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One Mega Watt Microgrid Solar Energy and Diesel Generator Using MATLAB

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Abstract

Due to the increasing demand for energy and environmental pollution, researchers are interested in the grid connection capabilities of distributed generation as a new developing technology for delivering dependable and clean power supply. Energy production, storage and loads are all part of the microgrid control system that may operate in grid-tied or isolated mode. There must be a way for the microgrid to handle voltage and frequency adjustments in order to safeguard the grid and any linked loads. Needed is support for control of the generating and load sides, as well as the resynchronization process A microgrid is described in this article, along with standard distributed generating technologies. Additionally, a thorough examination of energy storage devices, microgrid loads, interfaced distributed energy resources (DER), power electronic interface modules, and the connectivity of various microgrids is included. This research also covers stability, control, and communication tactics in depth. This article explains the current microgrid control strategies in use throughout the globe and provides a comparison of several control systems with their advantages and disadvantages. As a result, it helps researchers imagine how a microgrid would be used in a real-world scenario, as well as how the grid may grow in the future. Conclusions highlight important discoveries and prospective research directions for improved microgrids in the future.

Keywords- Microgrid; Distributed energy resources; Distributed generation technology; Future grid, solar cell, MPPT algorithm, Diesel generator.

1. Introduction

It is a contemporary distributed power system that uses local sustainable power resources built via different smart-grid projects, such as the microgrid. In addition, it offers small communities with energy security since it may run independently of the main utility grid. In general, three key societal objectives are represented by microgrid technology: physical and cyber dependability, environmental sustainability, and economics (cost optimizing, efficiency). In the context of "distributed generation" (DG), the phrase refers to electricity production at or near the point of consumption. DG may decrease the generation, transmission, and distribution costs while boosting efficiency by reducing factors of complexity and interdependency, compared to "central generation." In many circumstances, distributed generators may offer cheaper generating costs, more dependability, and greater security than standard generators can deliver. According to Pike Research, 3.2 gigawatts (GW) of worldwide microgrid capacity is already in existence [1-4]. According to the research [3], North America is the world leader in microgrid generation, with an operational capacity of 2,088 MW. With 384 MW of installed microgrid capacity, Europe is second in the rankings, followed by Asia Pacific, which is third. Across 404 MW of microgrid capacity has been deployed around the globe. Using a generator, battery, or diesel engine as a backup power source would be the most expensive option if every power user (building, corporation, hospital/market), cared about having a stable power supply. Back-up resources aren't needed in a microgrid system since no one user is required to offer a general load during crucial times of consumption. One billion dollars' worth of electricity may be saved by moving or reducing loads during a few hundred summer peak hours. To put it another way, microgrid operation is mostly justified by its dependability [1]. Even in the southern United States, microgrids may be economically feasible. This new technology's environmental impact may not be as critical in the United States as in China, where environmental concerns are on the rise. Because of the decreased transmission losses, the microgrid may be able to help alleviate the current energy crisis. An additional benefit of a microgrid is that it supplies dependable and sustainable energy to the loads at a lower cost. Due to the system's localised design, it also addresses the problem of cyber security. [4] Microgrid technology may be used in rural settlements where there is little or no transmission infrastructure, making an island microgrid ideal. As a miniature model of real grid form, microgrids are supposed to have characteristics comparable to those of a regular grid in terms of power production, distribution, transmission, and control. As a result of this difference, microgrid technology varies from a traditional grid in that it is placed closer to the load-sites. Renewable energy sources such as solar, wind, geothermal, biomass, hydro, and geothermal power are also integrated into microgrids [4, 5]. Although microgrids' power output is restricted to a few megawatts, it is dependent on the application region and the sort of grid it is attached to. An interconnected network of microgrids, known as a "power park," has been constructed to fulfil the rising demand for electricity and the resulting need for more control and stability. It is also important to note that the linking of renewable sources and a microgrid reduces environmental emissions. Only one-third of the fossil fuel burned is transformed into electricity in a macrogrid (traditional grid application); the balance is lost as heat energy. To control demand and supply, a microgrid is able to connect directly with its customers. There is a 5-7 percent loss of electricity in a macrogrid's transmission lines, however in a microgrid, there is no loss of power. There is a 20 percent capacity to satisfy peak demand of 5 percent time for the utility system, which has a "domino effect failure" that may lead to a blackout, as well. More than a hundred power facilities in North America were forced to shut down in 2003 as a result of the domino effect of failed plants. Microgrids can operate independently in the event of a broad power outage, or even in the event of a power fluctuation (whether deliberate or inadvertent). Due to any kind of tragedy, the microgrid has the ability to start again from scratch [6-8]. The components, structure, and kinds of microgrids will be briefly described in this paper. There are several studies on microgrids, and this article provides an overview of the technology by comparing, comparing, and comparing. A microgrid's real-world use and prospective enhancements are the primary goals of this study. This will enable for a conclusion on the design requirements for a certain microgrid application scenario with specific, accessible resources after comparing the microgrids in different locations with different characteristics. Additionally, it compiles all of the relevant data on microgrids and then offers a standard microgrid for best power quality and maximum energy harvesting. Last but not least, it aims to fill up any knowledge gaps on power systems that may arise in the future due to a trend or improvement [1, 8, 9].

