own, add power together and extend the duration on the distribution of critical loads in emergency operating conditions if no supply is available from the main grid. All microgrids can be run together as a network, depending on the storage capacities and support capability of different sync generating systems in each microgrid, which can feed the global grid for sometime [71]. Networked microgrids are one complicated aspect of the network power system. The networked microgrid controller's two key objectives are to maintain the stability of frequency-voltage and overall economic energy supply. The essential function of the networked microgrid controller is the islanding and grid-connected operation of each microgrid. Optimal load sharing is achieved by various droop characteristics between all microgrids in networked microgrids and among dispatchable DERs within each microgrid. To operate networked microgrid, the

**TABLE 6.** **Comparison of different control method of microgrid.**

| Control Method | Functions | Limitations |
|---|---|---|
| Centralized Control [61] [45] | • Control voltage and frequency of microgrid.<br>• Monitor the amplitude and output voltage phase to regulate microgrid's active and reactive power.<br>• Easy implimentation. | • For an extended geographical area comprehensive communication and computing is needed. |
| Decentralized Control [61] [45] | • Controlled independently and each decision is taken locally.<br>• Controllers do not depends on others controller action.<br>• It uses different intelligent process. | • Very strong communication is important between system units and good coordination is must.<br>• If ESS is used as a voltage source, information on the DG units does not contain state of change (SOC). |
| Primary Control [61] | • Usually the control level is droop control.<br>• Maintain the voltage and frequency stability.<br>• Improves power reliability. | • It has the inherent load-dependent voltage deviation.<br>• When the microgrid is in island mode the use of pure integraters is not permitted because the total load will not coincide with the total injected power. |
| Secondary Control [45] | • Control the voltage and frequency deviation produced by primary control.<br>• Reduce the steady state error.<br>• Provide secure operation in both grid connected and islanded mode. | • The time frame is slower than the approach to primary control.<br>• This control loop has remarkable low bandwidth characteristic |
| Tertiary Control [45] | • Control the power flow.<br>• Control a optimal operation in both mode.<br>• Account economic consideration.<br>• Reduce voltage harmonic by harmonic injection. | • This control level has remarkable low bandwidth characteristic. |

following four types of droop control are usually needed. These characteristics are: a) active power-frequency droop, b) reactive power– voltage droop, c) DC power–voltage droop, and d) Interlinking converter droop. Two types of control strategies are implemented for the proper functioning of networked microgrids: a hierarchical control strategy and a distributed control strategy.

### G. CONTROL ISSUES OF SOLAR POWERED MICROGRID

Solar photovoltaic power is a common term for electricity generated by the sun where electricity is generated from solar energy by a solar photovoltaic system. For environmental helpfulness and easy installation and control compared to other RESs, photovoltaic (PV) microgrids have generated interest. Some researchers proposed, PID and FLC control method [72], distributed virtual inertial based control algorithm [73], Robust control algorithm for power-sharing to control solar microgrid. Above all, the key elements required for controlling the PV-based microgrid are accurate PV array modeling, boost converter with maximum power point tracker (MPPT) capabilities, accurate modeling of DC-link capacitor, LCL filter design.

1. A correct formulation and circuit model is essential for a solar microgrid. PV cell consists of semiconductor material of the p-type and n-type, which reflects the nonlinear electrical feature. A single PV cell is not able to generate high voltage and load current. Combinations of PV cells are formulated in parallel and series to produce high PV voltage. Thus, optimal circuit design is necessary for a solar-based microgrid system [74].

2. According to atmospheric changes such as solar insolation and temperature, the energy produced with PV varies. Hence, the PV generator's maximum power peak (MPP) is hard to monitor. The MPPT methods with boost converters are used to locate the MPP where the controller controls the MPP. For MPPT, conventional and soft computing methods are used to find maximum power peak (MPP) for PV-based microgrids. Here, Perturb & Observe algorithm, Incremental Conductance (IC) method, Hill-Climbing (HC) algorithm are used as conventional techniques, and Fuzzy-Logic Control (FLC) method, Artificial Neural Network (ANN) method, Particle Swarm Optimization (PSO) MPPT algorithm is used as soft computing techniques [75].

3. Controlling the inverters for a photovoltaic system where controllers are essential to control the voltage, current, and

power-sharing of the solar connected microgrid. Several experiments on controller architecture for PV-based microgrid systems have been performed. Based on the microgrids operating points and function conditions, these control methods can be linear or nonlinear. Direct controller (PI, FOPI, PR, Droop control and PQ control method, Volt-Var, MIMO FLC, CFHCC, Output feedback direct quadratic controller, H-infinite, Digital MPCC, LQG) are used, and non-linear controller (PBC, PbFoSMC, Adaptive Neural Model Controller, MPC, PFL, PFLMPC, SMC, FSSMC, NBC, RNABC) are used for controlling the inverter [76], [77]. Some highly preferred controllers for solar-powered microgrid has been depicted in Table 7.

### H. CONTROL ISSUES OF WIND POWERED MICROGRID

Wind power is the energy produced by wind turbines that are installed in wind-strong areas. The wind blows through the turbine blades, mounted on a high height pole, far from barriers to the earth [78]. For frequency regulation in a wind-diesel-driven microgrid, a control system may be suggested. The sustainability and efficiency of the system are supplied electricity is a big concern for wind as critical renewable energy. Order can be operated in three modes; diesel-only mode, wind-only mode and wind-diesel mode [79].

A solution requiring the use of two separate energy storage technologies was investigated to minimize the detrimental effects induced by wind fluctuations, intermittency, or uncertainty in the system frequency and to increase the efficiency of the diesel generator. The control mechanism for incorporating various energy networks, like WTGs, DG, FW, FC, and electrolyzer into the microgrid. This system is made up of a wind turbine and a DG, supported by a fuel cell (FC) hydrogen storage as long-term energy storage and a flywheel (FW). At low demand and high wind hours, the excess energy produced will be deposited in the flywheel as kinetic energy and after water electrolysis as hydrogen gas. The flywheel supplies energy in periods of a low wind speed or increasing demand by shedding its rotor speed and the fuel cell transforms hydrogen into electricity. Thus it provides a fluent power supply to the customers [80], [81]. Some highly preferred controllers for wind-powered microgrid has been depicted in Table 8.

### I. CONTROL ISSUES OF BATTERY ENERGY STORAGE POWERED MICROGRID

In the control device and microgrid, energy storage systems (ESSs) are essential elements. Various forms of ESSs have been developed and used recently such as Battery Energy Storage Systems (BESS), Flywheel Energy Storage System (FESS), Super Capacitor (SC), Super Magnetic Energy Storage (SMES) are generally used as energy storage systems [82]. The BESS is seen in various applications as mature technologies. Many of them are used for high-performance devices, such as the SC, SMEs, and FESS that have a long lifespan and high power consumption. The ESS implementation is necessary for establishing stability in microgrids. Because of many challenges, microgrid operators need to pick the right alternative from different ESSs. Three key ESS configurations, aggregated, distributed, and hybrid, are used in island mode [82]. All the ESS modules were mounted at one position in the aggregated configuration. They were distributed throughout the microgrid region in the distributed configuration. For control of ESSs, there are three major control strategies [82]. The ESSs are generally controlled with the PQ control strategy in the grid-connected microgrid. The v/f control strategy could be applied in the islanded microgrid with aggregate ESS. For co-operation between different ESSs, the droop control strategy has been used.

1. PQ Control Strategy: The ESSs could inject power into the main grid due to economic considerations. An active and reactive Powerpoint was established in this situation. The ESSs inject or absorb power by utilizing two proportional integrated (PI) controllers. This technique is known as the PQ control strategy [83]. This control technique may monitor some DG's with a slower response, such as fuel cells.

2. V/f control strategy: In islanded mode, some of the ESSs have to take part in microgrid voltage and frequency control. In general, these ESSs serve as voltage sources. It is known as the v/f control strategy [84]. The frequency and voltage comparison setpoints are gained from a higher control level.

3. Droop control method: The droop control approach is a way to implement centralized and decentralized control techniques to MG ESSs [85]. This technique is similar to synchronous generators when the frequency and tension decrease to the active and reactive power generated. Local voltages and currents are measured and processed to establish the reference frequency and voltage. As a consequence, no contact network is needed, so the wireless approach was also named. The droop technique is modified to monitor micro sources and stabilizes the MG during load shifts. This is used in centralized and decentralized management approaches. As the measurements are local in every DG, multiple different ESS may be added in the microgrid [85].

The ESSs may be regulated locally or localized, or managed (centralized) by the MGCC. The hierarchical system may carry out two techniques described above. In other terms, the primary, secondary, and tertiary control stages will be used on the ESSs in a close manner to power systems operations. Throughout the stability dimensions of the microgrid, the droop regulation system was extended to the ESSs. One of the core problems in managing, running, and sustaining ESSs is matching SoC between separate ESS systems [82].

Some controllers preferred by the researchers for battery energy storage powered microgrid have been depicted in Table 9.

### J. FUTURE CHALLENGES OF MICROGRID

Microgrid is a system that requires continuous improvement from various perspective to cope with the changes of the technologies. In this section, we summarized some of the challenges that are required to overcome in the coming days.