2. Summary of the Microgrid

In order to build test beds and demonstration sites, researchers are investigating microgrids intensively. It is thus necessary to address the categorization of microgrids and important core technologies [1, 10, 11]. Facilities, distant sites, and utility-scale microgrids all fall under the same umbrella term in this research. Characteristics like as their degree of utility grid integration, their influence on the major utility providers, and their important core technologies are all taken into account. Unlike distant microgrids, facility microgrids and utility microgrids have utility connections. When compared to microgrids at facilities and utilities, remote microgrids are spread out across a much larger region. Intentional or unintended island mode may be maintained by facility microgrids. But there are a variety of microgrid types [1,10,11] with different micro sources, loads, network characteristics, and control architectures.

When it comes to microgrids, the term "localised collection of energy sources and loads that generally run integrated, and works as a single controlled unit that is synchronised with the conventional centralised grid, but may detach and function independently" [12] is used. There are a variety of renewable and non-renewable distributed generators, as well as energy storage devices, varied microgrid loads, interconnected distributed energy resources (DER), stability and control systems, and communication systems that make up a microgrid as depicted in Fig. 1. When a macrogrid and a microgrid are interconnected, a point of common coupling (PCC) is formed [39-44].

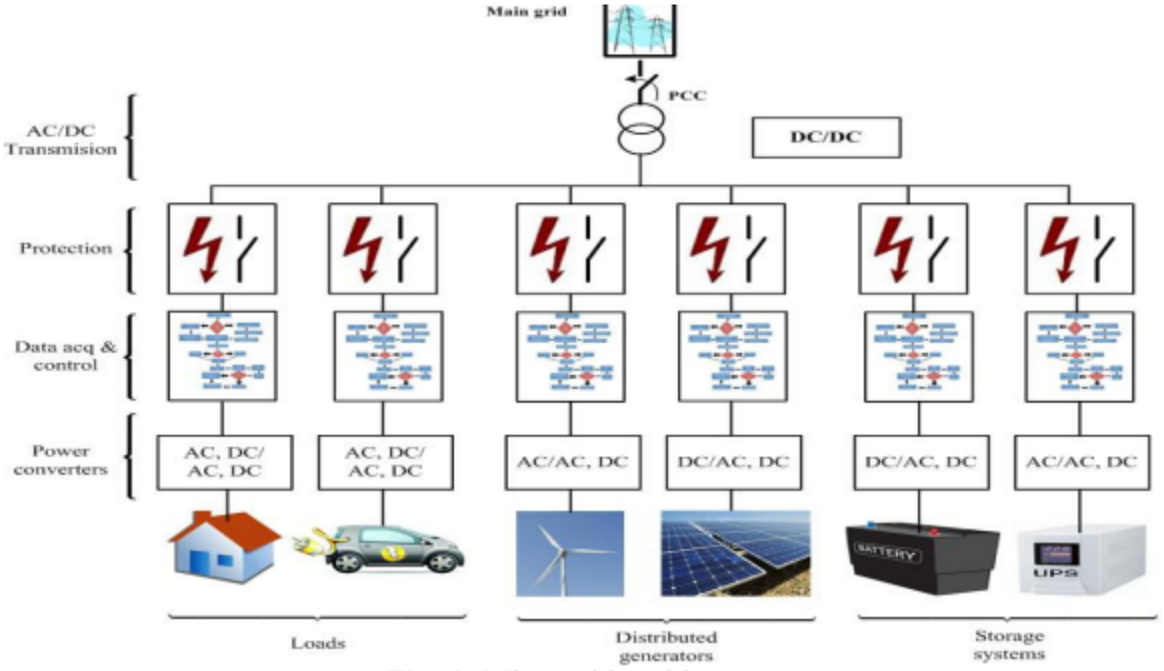


Figure 1: Microgrid architecture

2.1 Distributed Generators

There are two types of generation technologies that can be used in microgrid design: non-renewable distribution generation (diesel engine; stream turbine; gas engine; induction and synchronous generators; etc.) and renewable distribution generation (solar thermal; photovoltaic (PV); wind; fuel cell; CHP; hydro; biomass; biogas). Wind energy, along with solar energy, has grown fast in popularity in microgrids throughout the globe, with annual growth rates of approximately 30%. It is beyond the scope of this article to go into great depth on these new technologies and well-established generating systems, which are well-known. Distributed generating technologies are summarised in Table 1 and