**TABLE 7. Controllers applied to solar powered microgrid.**

| Control Approach | Advantages | Limitations |
|---|---|---|
| PI [76] | 1. Good performance of active power control at unity power factor<br>2. Zero steady state error under normal operating conditions<br>3. Simple control structure<br>4. Designing is easy<br>5. Low cost | 1. Reactive power control is accomplished by unity power factor<br>2. PI controller is not tackling the nonlinearities of the dynamic system<br>3. Not robust against parametric uncertainty of system<br>4. Unable to handle external disruptions |
| PR [87] | 1. Power efficiency against device resonance requirements is improved<br>2. The controller is robust with grid inductance variations<br>3. It provides full bandwidth<br>4. Outstanding damping property against resonance conditions | 1. Under the PV unit interconnections the control output is reduced<br>2. The output of the controller is highly sensitive to many operating points<br>3. The external disturbance management can not be tackled |
| Volt-Var [88] | 1. Smart inverter uses the Volt-Var controller to monitor reactive power injections and grid absorption<br>2. Improves the regulation of voltage<br>3. In transient settings, faster voltage regulation is achieved<br>4. Reactive power, capacitive and inductive effect is stated | 1. Delayed communication can affect control signals Volt-Var<br>2. The regulation of active power is not addressed<br>3. External unrest is not taken into account |
| MIMO FLC [89] | 1. Smart power control is done under different operating points of the proposed systems<br>2. Does not need dynamic system equations<br>3. It achieves efficient operation<br>4. Less complexity | 1. Input-output data trained is time consuming which can impact device efficiency<br>2. The nonlinearities of the system are partially handled<br>3. External disturbances affect controller output |
| LQG [90] | 1. Reducing steady-state tracking errors improves grid power efficiency<br>3. It increases sensitivity to noise and the decoupling effects of channels<br>4. The complexity of computations is reduced<br>5. Easy to design and implement | 1. The Kalman filter gain is very costly to measure<br>2. It is sensitive to noises<br>3. Over a large variety of operating points the controller can not operate<br>4. Nonlinear |
| PBC [77] | 1. The dynamic efficiency is improved under rapid temperature and solar insolation variations<br>2. Accurate tracking error<br>3. Good performance<br>4. Designed by considering dynamics of the system | 1. This controller cannot handle the parametric uncertainty of PV inverters, PV system, and grid model<br>2. Dynamic performance under fault conditions degrades<br>3. It cannot ensure the robust performance |
| MPC [91] | 1. Under a fixed operating point, the controller provides fast dynamic response<br>2. Having very good tracking ability<br>3. This indicates the constant frequency switching rather than the variable frequency switching | 1. The controller is very sensitive to unknown parameters<br>2. Controller efficiency degrades because of interactions between different PV units<br>3. It does not provide robust performance |
| PFL [92] | 1. Follows the procedures systemically<br>2. Under transient conditions the controller displays improved tracking performance<br>3. The controller is constructed according to the linearization methods that cancel system non-linearities | 1. Controller efficiency is highly vulnerable to grid and photovoltaic parameter variations<br>2. The controller can not manage interactions between multiple PV units<br>3. Under large operating conditions stability cannot be guaranteed |
| SMC [93] | 1. The controller is less sensitive of changes in parameters<br>2. The controller guarantees high reliability of the system<br>3. Provide robust performance against the external disturbances<br>4. Exhibits excellent convergence rate of tracking errors | 1. Presents a chattering phenomenon which can lead to instability in the controller<br>2. Complex design<br>3. Difficult to implement |
| NBC [94] | 1. It can control the active as well as reactive grid power<br>2. Simple design<br>3. The Controller can accurately track the reference signal | 1. the controller does not Provide robust performance against the external disturbances<br>2. Expertise is necessary to obtain the controller's gain parameters |
| PbFoSMC [95] | 1. The uncertainty parameters of PV inverters are modeled in the control design<br>2. Depending on the Lyapunov theory, the insight features of system behavior is evaluated<br>3. Strong robustness | 1. Accurate model is required to analyze the physical properties of the controller<br>2. Grid overcurrent cannot be handled by this controller<br>3. The controller design is complex |

**TABLE 8.** Controllers to control the wind powered microgrid.

| Control Approach | Advantages | Limitations |
|---|---|---|
| First order PI controller [96] | 1. Enhanced the power quality and stability<br>2. It can control the load smartly<br>3. It removes frequency fluctuation<br>4. Strong robustness<br>5. Easy implementation<br>6. Simple and reliable features | 1. Complex design<br>2. May creat optimization problem<br>3. It is expensive<br>4. It is applied only when wind speed exceed a rated value<br>5. Compensator is required |
| Fuzzy Logic Pitch Controller [97], [98] | 1. By increasing the pitch angle, it smooth the output power fluctuations and frequency fluctuation maintained significantly<br>2. Show robust performance<br>3. Provide stability operation during the rapid change in operating point<br>4. Can work in low wind speed<br>5. Reliable features | 1. Complx design and hard implementation<br>2. During interconnected mode it can not be activated<br>3. Start to work 20s after islanding<br>4. Output power generation is partially solved which resulted in a large output power drop |
| PID [99], [100] | 1. Maintain microgrid frequency deviation<br>2. Able to maximize wind energy<br>3. Improve system dynamic performance<br>4. Easy to implement<br>5. Simple design and feasible<br>6. Robustness against noise | 1. Not suitable for non linear plants<br>2. May cause time delay<br>3. Does not provide optimal control<br>4. Can not incorporate with slow disturbance |
| Hybrid controller [101] | 1. Control the pitch angle of an Squirrel Cage Induction generator (SCIG) based wind power microgrid.<br>2. Improve output power quality<br>3. More feasible and reliable<br>4. Good performance and it can work at low wind speed | 1. Mathmatical model is critical<br>2. Complex design<br>3. It is costly |
| ESC (Energy Capacitor System) [102] | 1. Completely remove the fluctuation of voltage flicker, frequency, active and reactive power generate by wind power fluctuation in the microgrid.<br>2. More efficient than conventional PI controller<br>3. More reliable<br>4. Used for sensitive load high quality power quality | 1. Costly<br>2. Can not activated while in interconnection mode<br>3. Complex design |
| FTSC [103] | 1. Fault Tolerance supervisory controller can fulfill the power demand<br>2. Low cost and provide reliable service<br>3. Provide robust performance against various uncertainties | 1. Can effect maximum available power<br>2. May cause lubricant system failure<br>3. May cause converter fault |
| FOPID (Fractional order PID controller) [104] | 1. It can provide dynamic system stability<br>2. It can control the reactive power management<br>3. More feasible for the system dynamics<br>4. Robust<br>5. Less overshoot and less setting time | 1. The controller can not always provide a better response<br>2. The controller is non linear in nature |
| dsPIC 30F4011 (MPPT controller) [105] | 1. Circuit simplicity<br>2. Simple control algorithm<br>3. Improved reliability in wind generation<br>4. Continiously monitor the microgrid current<br>5. Independently of the machine and wind turbine parameter | 1. Under external disturbances the controller can not perform |
| MGCC (Microgrid Central Controller) [11] | 1. Higher smpling rate<br>2. Good accuracy<br>3. It can improve the transient system dynamics<br>4. Simple design | 1. May increase initial cost<br>2. Protection of this controller is challenging |

**TABLE 9.** Controllers to control the battery energy storage powered microgrid.

| Control Approach | Advantages | Limitations |
|---|---|---|
| Fuzzy Logic controller [106] | 1. It is based on linguistic model<br>2. It uses very simple mathematics to nonlinear integrated complex system<br>3. It has high precision and provides rapid operation<br>4. Flexible, low cost, easy implementation | 1. It has lack of real time response<br>2. It has lower speed which may cause time delay<br>3. It is not very sensitive to variations of system structure, parameters and operation points<br>4. It requires more fuzzy grade for good accuracy |
| Fuzzy PID controller [107] | 1. Used to maintain constant voltage and frequency of ESS<br>2. It improves the performance of frequency control of energy storage<br>3. Simple design<br>4. Easy implementation | 1. It is not so sensitive with the variation of system structure, parametre and operating points<br>2. Non linear in nature<br>3. Optimization task is very difficult because many parameters that have to tuned.<br>4. Non optimization fuzzy logic controller can not assured good performance when fuzzy logic controller is working alone. |
| Fuzzy fractional order PID Controller (FFOPID) [108] | 1. It improves frequency deviation and transient stability<br>2. It shows robust performance<br>3. Fast response<br>4. Support internal bus voltage in both mode of MGs in accordance with failure time | 1. Complex design and hard implementation<br>2. Overloading problem and state of charge (SOC)<br>3. May cause error when sudden change in loading condition during islanded mode |
| Droop control and PQ control method [109] | 1. Using an artificial colony system, the parameters of the proposed controller are optimized.<br>2. For the proposed configuration both island and grid mode are considered.<br>3. The power sharing among the sources is achieved under load variations using droop method<br>4. PQ control action enhances the active and reactive power of the grid<br>5. No communication among sources is required | 1. Under solar irradiation and load variations, the controller's effectiveness is not measured.<br>2. It provides slow convergence speed for tracking errors<br>3. Not robust against the external noises and model uncertainties |
| DC-Bus Voltage controller [110] | 1. Improve voltage stability<br>2. Provide robust performance<br>3. It does not affact the output power sharing of DC source<br>4. Improve the stady state performance | 1. During transient state, some voltage oscillaion may appear, which depends on the controller gain.<br>2. Mathmatical model is critical<br>3. Complex design<br>4. Costly |
| Optimized fuzzy cuckoo controller [111] | 1. It can determine the reference power of each unit combining the data of voltage and current from network lines<br>2. Maintain the uncertainty of system structure and show robust performance and also manage the change between production and consumption<br>3. Easy implimentation<br>4. Control the voltage amd frequency and show good efficiency | 1. Slow response<br>2. Complex calculation and long process<br>3. Complex design because fuzzy controller and cockoo optimization algorithm are merged |
| Online intelligent BESS based controller [112] | 1. Improve power quality<br>2. Enhanced the stability of MG system<br>3. Provide robust performance against various uncertainties<br>4. Reliable service and simple and effective<br>5. It is based on hybrid DEO and artificial neural network (ANN) | 1. It may influenced by unknown low level disturbance<br>2. Difficult to handle critical disturbance of microgrid |
| BOA optimized PFOID controller [113] | 1. Used for controlling the dynamic response<br>2. It can manage frequency deviation<br>3. Simple and reliable<br>4. Easy implementation<br>5. It preserves system ability | 1. The external disturbance can not be tackled by this controller |