cost analysis data is displayed in Table 2, which is based on plant design and system requirements. It is difficult to generate electricity from renewable sources since they are intermittent. There are many types of renewable energy, but they all have some connection to a solar energy system. In terms of dependability, establishing a power system without any non-renewable DGs is dangerous. Over 80 percent of the US population, or 37 states, have enacted renewable energy rules that may account for up to 33 percent of the energy distributed to consumers by 2020, according to a research from the Resnick Institute. There will also be an investment of $675 billion by 2030 in the United States for the construction and maintenance of transportation and distribution infrastructure. Each state has thus increased its goal of standard distribution and production and the creation of renewable energy. A growing number of jurisdictions have already begun significant electrification programmes in response to rising demand and increasing reliability concerns.

Table 1: Summary of distributed generation technologies

Overview for Distributed Generation Technologies											
		Size Range (kW)	Efficiency(%)		Emissions (g/kWh)	Foot print (sqft/k W)	Packaged Cost ($/k W)	Installation Cost ($/kW)	Electric- Cost-to-Gen. (cents/kWh)	Cogeneration Cost -to-Gen.(c/kWh)	Maintenance Costs (cents/kWh)
			Electric	Overall							
		Reciprocating Engines									
Spark Ignition		30-5.000	31-42	80-89	Nox:0.7-42 CO:0.8-27	0.28-37	300-700	150-600	7.6-13.0	6.1-10.7	0.7-2.0
Diesel		30-5.000	26-43	85-90	Nox: 6-22 CO: 0.1-8	0.22-0.31	200-700	150-600	7.1-14.2	5.6-10.8	0.5-1.5
Dual Fuel		100-5.000	37-42	80-85	Nox: 2-12 CO: 2-7	0.15-0.25	250-550	150-450	7.4-10.7	6.0-9.1	
Turbines											
Microturbines	Non-Recup	30-200	14-20	75-85	Nox: 9-125ppm CO: 9-125ppm	0.15-0.35	700-1.000	250-600	14.9-22.5	10.1-15.9	0.8-1.5
	Recup.		20-30	60-75		0.15-0.35	900-1.300		11.9-18.9	10.0-16.8	
Industrial Turbines		1.000-5.000	20-40	70-95	Nox: 25-200ppm CO: 7-200ppm	0.02-0.61	200-850	150-250	8.7-15.8	5.8-12.2	0.4-1.0
Fuel Cells											
PEM		5-10	36-50	50-75	Nox: 0.007 CO: 0.01	0.9	4.000-5.000	400-1.000	21.9-33.3	20.7-33.3	0.19-1.53
Phosphoric Acid		200	40	84	Nox: 0.007 CO: 0.01	0.9	3.000-4.000	360	18.6-22.8	17.0-21.2	
Renewable											
PV		5-5.000	NA	NA	NA	NA	5k-10k	150-300	18.0-36.3	N/A	0.3-0.7
Wind		5-1.000	NA	NA	NA	NA	1k-3.6k	500-4k	6.2-28.5	N/A	1.5-2.0