For example, the distribution level of the microgrid is at risk of over-voltages. This is due to the production at distant areas, unsafe protection equipment, and uncontrolled islanding. The overload of feeders and transformers due to high output volumes at low demand periods increases the risk of over-voltages. Power balancing may be hampered due to the high penetration of EVs and other load types. The overwhelming array of data and management challenges could make situations for the energy market even more complicated. It will affect potential microgrids to preserve the flexibility of the whole system, voltage stability, optimal load flow, harmonics, adequacy of fault currents, demand management, and storage issues for protection and equipment configuration [86]. The use of modern control from different aspects is undoubtedly a possible solution to meet the challenges mentioned above.

## IV. SMART GRID - HOW IT DIFFERS FROM TRADITIONAL GRID?

The smart grid idea consolidates various advancements, end-client arrangements and addresses different approaches and administrative drivers. The name smart grid was first used by Michael T. Burr [114]. The adaptive electric grid is known as the intelligent grid. It senses local changes when power is applied and automatically responds without human desideratum. The smart grid is developed utilizing modern digital communication technologies. Grid communicates with a cellular tower to push vital parameters such as instantaneous power utilization, cumulative power utilization, maximum demand etc. A microgrid can also be a smart grid [115]. Albeit, the smart grid is considered a smart microgrid (utility grid). The user can be remotely connected or unconnected. Services need not go to the houses or industries of customers to access the energy needed to pay bills. Smart meters transmit billing data directly to the control unit, which can generate statements. Meter readers won't arrive every month at the houses to register the reading. So, in the smart grid scheme, there are many options for the user. Smart grid reduces losses of power (transmission, distribution) and prevents the abuse of resources. It lowers the cost of electricity, reading meters and so on. Due to automatic operation, it eliminates equipment failures based on varying load conditions. Smart grid decreases long-term outages and the associated reconstruction costs. Smart grid helps to maintain the green environment. The use of oil and extensive blackouts is minimized. Consequently, the smart grid provides people with continuous power protection. Through advertisement infrastructure, the smart grid can meet rising customer demand. A smart grid would also provide a more reliable future solution for power generation. The power sector should be able to control its infrastructure better, tackle more expensive power outages, and give its customers competitive pricing options [116]. Smart grid and microgrid generally operate in two modes. First one is grid-connected way, where all the distributary are connected to the utility grid and the second one is island mode. Island mode is activated when load shedding or accidental disconnection from the primary grid. Control and technical challenges are the momentous part of the smart grid [117]. The general concept of smart grid technology is almost similar to almost all countries. Still, some researchers have shown that the control policy and the operational process vary from different regions [118]. The research trends of the smart grid in the last five years (2016 to August 2020) in terms of their keywords are shown in Fig. 5.

### A. TRADITIONAL GRID VS SMART GRID

Traditional energy infrastructure is electro-mechanical, indicating that it belongs to, relates to, or denotes a mechanical device powered electrically. Power can be distributed only through conventional energy infrastructure from the main plant [119]. The system is not capable of managing a large number of sensors. The location of an issue is difficult to locate and can cause more extended downtimes. Technicians must physically go to a place where the maintenance of the traditional energy system is not carried out. It needs to extend the time it takes to break out. Therefore, the traditional energy system is not customer-friendly. The conventional energy system is vulnerable to failures due to aging and constraints. Electricity is complicated to manage with conventional power infrastructure. Customers are not correctly fitted with the traditional grid systems infrastructure to allow them to choose the way they get their electricity. There have been some variations summarized in Table 10 between the smart grid and the traditional grid.

**TABLE 10.** Differences between the traditional grid and the smart grid [120], [121].

| Traditional grid | Smart grid |
|---|---|
| Electro-mechanical. | Digital technology. |
| One-Way Distribution. | Two-Way Distribution. |
| The power is generated from a central location with the existing energy infrastructure. | Power supplied from several plants and substations. |
| The network isn't equipped to handle many on-line sensors. | Transmission lines are equipped with many sensors. |
| Manual. | Self-Healing. |
| Not sufficiently designed to enable consumers to select their electricity. | Infrastructure can be shared using intelligent technologies. |
| No relation with customers. | Customer friendly. |

### B. COMPONENTS OF SMART GRID

#### 1) SMART POWER GENERATION

To minimize the generating costs while satisfying the energy demand of customers and loading plants, smart power generation is connected to the market and automatic generation control (AGC) [122]. For many years, the AGC has been used to manage production and load changes by sharing necessary power between generators. Integration of the new grid with the smart grid from various renewable resources would undoubtedly entail the greater use of computer modeling and IT. Therefore, the impact of the smart grid on traditional generation, DGs from different renewable resources are also being introduced. The distribution side of the grid can be connected to PV, WT, EV, FC and other outputs in every section of the network [123].

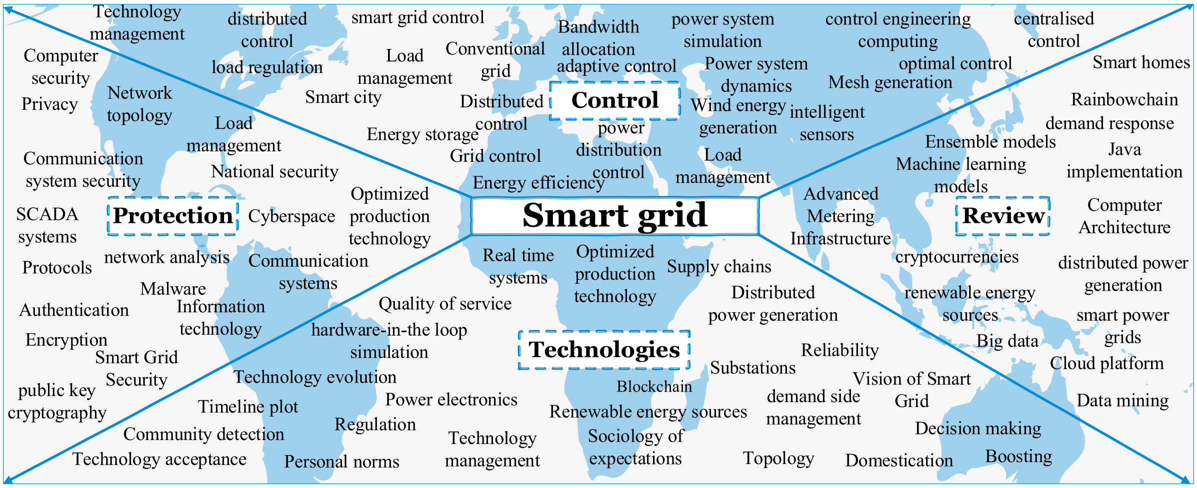

**FIGURE 5.** Keywords used in research article of smart grid from (2016 - August 2020).

### 2) TRANSMISSION SYSTEMS

Sensors and measuring devices are installed to provide monitoring and control of the smart grid to optimal use while protecting the transmission system from overload. FACTS (Flexible AC Transmission System) can also be introduced to raise the system's output quality, reliability, and stability by microprocessor-based controllers and power-electronics. The smart transmission systems can also incorporate self-awareness and self-healing to redirect power flows or lower the loads at default sites to avoid health threats or possible failure in unexpected conditions [124].

### 3) SMART SUBSTATIONS

The transmission lines transmit electric power to the substations. Switching plants are also available between big plants to raise the voltage to transmission levels and insulate the magnet [125]. Switch-yards also dispatch power to various parts of the network. The voltage is lowered for delivery over smaller networks at a lower tension in the middle of transmission and distribution systems [126].

### 4) SMART DISTRIBUTION SYSTEM

The distribution system involves a network of feeders from the substation to the customer [127]. Installation of the smart meters is the first upgrade for the distribution system. In a variety of ways, the intelligent delivery system can be used. It can be made up of microgrids. Automation distributed generation is two additional elements of the implementation of the smart grid [128]. Automation distributed consists of observation, control, and communication. This network is used to keep an eye on switches and additional types of equipment over the entire grid to restore areas of trouble, prevent more failures and reduce losses. Distributed generation is accomplished by interconnecting generators from various resources distributed all over the network that injects power into the system. Customers will have a wide variety of options in the production of electricity for both local and for export to the grid with the introduction of PV, EV, FC, independent generators, individual wind turbines, biological fuel turbines, and other types of local energy generation [129].

### 5) SENSING AND CONTROLLING DEVICES

Measuring units like high-speed sensors known as PMU's can be used in their networks to track and in some cases, automatically respond to the power quality. Phasors are the waveforms of alternating current, preferably the same everywhere on the network in real-time and in keeping with the most suitable shape. Research shows that auto systems can transfigure the governance of the power system by quickly and dynamically make a response to system conditions by a large number of PMUs and by comparing the various types of current network readings [130].

### 6) SMART METER

Smart meters provide electrical power, metering, and billing network contact in one or two ways. The measuring data, re-enlistment, and information for the automatic response to demand and self-healing change can be shared as appropriate. A smart grid combines analog mechanical meters with real-time digital meters. The advanced metering network meter is similar to smart meters and provides a communication route from the grid by smart devices. Such machines can be shut down in periods of high demand by the consumer [131].

### 7) COMMUNICATION SYSTEMS

The communication network is the supreme element of the smart grid. By incorporating advanced technology and applications for a more intelligent electricity supply network infrastructure, a vast amount of data is created for further research, control and real-time pricing methods from various forms [132]. Therefore, the concept of communications requires and the best communications network is essential for the electric utility to manage production data and provide a reliable, efficient, and economical service across the grid. For the transmission of data between smart meters and electrical utilities, various communications technologies are sponsored by two significant communications media, cable and radio. The communication among the smart devices like smart meters, utility data center, customers smart devices can be cellular technology or wireless communication like ZigBee, 6LowPAN, Z-wave etc [133].

#### 8) DYNAMIC PRICING

Electricity providers can offer customers innovation pricing forms commonly called dynamic pricing using detailed, real-time information [134]. Instead of merely paying the same price for each consuming unit of energy, dynamic pricing provides consumers lower prices when delivering power is more economical than usual and higher rates at peak hours, when the electricity is more competitive. By moving consumption from higher-priced periods to lower-price hours or by complete retention, customers may reduce their electricity bill through this information.

#### 9) SMART HOME

A core element of the smart grid project is the home network. The ultimate goal of the demand response is to bring down the load over peak periods [135]. Smart home appliances include heaters, air conditioning systems, washing machines, dryers, and others. The AC unit temperature will increase by several degrees in response to demand. It will have a massive effect across the whole grid on the number and output rates of the generators that must be online [136].

#### 10) SECURITY

For power utilities, particularly billing and grid control, secure data storage and transportation are exceptionally essential. Efficient security frameworks and standardization of the power grid protection measures should be established to prevent cyber attacks [137].

### C. CONTROL REQUIREMENTS OF SMART GRID

Nowadays, smart grids with their interconnected, dynamic, and communicative infrastructure are realistic [64]. Some problems arise during the implantation of a smart grid. Power fluctuations, voltage unbalance, frequency mismatch, transition management are the most common challenges. Power variations arise from the irregular activity of renewable energy sources. DG re-connection and disconnection from the main grid lead to an unbalance in the voltage profile. Small voltage decreases may cause partial voltage instability during heavy loading conditions [138]. The voltage regulation system needs to be strengthened in the context of new problems such as the large-scale deployment of wind/solar power. To account for these problems control sections are discussed in this paper. Control deals with the difficulty of centralized energy networks with dynamically interconnected and communicative design [139].

To increase the stability, performance, economics of the energy supplied, smart grid control is needed to solve possible problems related to the power supply, voltage control, frequency regulation, and harmonic compensation [140]. It makes for implementations on smart grids. Advanced control methods allow a renewable generation to participate quickly. Smart grid control is needed to handle scheduling, dispatch optimization, dynamic segmentation feeder, analysis of interconnection and microgrid activities, and other services. The efficiency, stability, and efficiency of electric power need to be strengthened. This is important to allow the smart grid to manage problems on real-time data in the power network and computation. The microgrid which is attached to the smart grid needs to be controlled for the following reasons [141]:

- Controlling the output voltages and currents to monitor their reference values at various DER systems.
- Maintaining the variations in frequency and voltage within the healthy ranges.
- Improving efficiency by the use of cost-effective DSM approaches and robust load controls.
- Growing the benefits and reducing running costs and emissions by dispatching DER units accordingly, and finally.
- Ensuring a seamless transition between operating modes by the use of an effective detection algorithm for the islanding phase.

### D. CONTROL OF SMART GRID

Renewable energy incorporation into power grids includes network adaptation and electricity system maintenance. Intermittent, non-controllable and the need to maintain the production or consumption balance on the local grid is a problem for the owners of the delivery system. It would entail an adaptation of the electricity system operation. To integrate renewable energy into the electricity network, networks should be managed more responsively using smart grid technology. These solutions provide other network security tools and applications more reliable. Emerging information and communication technologies may also be involved in the maximization of power flows [142].

A smart grid can handle the intermittency of renewable energy better by improving observability, predictability, steering, and versatility [143]. It is essential to track the network state at all times to improve observability, predict accidents and promote decision-making to automate the network. To strength the incorporation of automated output into the networks while maintaining system reliability and efficiency, control and management mechanisms have been placed. The goal is to engage with unified production through the implementation of automation functions [144].

Smart grid technologies would allow network flexibility to be built and thus the erratic nature and volatility of renewable energy to be handled [145]. Smart control of the power system includes sensors, actuators, communications, computing devices, user interfaces, and other technological devices. Measurement is essential for control. So that, sensor and instrumentation are necessary. The smart meter is for an automated meter reading. Phasor measurement units (PMUs) are significant measurement development in the power system. Home automation devices, uniquely connected thermostats, can report temperature and other information to cloud platforms [146].

Table 11 summarizes the functions and limitations of different control methods of the smart grid.

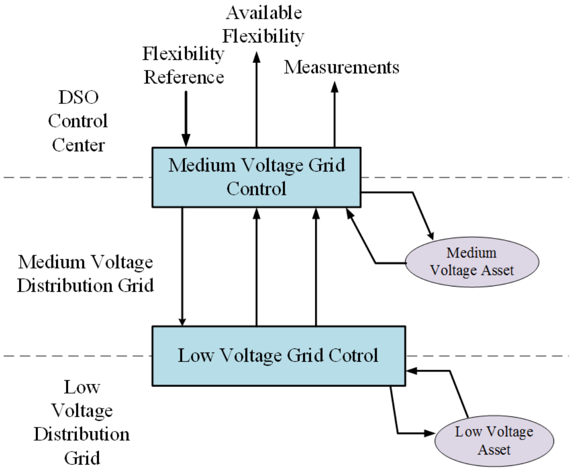

**FIGURE 6.** **Hierarchical control structure of smart grid control.**

### 1) HIERARCHICAL CONTROL STRUCTURE

A typical distribution grid consists of hundreds of primary substations, with hundreds of consumers, each with thousands of secondary substations. Steps must be taken to improve the control system to achieve a controllable and manageable system.

A hierarchical structure with two layers is shown in Fig. 6. [147]. Every layer has a corresponding controller and an asset list. The MVGC (Medium Voltage Grid Controller) receives a power setpoint from a higher hierarchical layer and returns measures of grid values and proper functionality in terms of interfaces.

Afterward, the MVGC tracks its assets as stated. It is worth noting that this system also serves as a versatile device for the MVGC with the Low Voltage Grid Controller (VGC). Likewise, LVGC manages its properties in compliance with the concept provided by the MVGC and returns information, e.g. on versatility to the MVGC. The controller for the low voltage grid controls the use of resources within the small voltage grid. Batteries, photovoltaics, electricity, and households compose these properties. The medium-voltage controller operates in the balance of energy and eliminates losses.

### 2) HYBRID CONTROL

With a certain degree of topology, operation and versatility, the grid is being made intelligent by incorporating sensing and communication technologies. Optimum performance in steady and transient operating modes can be reached using hybrid control technology [138]. The hybrid control uses continuous and discrete signaling from all power sources and switches between them. The network utilizes this information for effective power flow in both on and off-grid modes. With low power fluctuation, load delivery can be achieved effectively and reliably by using different source combinations [148].

By building finite hybrid automation (HA) for service in stable and transitional conditions, a multi-source load gird hybrid regulation can be created. This is a state machine where a state is calculated by an evaluation of a series of variables and the state changes either immediately or along a pre-determined period over a time frame [149].

In addition to grid-connected and insulated configuration, multiple configurations of source-loads are feasible at the subsystem level for an adequate and secure power supply.

### 3) HARMONIC MITIGATION AND DROOP CONTROL

During the operation of the smart grid, harmonic current from load may be produced which creates harmonic waves. The harmonic waveform is a disturbance of the normal sinusoidal wave. It is characterized by its level of distortion, voltage distortion, increase in the apparent power and over-sizing of sources, the flow of current in the neutral conductor are some bad effects of harmonic waves. Advanced distributed control strategies of power flow and power exchange features have been developed for this purpose [138].

A distributed framework can be controlled without the use of communication. It can only be done at the expense of allowing for a minor mistake. Therefore, these methods are generally referred to as droop control methods. The droop control system is based on locally calculated data, does not rely on the contact signal, and thus avoids the difficulties caused by the physical location. The droop method has other benefits, such as high flexibility, high efficiency, easy structure, ease of execution, free interface, and different power ratings [150].