2.2 Energy Storage Devices

To make renewable energy sources trustworthy contributors to the main energy supply and to ensure the effective functioning of a microgrid, energy storage is essential. Keeping the balance between power production and demand is critical, and this is where the energy storage process comes in. A microgrid's energy storage components must meet the following specifications:

I. Energy storage systems must prioritise balancing power demand between generation and consumption (due to intermittent and transient disruptions lacking in inertia in the sources).

II The ability to store and provide all of a building's energy needs during off-peak hours.

III. To reduce the microgrid's load in order to fulfil unexpected and urgent requirements.

seamless transitions from grid-tied to islanded operation or the other way around are required.

Batteries and flow cells are two of the most common types of electrochemical energy storage systems, but flywheels, pumped hydro, and compressed air are also examples of kinetic energy storage systems [16,18,19]. Here is a table that summarises the current storage technologies. More appropriate for microgrid use are batteries, flywheels, and supercapacitors. Sustainable operation at fixed voltage and frequency can only be achieved with the use of battery-based energy storage devices [8, 11, 16]. Because of its rapid absorption and release of energy, the flywheel alternative is an excellent central storage device. For large-scale power system applications, the flywheel approach remains prohibitively costly. Batteries and flywheels compete with one other in terms of high power needs, power density, and efficiency in uninterruptible power supply applications [16]. As an alternative, a microgrid storage system might make use of fuel cells or classical generators with very high moment of inertia.

2.2 Microgrid Loads

The loads in a microgrid system play a critical role in the system's operation, stability, and control. Static and motor/electronic loads are two types of electrical loads. There are several types of loads that may be supplied by the microgrid, including as home or industrial, that are regarded as important or sensitive. Priority for essential loads, power quality improvement for particular loads, and reliability enhancement for pre-specified load categories are all factors in this kind of operation. As a result, local generation is able to avoid unanticipated disruptions using quick and precise protection measures.

3 Distributed Energy Resources (DER) Interfaces

The use of power converters makes it possible to link many pieces of equipment to a single network. In order to provide the grid or end users with the appropriate power types, distributed generation (DGs) technologies need particular converters and power electronic interfaces.