### 4) VOLTAGE AND FREQUENCY CONTROL

Modern power grids involve high-speed data processing by different control components in centralized control methods. The power control method of preference relates to the interdependence of microgrid components. In load frequency regulation, microgrid operation can use some ways to regulate voltage and frequency due to the unbalance of the load. In the decentralized process, control modules are implemented separately on active and reactive power. This also has a significant effect in changing the power balance and incorporating the framework for frequency recovery [151].

### 5) DISTRIBUTION MANAGEMENT SYSTEM (DMS)

The distribution of power is handled by the distribution management system (DMS), which provides a higher level of monitoring, control, and management of the entire power network. Implementing an intelligent metering program offers

**TABLE 11. Comparison of different control methods applied to smart grid.**

| Control Method | Advantages | Limitations |
|---|---|---|
| Hierarchical Control Structure [153] | • Each Layer has a corresponding controller and asset collection.<br>• This system also acts as a multi-faceted LVGC, MVGC device.<br>• The medium-tension controller works in the energy balance and eliminates losses. | • The control mechanism needs to follow the physical restrictions on e.g. grid cables. |
| Harmonic Mitigation and Droop Control [138] | • Used to control voltage or frequency, and PQ.<br>• Harmonic approaches to mitigation act as a resistance against harmonic frequencies.<br>• For proper power-sharing the inverter frequency and voltage amplitude are tuned in droop control. | • The voltage frequency and magnitude is dependent on the droop controlled voltage source inverter. |
| Hybrid Control [138] | • This control system is used to achieve optimum steady-state output and intermittent operating modes.<br>• Hybrid control integrates and distinguishes between continuous and discrete inputs from both power sources, and utilizes this information in both on-grid and off-grid environments for optimum power distribution. | • The temporary consistency utilizing change management and supervisory control is one of the main technological difficulties in the application of hybrid control systems. |
| Voltage and Frequency Control [154] | • Used for both centralized and distributed control.<br>• Used for controlling voltage and frequency.<br>• Control modules are configured independently on the active and reactive capacity. | • To achieve this, the appropriate device response requires high speed data processing across various control components. |
| Distribution management and operation [138], [152] | • Used for quality, reliability and economic success in distributed generation systems. | • This distributed management approach would need specialized control functionalities to further improve the functionality of the delivery network. |

contact capabilities for all devices. For both planning and operation, the wide-scale introduction of distributed generation into distribution grids requires significant changes in network automation [152]. It is compatible with the shared vision under the general smart grid paradigm for future distribution systems. It will further enhance the functioning of the distribution network by introducing advanced control functions [138].

### E. DEMAND-SIDE MANAGEMENT

The two forms of power system management are supply-side management (SSM) and demand-side management (DSM). Both approaches are effective in reducing peak loads, increasing network loading capacity, and reducing the likelihood of disasters. The objective of supply-side management is to improve the efficiency of electricity generation, transmission, and distribution. As energy demand grows faster than power system growth, demand-side management becomes more advantageous than supply-side management [155]. Demand-side management (DSM) is a group of methods targeted at optimizing the demand side of the energy system. It can range from improving energy efficiency with improved materials to smart energy pricing that rewards certain consumption patterns to sophisticated real-time control of distributed energy supply [156].

Demand-side management is also necessary for improving energy power system market performance and decreasing environmental damage [157]. The aim for the future smart grid is to integrate a growing number of storage devices in distribution grids for better balancing between demand and supply. The growing integration of distributed energy resources (DERs) into distribution networks, such as battery energy storage systems (BESS), electric vehicles (EVs), solar generation and so on, have been created new challenges [156]. The use of smart metering devices in the automated metering infrastructure enables smart pricing, which is a characteristic of the smart grid. Real-time punishment and reward systems at all levels of the supply chain will affect consumer energy usage control when smart pricing is coupled with demand-side management [158]. Methods of DSM that are widely used: [159].

(a) Peak clipping. (b) Valley filling. (c) Strategic conservation. (d) Strategic load growth. (e) Load shifting. (f) Flexible modeling.

Peak clipping is the practice of reducing load or demand during periods of high demand. Valley filling encourages energy use during off-peak hours when production costs are lower than during peak hours. Strategic conservation reduces seasonal energy use, largely through reducing energy waste, to improve energy consumption efficiency. The rise in seasonal energy demand is managed through strategic load growth. Load shifting is the process of moving a portion of demand from peak periods to off-peak times. Flexible modeling is a set of actions carried out by a shared plan between the customer and the concessionaire and in response to the current demand.

DSM may be classified into the following categories based on the time and impact of the implemented measures on the customer process: [156].

(a) Energy Efficiency (EE). (b) Time of Use (TOU). (c) Demand Response (DR). (d) Spinning Reserve (SR).

At present understanding the activities is the first step for improving the energy efficiency of buildings or industrial facilities. If the operation of the equipment necessitates consumption-driven changes, an energy controller may be used. Demand response comes in a variety of forms and all of them provide a substantially quicker response. Distributed spinning reserve tries to help them by imitating the behavior of traditional auxiliary service providers. The need for information on the daily behavior of loads in the electrical system, which is typically not accessible from systems based on standard electromechanical meters, is the major obstacle in implementing a DSM program [157].

### *F. CYBER SECURITY OF SMART GRID*

Protection is the leading concern in smart grid systems [160]. In recent years, the energy grid has been faced with many cyber-related attacks that highlighted the question of security vulnerabilities and their broad-scale effects on vital power system infrastructure [161], [162]. The smart grid system is connected to the internet. However, the internet uses cyber insecurity. The smart grid uses wifi, TCP or IP, and other operating systems as opposed to the first power network, rendering the infrastructure more vulnerable to attack. The intelligent grid will improve power system efficiency, but it is now a problematic challenge to secure the grid. When the system has been breached, the intruder will monitor the system's load balance several meters or interrupt it [163]. The infrastructure for smart grids must be safe from significant risks or attacks. Hackers, cyber threats, and organized gangs, some of them criminals, industry players, carefree or under-educated employees will target the smart grid. The system's reckless running of the processes by the improperly skilled staff may make the whole network vulnerable to security threats, such as a group of hackers, cyber attackers, individual criminals, or organized criminals. As this equipment is connected through the whole infrastructure, the entire infrastructure is inevitably exposed to severe attacks if one part of the network is breached, which can result in complete loss or collapse of the device. Cybersecurity must also be sufficiently good to make the device operate seamlessly and efficiently. Cyber defense is also one of the most complicated issues of the smart grid that develops. Cyber defense measures must be implemented in both essential and insecure points and interfaces of a full-scale network to guarantee the whole intelligent network connectivity system is safe from cyber-attacks [164]. Until recently, new infrastructure and appliances of communication were generally considered as promoting the stability of the power sector. Improved connectivity is becoming increasingly important in computer power network defense. The information protection of the energy sector generally encompasses both IT and communication devices that influence the operation of power supply networks and utility management. In specific, power grid safe avoids, plans to defend, and eliminates ornamental hazards from accidental cyber incidents [165]. The general architecture of the smart grid with a cyber layer and security threats is shown in Fig. 7.

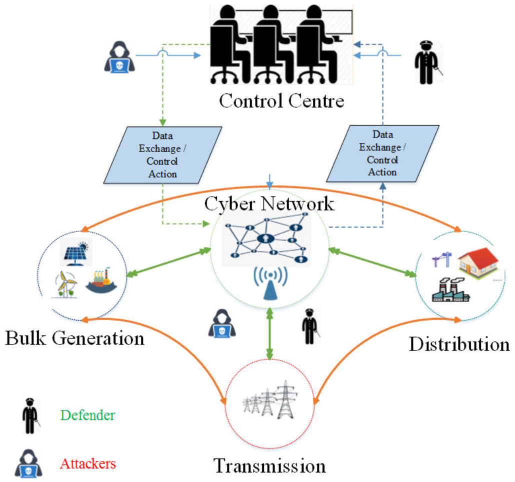

**FIGURE 7. Smart grid architecture: cyber layer and security threats.**

### 1) REQUIREMENTS OF CYBER SECURITY

The NIST study also suggests broad smart grid security requirements, including cyber and physical protection [166]. Specifically, the information security section outlines specific security threats and specifications relating to network infrastructure which describes the public safety division criteria for protective facilities and protection of the environment.

1. Attack detection: The smart grid features a transparent contact network spanning broad geographical areas as opposed to conventional power grids. Therefore, every component or node of the smart grid can also be assured that it will become active in network attacks. The communications network will also regularly track network traffic status for monitoring, checking and evaluation, to detect and recognize anomalous attacks. In fact, in the face of threats, the network must also have the potential to self-heal. Since the stability activities of power infrastructures are vital to sustainable systems [167].

2. Identifying, authenticating, and access control: Millions of mobile devices and applications are used in the smart grid network system. Identification and authentication is the primary mechanism to validate computer or user identity as the requirement for having access to smart grid services. Access

management aims to ensure that services are obtained only by the right workers. Regulation of access to classified information and the protection of essential resources must be implemented to deter unauthorized users. Any smart grid node needs to be at least cryptographically stable to meet these criteria to perform data encryption and authentication, such as symmetry and asymmetric cryptography primitives [167].

3. Secure and efficient communication protocols: The delivery of messages needs time-critical and safety as opposed to traditional networks. However, the two goals generally go against one another. As smart grid networks may not always physically secured and high-speed transmission canals are required in developing connectivity protocols and architectures for the smart grid to balance transmission efficiency and information security [167].