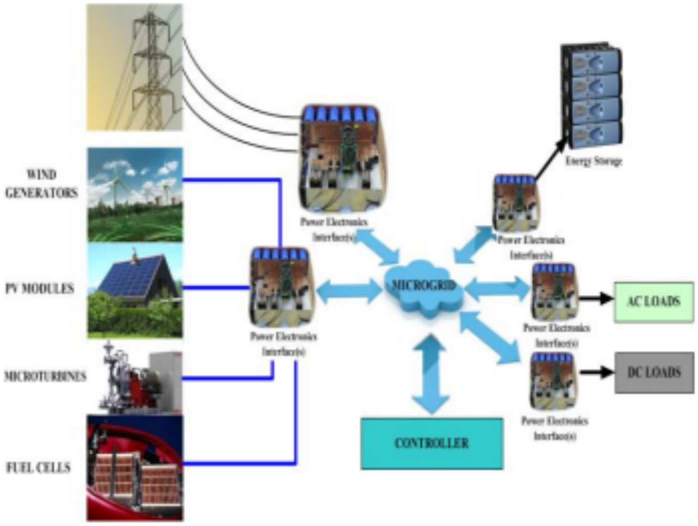


Figure 2: Power electronics interface in a microgrid

4 Microgrid Strategies for Stability, Control, and Communication

Because of the lower power and energy ratings, microgrid stability concerns are more common than in big electric grids. However, the ideas used to analyse AC microgrid stability issues are the same as those used in the main/macro grid. It is necessary to adjust both the voltage and the frequency using active and reactive power controls. Machine shaft torque and speed control is used to maintain system stability when conventional AC generators are directly linked without power electronic interfaces. Reactive power interactions do not exist in DC microgrid systems, which suggests that there are no stability difficulties. Only in a DC-based microgrid does system control seem to be focused on frequency regulation. Microgrids and their connections to distributed generation (DG) systems face significant challenges in terms of power quality. RESs, hydro, and diesel generators, which are key sources of DG systems, have power quality difficulties listed in Table 7 [5]. A microgrid's stability may be divided into two categories. Small-signal and transient stability are included in the first kind of stability, which also includes voltage stability.

Continuous load switching and regulating micro-source power demand may be addressed using closed-loop controller-based analytical approaches for tiny signal stability. Microgrid transient stability is affected by any fault in one of the following islands. This instability is mostly caused by low reactive power, dynamic loads, and transient sources like tap changers. To improve the stability of tiny signals, additional closed-loop controllers, observers, and control algorithms suitable to the situation may be developed. Adaptive protection devices and storage devices increase transient stability. Reactive power compensation (RPC), load limiting (LC), voltage regulation (VR), and current limitation (CL).

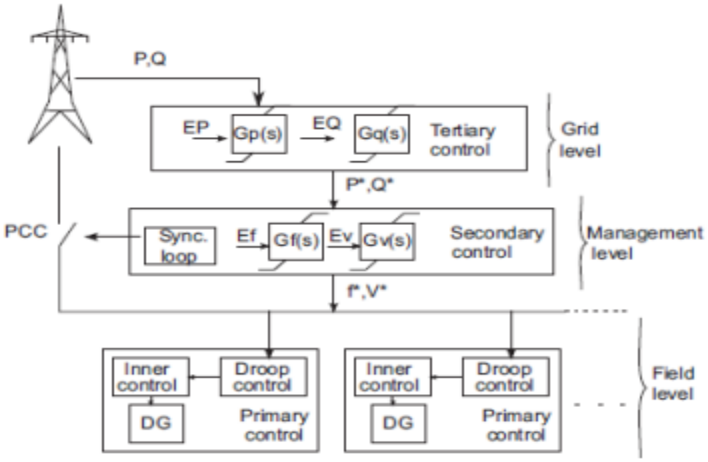


Figure 4: Centralized hierarchical control of microgrids

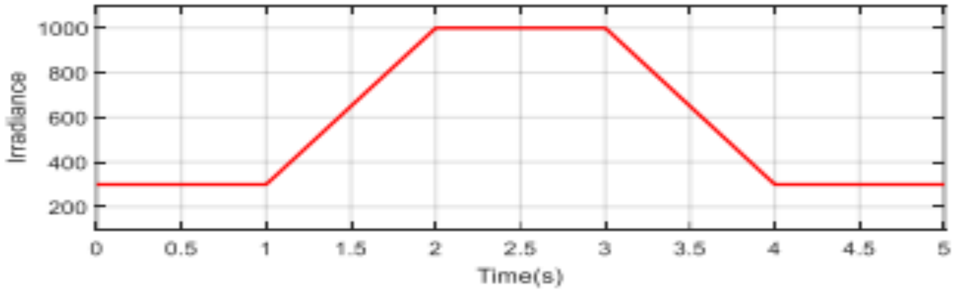
Rather of relying on a single "master" controller, the decentralised controller allows all devices to operate independently. The overall system's communication speed is increased whether a decentralised controller requests operation from a distribution point or not. It is also possible to combine numerous issues in truly decentralised systems. The manager may lose control of the microgrid as a whole if all decisions are made at the distribution level. If this is the case, the installation costs are greater for a well-organized control system than they are for centralised systems. This means that choosing a microgrid control system is a trade-off in terms of cost. A better choice would be a system that combines the advantages of both single-agent and multi-agent control systems. After many scholars came up with the idea of using MAS to decentralise the control, several more ideas were created. Local controllers (LC) may be simply constructed using this sort of control, which is the basis of DER's autonomous structure. A vast region where voltage regulation is also supplied by MAS may benefit from the cooperation of these controllers [21,32,33].