### 2) CYBER SYSTEM VULNERABILITIES

The smart grid provides a wide variety of flaws because the network is comprehensive. Demand could be diminished as utilities triggered by cyber threats are not available. The smart grid network replaces the existing power network with advanced functionality, making it more flexible and vulnerable to different forms of threats [162]. As mentioned, smart grids have the most significant vulnerabilities:

1. Consumer awareness: A practical and comprehensive defense framework for smart grids with all the core features required to identify and track threats involves an intensive investigation that may not be achievable for the service alone. Therefore, because of the need for improved protection and help for the utilities both themselves and society, consumers need to be fully aware of the dangers, costs, and advantages of our services [160].

2. The Large number of points of access: The smart grid consists of multiple tools used to monitor the flow of electricity and the need for a network. Such various tools provide attackers with broad access. The control of too many computers is often a challenging job [160].

3. Young and unknown technologies: The smart grid is applied to a vast range of emerging innovations that can be visible to hackers and adversaries since the limitations and safety requirements of these systems have not yet been known. Therefore, it will be straightforward to locate a loophole to bypass the faults [160].

4. Lack of standards and regulations: The interoperability of the smart grid ensures that various systems can work together, share devices or data, and use a harmonious component to execute a function. Standards and regulations shall protect each section of the smart grid to ensure interoperability. It is also worth noting that the constant publishing of new protocols often contributes to a lack of security [160].

5. Dissimilarity between teams: Various teams work in smart grids in sensitive areas. The lack of consistency and coordination between teams results in errors and leaves device protection with loopholes [160].

6. Use of internet protocol(IP), hardware, and software: IP provides the bonus of making computer compliant. However, IP may be vulnerable to a range of cyber threats, such as DoS or spoofing [160].

### 3) POSSIBLE THREATS AND THEIR CATEGORIES

The detection of new vulnerabilities is of considerable importance with a variety of destructive cyber threats on the networks. Any intruder can have different reasons for the vulnerabilities mentioned in the previous section and affect network protection. External or internal to the system may be an intruder. This section outlines the framework for risk management and provides the basis for the use of potential entry points vulnerable to malicious attacks. It has also been pointed out how such attacks allow a competitor to take inappropriate action and thereby affect the entire smart grid network.

1. Man-in-the-middle(MITM) attack: This method helps the opponents to make separate contacts with dangerous communications at all endpoints and to communicate intermediate details. Therefore, it allowed users at endpoints to believe that they speak to each other directly via their contact. The MITM attacks are typically used to use manipulated information, including control orders, calculation values, and they are often used to take advantage of essential parts of the network for coming attacks [162].

2. Distributed service denial of attack (DDoS): Many bugs in the WAN require the PMU communication network to be accessed. It is possible to mount the malware in the router in the replacement station or to enter the contact network by supposing the default system password. A DoS assault is attempting to inaccessible an essential resource in a sufficient quantity to its registered users [168]. All communication canals must be accessible in the power system as much as possible, particularly when a significant control action is needed when the power system closes to the point of instability. The stability of the global power grid, if the DoS attack in this case works, is in question [162], [169].

3. Terrorists: Intelligent networks try to cut off or get valuable information [160].

4. False data injection attack: A good-designed kind of credibility attack, can affect the function and control of smart grid by state calculation of the poor detection systems [170], [171]. Compressed sensors can mimic events that do not exist. A particular meter may be injected with malicious information to interrupt the state variables. The last attack is more reliable because the attacker understands the topology of the network well and induces predefined modifications of the status variables. When vital meter shave is impaired, the detection of malicious attacks would be more difficult. Some traditional techniques protecting some critical sensors in the electricity system can relieve the injection of false data [162].

5. Unauthorized access: Intruders have unauthorized access to the network because the client does not have a security framework for checking login authentication. Unauthorized access can take advantage of network services and it is hard to detect that the authentication is not stable [160].

#### 4) POSSIBLE SOLUTIONS OF CYBER ATTACKS

1. Cryptography: We need to protect data with encryption to achieve information protection. Cryptographic rudimentary methods are effective anti-attack steps [163]. Encryption and authentication procedures are important to maintain the security of and secrecy of the data in the smart grid [172]. However, cryptographic preventive steps to the smart grid include these cryptographic techniques and also the use of a range of key management schemes. Core control is yet another important mechanism to ensure the secure operation of the intelligent system [167].

2. Privacy: Unable to establish protection. The basic concept of privacy is "the right to be left alone." Privacy concerns should be discussed in the light of generated user data produced in measuring devices. Comprehensive analysis is given on purchase data to obtain insight into the actions of a consumer. The protection of information should not be mistaken. Data secrecy is data that only a few can handle. The smart grid protection ensures that consumers' rights, beliefs, and desires (such as their knowledge, electrical signatures, etc) are taken into account. A PIA is used as a method to assess the identity and safety implications of gathering, storing, and transmitting sensitive data [124].

3. Authorization: Authorization also is known as access management, aims at stopping individuals or devices from entering the network without permission. The authorization applies more generally to the process that differentiates legitimate from unauthorized users for all other security reasons, e.g. secrecy, honesty, and so on. It refers to limiting the right to permit the control system of the factory, in the broader sense of access control. Breach of the license can trigger security problems [124].

4. Third-party protection: The defense to third parties applies to an avoidance, by contact mechanisms, to harm to third parties, but may not include the health risks of the controlled facility itself. An adequately targeted automation system may be used to target multiple communication processes [169]. This system may be exploited. The implications range from a weakened smart grid network owner's image to civil responsibility for third-party losses. Other security goals, in particular authorization or access control, provide the concern for third parties from potential plant security-related vulnerabilities resulting from attacks against the plant automation network [124].

5. Logging and monitoring: In the field of signal processing, insightful work has been carried out mingling conventional data mining techniques, with the multi-resolution study of transform wavelets. Recording with tracking provides evidence for the detection of threats or for reconstructing incidents in the case of natural calamities. The data security log analysis can detect a more significant number of risks on a specific time scale [172]. A summary of cyber-security threats and solutions of the smart grid are listed in Table 12.

**TABLE 12.** **Summary of cyber security threats and solution of smart grid.**

| Possible Threats | Possible Solutions |
|---|---|
| • *Integrity Attacks:* 1. Data injection attack 2. Man in middle attack<br>• *Availability attack:* 1. DDos attack<br>• *Dynamic System Attack:* 1. Reply attack 2. Malware uses 3. Unauthorized access 3. Covert attack<br>• *Physical Attacks:* 1. Physical damage 2. Metre manipulation 3. Terrorist | • *Prevention:* 1. Vulnerability assessment and risk analysis 2. Security reinforcement<br>• *Protection:* 1. Cryptography 2. Privacy 3. Authorization<br>• *Detection:* 1. Logging and monitoring 2. Update compromised components |

### G. FUTURE CHALLENGES OF SMART GRID

The concept of the smart grid has been facing deployment challenges since from the inception. These challenges are related to emerging technology adaptation, socio-economic issues, lack of policy, and awareness [173]. There is a gap in the smart grid between the structure of the resource application and market demand, the actual transmission structure is insufficient and there is limited power for future development, which are also factors that limit the further development of the smart grid [174]. Due to the diversity of the components and the contexts in which smart grids are deployed, the challenges of ensuring cybersecurity in a smart grid are diverse. Insufficient security measures can also compromise the reliability of the grid [175]. Solid ultra-high voltage (UHV) power grid planning and development would be a challenge for the future smart grid. The incorporation of large-scale thermal electricity, hydropower, and nuclear power bases into the power grid and the integration of large-scale clean energy sources into the power grid would be some of the key obstacles facing future smart grids. Distributed generation and organized production of multi-voltage grids to boost the controllability of the power grid centered on power electronics technologies may also be challenges for potential smart grid implementation. Security analysis of the power system, rapid modeling, smart decision-making, and robust safety technology could be challenges for the smart grid in the future. High traffic issues on the transmission networks would be a concern for the smart grid communication system. The use of the two-way communication capacity for improved connectivity between customers and utility [176] is another obstacle. The extraction from the calculated signals of the critical characteristics and their effective accumulation remains unresolved and requires further investigation. The development of intelligent management systems capable of combining many functionalities, controlled in an automated and effective manner, would be the greatest challenge in the future [177]. Nevertheless, the prospect of control cannot be hide to meet up the future challenges of the smart grid.

## V. VIRTUAL POWER PLANT - BOUNDARIES WITH MICROGRID

Virtual power plant (VPP) is a transformed form of microgrid with the blessing of modern communication systems and intelligence technology. For certain microgrids, the operators must contend with DERs issue [178]. Otherwise, green resources would instead be thrown away instead of used. The latest approach for reducing the harmful impacts of DERs is by turning microgrid into VPP [179]. As a single administrator, VPP integrates all DERs to incorporate them into the grid without losing network efficiency and resilience, providing numerous new advantages and incentives for customers, prosumers and grid operators [179]. VPP is a software-based, intelligent grid-based network for sending and optimizing distributed energy resources (DERs) remotely and automatically. VPP provides a group of dispersed generator units, loads, and storage systems, which are indexed for operation as a single power plant. It is still in the hypothesis stage, and there is no uniquely defined VPP framework [180]. It is equivalent to an autonomous microgrid. It sums up the capacity of many different DERs. The EMS and the availability of products play a crucial role in fully exploiting the potential of the VPP. A combination of parameters produces a single operating profile of VPP that defines the individual DERs and may include the effect on the overall DERs output of the network. VPP can be used to render wholesale contracts to supply the machine operator with services. Fossil and green energy sources can be used by the generators. The center of a VPP is used for controlling power flow, load, and generator storage. The contract is two-way such that the VPP not only gets details on the unit's current state but also sends signals to monitor the artifacts. Some of the technologies on a smart grid can help intelligence algorithms to integrate VPP. Web to Energy (W2E) is the leading technology in the area of smart grid, easily appropriate to VPP concepts. Similar to IoT, for each agent of the DERs, VPP combines, communicates, and acts as a neural network [179]. VPP contributes to reducing network losses. Researchers are working restlessly on VPP. The research trends of the VPP, in the last five years (2016 to August 2020) in terms of their keywords are shown in Fig. 8.