There are a number of benefits to using MAS-based decentralised control in addition to those already mentioned. Topic shows the comparison criteria and outcomes. Consequently, centralized control is assumed to be the most proper method when a defined operator operates the microgrid, and the generation and consumer sides of the system have agreed on similar expectations from the microgrid. Installation expenses are substantially lowered because to its development of an efficient management infrastructure. However, decentralised control is best employed in situations when the variety of sources and loads necessitates real-time monitoring and adjustment, such as when the generating and consuming sides of the microgrid face multiple demands. A centralised control would not have met the needs in this situation. In these cases, MAS-based systems are often considered to be the most cost-effective options. Installing and maintaining MAS is more expensive than centralised control, but it pays for itself in a relatively short period of time. Additionally, the MAS control system allows simple plug-and-play operation while balancing controller prices and complexity. Include analyses of traditional droop control, local control, and hierarchical control systems for microgrids [21].

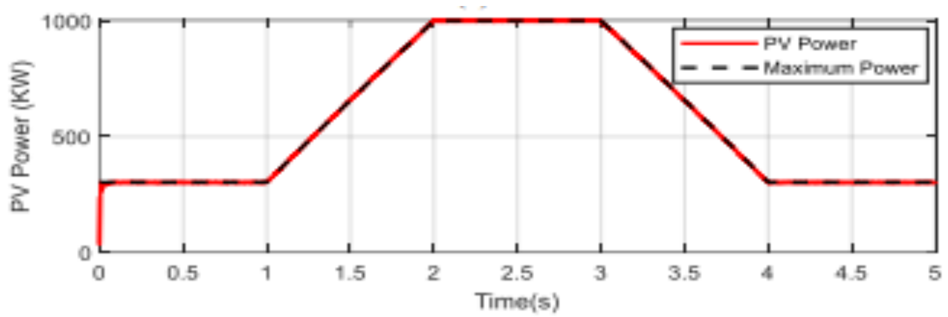
5 Results & Simulation

A. First case: a variety of weather conditions Different weather conditions limit the electricity generation of solar panels, which is one of the hurdles for photovoltaics. Under this case, the investigation demonstrated the performance of the recommended MG in a variety of meteorological conditions. For this simulation study, the load demand was kept constant at 800 kW. We used a time-varying irradiance profile applied to the solar panels to mimic weather conditions. Solar panels generate the most electricity under typical conditions when exposed to 1000 W/m2 of light. The solar panels' irradiance profile.

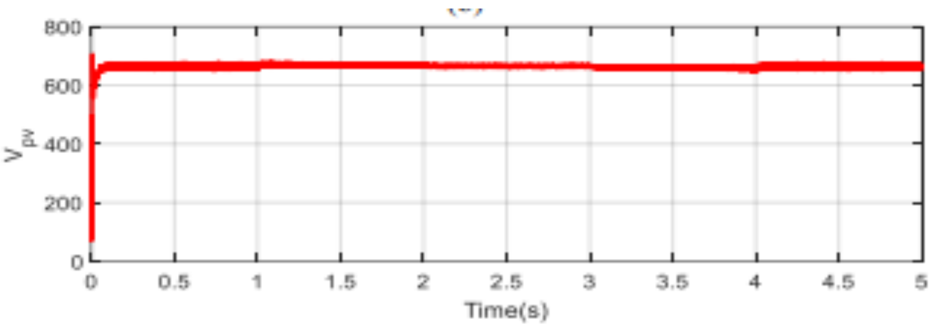
(a)



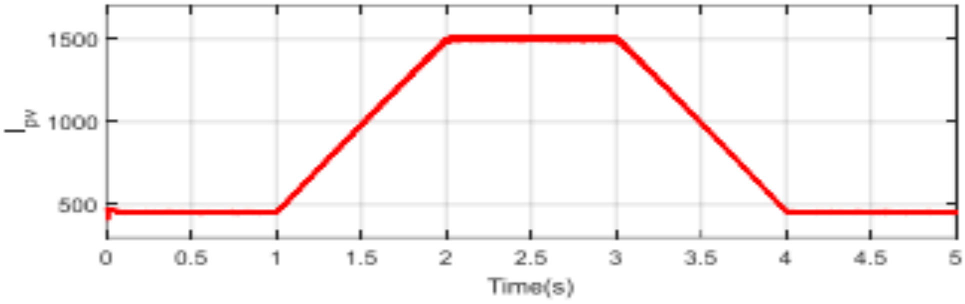
(b)