### A. VPP BOUNDARIES WITH MICROGRID

The similarities between microgrid and VPP is almost 75%. The virtual power plant has a wider concept than microgrid but their major differences are listed in Table 13. Aggregation and optimization of distributed energy resources(DERs) are what they have in common. In VPP, the DERs portfolio is as varied as a microgrid. The microgrid has a confined network boundary and can separate to create a power island from the wider grid but VPP can spread across much broader geography and based on real-time market dynamics, can expand or shrink.

Microgrids may be either grid-connected or off-grid networks, where VPP's are always grid connect. Microgrids may disconnect themselves from the broader utility grid, but this option is not provided by VPP. Usually, microgrid needs any level of storage, while VPPs may or may not have these features. Microgrid relies on hardware including inverters and smart switches, while VPP relies heavily on smart meters and IT. Microgrids are also facing legislative and political obstacles, while VPP can be enforced under existing regulatory frameworks and tariffs more often than not. Usually, microgrids only target DERs at the retail delivery level, while VPP can also build a connection to the wholesale market.

**TABLE 13. Differences between the microgrid and the VPP [33].**

| Microgrid | VPP |
|---|---|
| Grid-tied or off-grid remote systems can be used for microgrid | Only grid-tied mode |
| Storage is essential | May or may not require storage |
| Only tap DER at the retail distribution level | Vpps generally dependent on smart meters and information technology |
| Controllable loads | Cluster of loads |
| Focuses on self-management | Focuses on participation |
| PCC is used | Open protocol is used |
| The geographical position of each element is closely linked to MG | VPP relies primarily on the network of contact and technology |

### B. COMPONENTS OF VPPs

#### 1) GENERATION TECHNOLOGY

Nowadays, with the accelerated implementation of renewable energies, it becomes an integral part of the VPP. Its production comes from typically natural energy sources resources like wind, water, or sunlight. Those stochastic generating units are also non-dispatchable. Therefore, backup units like traditional dispatchable power plants and storage facilities must also be provided. Generation technology is a combination of different types of DERs. DERs may be either the distributed generator(DG) or the network-based controllable loads. Here is some DGs which is used for VPP: (a) Wind-based generators (b) Photovoltaic arrays (c) Solar-thermal systems (d) Small hydro-plants (e) Diesel generators (f)Fuel cells [181].

#### 2) STORAGE TECHNOLOGY

Energy Storage System (ESS) plays a crucial role in balancing production and supply. The energy storage system components will store energy in off-peak times and feed it in the peak periods [181]. ESS can today be regarded as a new means of adapting the changes in demand for electricity to a given power generation level [180]. The storage system offers a VPP the ability to shift electrical resources from different cycles. The key purpose of implementing energy storage systems is to use this capacity in the future. There are many storage unit types, which can be used in current VPP: (a) Hydraulic Pumped Energy Storage (HPES) (b) Compressed Air Energy Storage (CAES) (c) Flywheel Energy Storage (FES) (d) Superconducting Magnetic Energy

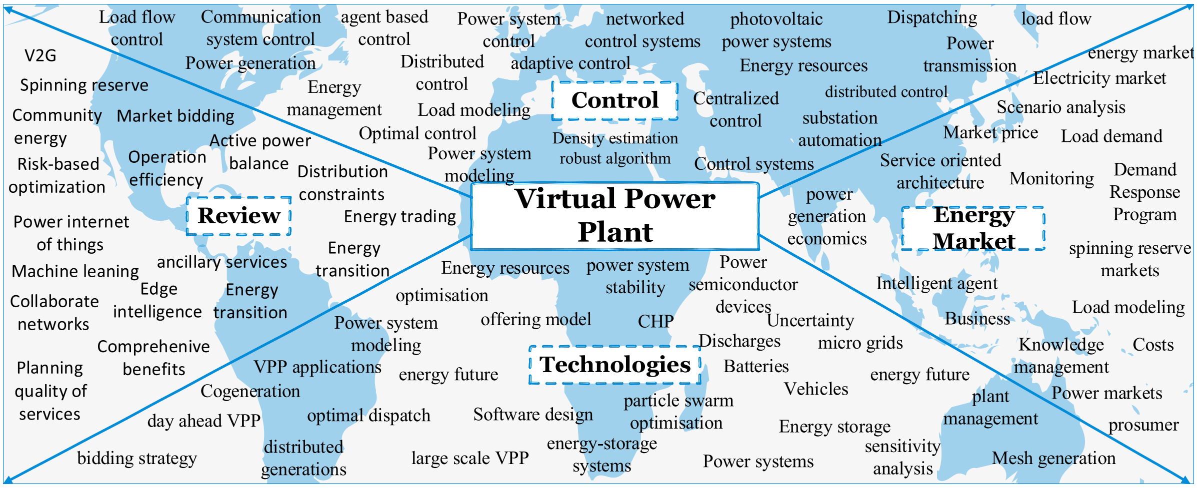

**FIGURE 8.** Keywords used in research article of virtual power plant from (2016 - August 2020).

Storage (SMES) (e) Electric Double-Layer Capacitors (EDLC) (f) Battery Energy Storage System (BESS) (g) Plug-in Hybrid Electric Vehicles (PHEVs) [182].

#### 3) INFORMATION AND COMMUNICATION TECHNOLOGY

Communication and infrastructure are essential requirements for VPP. Energy Management Systems(EMS), Supervisory Control and Data Acquisition(SCADA), and Delivery Dispatching Center(DCC), etc are the communication technologies can be taken into account several for specific communication purpose for VPP [180].

### C. CLASSIFICATION OF VPP

VPP can be subdivided into two parts that operate together to achieve the VPP functions. 1. Technical virtual power plant (TVPP). 2. Commercial virtual power plant (CVPP). One of the key issues is that the communication between participants is not obvious. VPPs produce their power and transmit the energy by transmission lines that do not belong to VPP operators. The cost is also be taken into consideration.

#### 1) TECHNICAL VIRTUAL POWER PLANT

TVPP includes the local network real-time influence and it allows DERs visibility to the operator of the system and enables DER units to contribute to system control. To manage energy flows within the VPP cluster and the execution of additional services, TVPP is responsible for operating the DERs and the ESS properly. Based on data received from the CVPP, TVPP ensures that the system optimization and securely with the physical limitations and detailed information on distribution network topology [181].

#### 2) COMMERCIAL VIRTUAL POWER PLANT

CVPP regards DERs, as commercial enterprises that offer the price and the quantity of energy they provide, optimizing the industrial use of the electricity market's VPP portfolio. Both DG units and clients are subject to bilateral contracting by CVPP. The details of such contracts shall be submitted to the TVPP for use in technical studies to take into account the sum of the contracting force. Small DG units cannot participate individually in the electricity market. CVPP combined profile and output that reflects the DERs portfolio costs and operating properties. In the aggregated CVPP profile, the influence of the delivery network is not included. Commodity in the wholesale energy industry, the balance of commodity and utility portfolios to the network operator provides utilities or CVPP features. Any third-party aggregator or BRP, with market access, can be a CVPP operator [183].

### D. CHALLENGES OF VPP

The VPP aids each DER in the management of retail and wholesale energy markets but also questions the allotment of capital, processes and control structures, electricity transfers, protection, and security. Many specific implementations and VPP management methods have been taken. All have faced a variety of challenges:

#### 1) RESOURCE ALLOCATION

No DER is static in the VPP [33]. Dynamic and practical characteristics are considered during allocating resources. The assessment index system and methods of evaluation must be developed [33]. Universal adoption is a major challenge for communicating between the DER units. Only one standard is permitted, and a package of information must be established. All exchange of data should be made according to one standard may be a good solution for generic adoption [184].

#### 2) OPERATION AND CONTROL SYSTEM

Operation of VPP is a significant challenge. According to the decision taken by the owner of the unit or the VPP operator, the actions exhibited by a production unit will change. It must respond quickly and effectively to adjust actions dynamically to suit the situation [184]. And also, a single method cannot control the system of VPP. Different DERs must be employed in the control system and interact with the power grid [33].

#### 3) SECURITY AND ROBUSTNESS

The system must be protected against external hazards and have a procedure in case of lack of contact for service. It is necessary to define safety standards and web services specifications. If the DER unit and the VPP operator are lost in the connection, the DER unit connects with 'Match Maker' to gain information about the new relationship with another VPP. This connection is achievable, and then the connection is dynamically established [184].