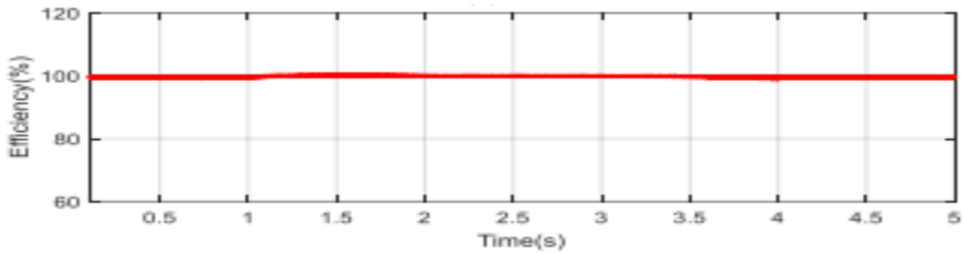
(c)



(d)



(e)


Efficiency(%)
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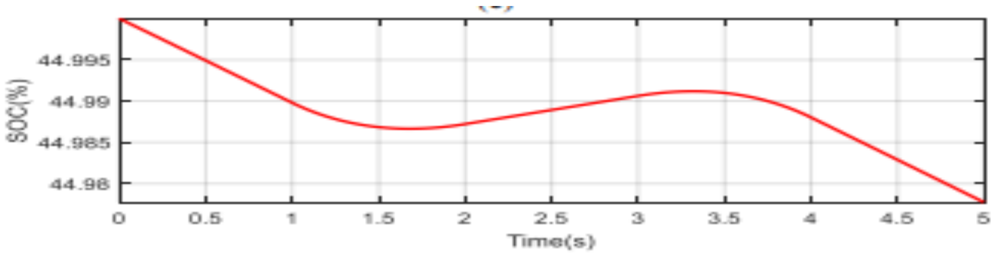
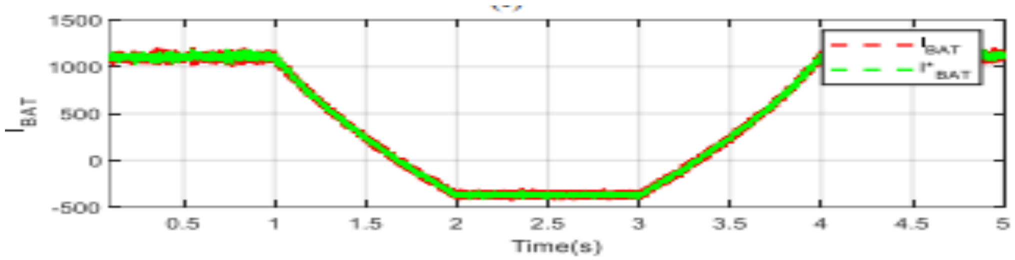
100
80
60
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time(s)

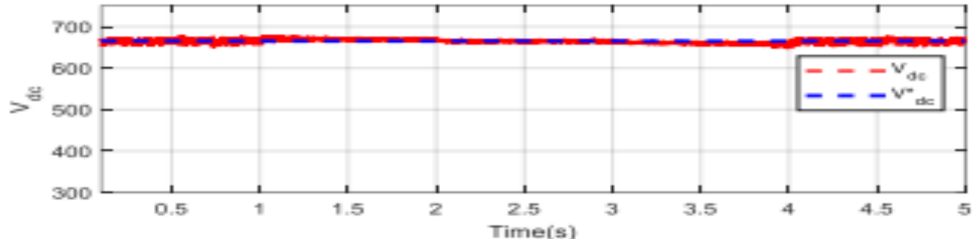
(f)