### *E. INTEGRATION WITH POWER SYSTEM*

#### 1) INTEGRATION WITH DISTRIBUTION NETWORK

VPP actively controls DG. It should be able to avoid or rising operating issues associated with DG integration. VPP's ICT infrastructure provides active monitoring that can be used to control the passive distribution network actively. When a VPP has established the VPP operator (VPPO) can cooperate with the distribution system operator(DSO) to minimize problems and maintain the stability of the system. In the worst-case cases, power supply blackouts can be avoided. VPPO will provide voltage control services to the distribution system operator. To prevent unnecessary voltage, VPPO supplies the secondary side of the MV or LV transformer. Service can be also provided in other cases to avoid the voltage tolerated being exceeded.

In the event of short-circuit failure, a DSO and VPPO communication are necessary if a DG bottom-up contribution is to be prevented. The differential feeder protection may be used with the use of VPP [185].

#### 2) INTEGRATION WITH TRANSMISSION SYSTEM

When aggregated VPPs, a large-scale virtual plant, account for a large percentage of energy demand in a region or country, they can provide options to compensate for the unanticipated loss of conventional power plants. The transmission system operator(TSO) can, in this case, consider LSVPP's (Large Scale Virtual Power Plant) available power as reserve energy. The LSVP operator could allow time to be taken to reduce DG's intermittent effect and secure the power supply.

### *F. REQUIREMENTS OF VPP*

Stabilization, cost reduction, and consumer demands are considered the criteria for VPPs. Here, some requirements of VPP are:

#### 1) VPP FRAMEWORK

DERs similar to transmission plants are portrayed in the commercial VPP. DERs similar to transmission plants are portrayed in the commercial VPP. It reduces the chance of disequilibrium. For consistency and clarification of DERs, the professional VPP is accountable to the operators. This deals mostly with the network, DERs, and transmission line system management.

#### 2) SELF-SUPPLY SCHEME

The method of self-provision is used to optimize possible market volume by local generation adequate VPP. The availability of the VPP internal demand is connected to the self-sufficiency system, where necessary and practicable, with the VPP generation. If the capacity for demand is limited, the system is used to minimize system costs. Two steps are taken into account in the self-supply model, VPPs in island mode is the first. If VPP demand cannot be fulfilled by local production, demand persists. In this situation, the central buying power is ignored to reduce the expense of production. But this transaction is allowed in the second phase and the program is therefore structured to minimize costs by formulating the original issue. To reduce the need for VPP, an external control device is used.

#### 3) PROFIT MAXIMIZATION

The VPP seeks to improve its security by exporting surplus oil at a high pace and by purchasing energy shortages at a cheaper market price. Surplus benefit generation from VPPs is related to the versatility on the demand side, which ensures that customers can reduce demand during peak times and move on to other times. In so far as the benefit is smaller, fluctuations in demand must be determined in addition to an optimum solution.

#### 4) AVOIDANCE OF PLANT AND GRID CONSTRAINTS

Because of the huge amount of loads and plants, the conformation of VPPs is compatible with other drawbacks, such as load supply and demand balancing, adjustable load variability, operations of equipment, power consumption failures, inability to supply device reserve, and pollution of fuel. To ensure stable service, correct design and scheme are required to escape these constraints.

#### 5) SECURITY

For the protection of virtual power stations, the security specifications are mandatory practical behavior. It includes smart electricity supply and delivery control. Inspection and verification must be performed on the systems. There is a need for adequate data backup. Stringent laws and legislation on robustness would control the overall protection criterion.

#### 6) ADAPTION TO NEW TECHNOLOGY

The introduction of emerging technology is another key necessity. Including the implementation of more advanced innovations with the VPP is also necessary. The incorporation of advances in high-density energy storage, computational processing, artificial intelligence, automation of autonomous systems, massive data analytics, etc into successful VPP operations is convincing.

**TABLE 14. Comparison of different control methods of VPP.**

| Control Method | Functions | Limitations |
|---|---|---|
| Centralized Control method [186] | • Activates ultimate power control for VPP.<br>• The VPP creates a management coordinating hub, which provides the sole authority over all interconnected DERs to be dispatched.<br>• Increase DER integration. | • Required sufficient communication bandwidth.<br>• Confined by computation efficiency. |
| Distributed Control method [186] | • Communication server provides information interchange services.<br>• As all energy supplies are outside VPP regulation, implementing distributed control means eliminating market monopolies created by centrally-located large-scale VPPs. | • Due to the lack of centralized optimization, each subsystem's operational profile will contradict one another, thereby reducing overall competitiveness and worsening competition on the market.<br>• Heavy estimation is important to manage selfish operational strategies. |
| Comprehensive Control method [186] | • The central co-ordination of the VPP avoids disordered competition.<br>• Make sure Nash equilibrium of agents bidding strategies.<br>• The VPP central optimization calculation speed has been improved vastly. | • Cyber-attack weakness.<br>• Stream of contact inadequate.<br>• Need more physical investment and technological updates. |

## G. CONTROL METHODS OF VPP

The incorporation to be a representative investor in the electricity sector various scientific researches attracts from DERs and the relevant control methods. Table 14 summarizes the functions and limitations of different control methods of a virtual power plant and the attributes of each type of control are described as follows:

### 1) CENTRALISED CONTROL METHOD

DG (Distribution Generation) units are centrally controlled by CCC (Control Coordination Centre), and it is located right in the center of DG units. The required signals (e.g. load signal) are sent to the CCC and processed using a logic algorithm. Signals are subsequently sent to every DGC (Distribution Generation Controller), and the CCC signals provide the active power output. This can conduct both technological and economic roles for the CCC so that the DG (Distribution Generation) aggregation will benefit. The centralized control system makes VPP with total control power compared to other methods. Although the position of the VPP on the market may differ with its integrated resources, VPP slowly recognizes its increasing impact on the functioning of power systems and the power market. In the central control system, VPP is ultimately responsible for the efficient management of internal energy services, where the basis of information gathering and decision-making is formulated with a sufficient contact bandwidth. In conclusion, centralized control VPP is limited at a reasonable scale. [186].

### 2) DISTRIBUTED CONTROL METHOD

The structure of the distributed control system is split into two separate rates by splitting VPP in comparison to the centralized monitoring process where the first is the core level of VPP coordination and the second level consists of the autonomous level of the circuit of the generators concerned. Regional energy services are targeted at individual subsystem schedules, although VPP offers knowledge sharing between multi-subsystems at the individual benefit maximization. As all energy supplies are outside VPP regulation, implementing distributed control means eliminating market monopolies created by centrally-located large-scale VPPs. However, a huge computation workload may be relieved by allocating decision variables to subsystems. Above all, VPP operates primarily as a communication server offering information-sharing services via the distributed control system. VPP helps to establish a loose coalition between independent DERs by implementing distributed algorithms, which increases overall benefits as long as communication network reliability is achieved [186].

### 3) COMPREHENSIVE CONTROL METHOD

Comprehensive control method also known as central distributed control where centralized control and distributed control characteristics are combined [187], [188]. This system can be split into two stages of sub-control, both linked closely by the VPP regulation center [186]. In level I, VPP centrally coordinates each agent's bidding strategy and formulates a definitive market participation bidding strategy. level II assumes the responsibility of dispersed agents for regional optimization and provides the VPP with a national operating profile for overall optimization. All officers shall perform regional rescheduling and execute the final coordinated operational pattern issued by VPP [189].

## H. FUTURE CHALLENGES OF VPP

There are several challenges for establishing a virtual power plant shown below:

- The VPP will not own the DER. If the concept of VPP is successful, there will be several VPPs on the market. The owner of the production unit will then be able to choose freely.
- VPP will have to adapt with different DER with different characteristics.
- When a production unit's purpose or control strategy changes, its conduct should be changed. Choosing a control scheme isn't easy.

### I. FUTURE FORMATION OF VPP

Future VPP should include a wide range of DG technologies in distribution networks of both low voltage and medium voltage. The DDG (Domestic DG) owners are committed to supplying their energy needs, and certainly the cost-effectiveness of their supplies in economic terms. The second type of DG Unit is Public DG (PDG) which does not belong to a single customer. Public DG plans to insert the output of power into the grid. All DG forms will be fitted with the storage of electricity. The objective of PDG owners is to sell their power output to the customers of the network. It can be broken down into very small microgrid sub syntheses, in conjunction with DDG's penetration into the network. Using the VPP principle, a broad group of controllable aggregates can be provided to each microgrid and PDG in device management. Many PDGs or DDGs are stochastic, but many can be dispatched. The PDGs and DDGs can be subdivided into two groups in this respect, i.e. dispatchable PDGs (DPDGs) and stochastic PDGs (SDGs). Some controllable loads, energy storages to compensate for the fluctuations in stochastic DG units should be included in VPP. A central power unit, i.e., should manage and control the VPP portion [190].

## VI. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The microgrid, smart grid and VPP will be the future of the power system. The role of these three domains of energy framework cannot be overlooked. Technical advancement from all aspect are required to be considered to energy sustainability. In this work, we present a brief summary on the role and prospect of control algorithms towards sustainability. We started our discussion presenting a detail analysis on the status of existing modern grids in the context of the technological advancement of its different roles. Then, detail of integration of various RERs like wind generation, PV generation, electric vehicles, energy storage systems, their role in energy sustainability and challenges in their implementation, and variable aspects of different control techniques employed in microgrid, smart grid, and VPP has been presented. Later future challenges of the three energy domains were discussed and it was clearly stated that the control has a major role to play with. For this purpose, to achieve outcomes with greater fidelity, sophisticated stochastic algorithms, predictive modeling and the use of nonlinear schemes should be implemented in future microgrid, smart and VPP applications.

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