SOC(%)
44.995
44.99
44.985
44.98
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time(s)

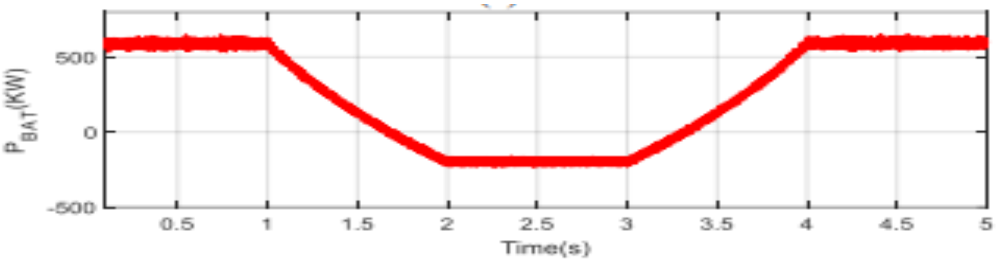
(g)


I_{BAT}
1500
1000
500
0
-500
I_{BAT}
I^*_{BAT}
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time(s)

(h)


V_{dc}
700
600
500
400
300
V_{dc}
V^*_{dc}
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time(s)

(f)


P_{BAT}(KW)
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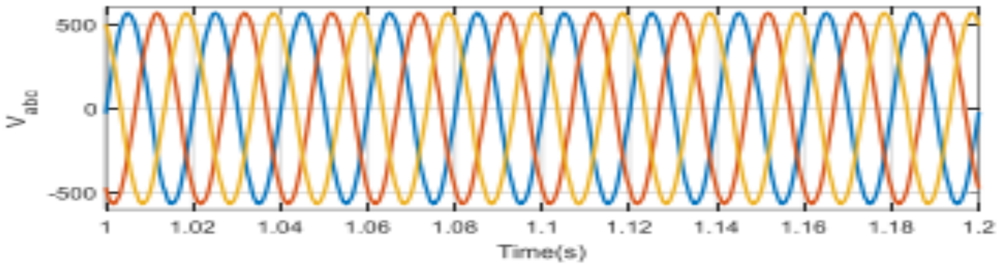
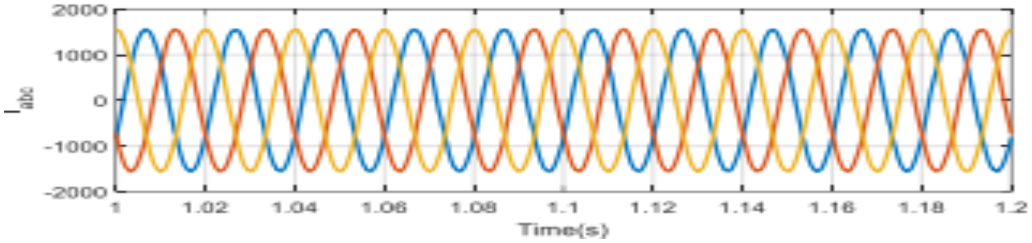
0
-500
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time(s)

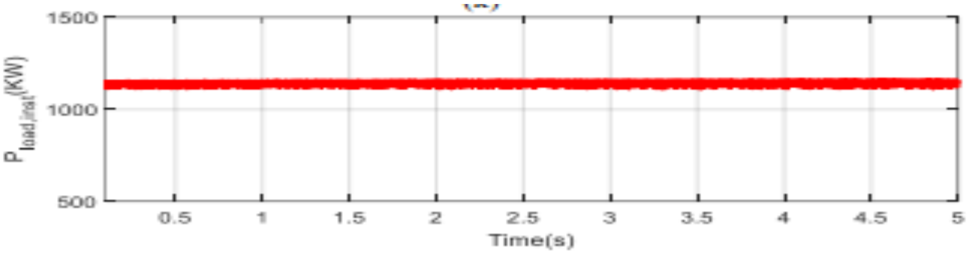
(h)


V_{abc}
500
0
-500
1
1.02
1.04
1.06
1.08
1.1
1.12
1.14
1.16
1.18
1.2
Time(s)

(i)



(j)



(k)

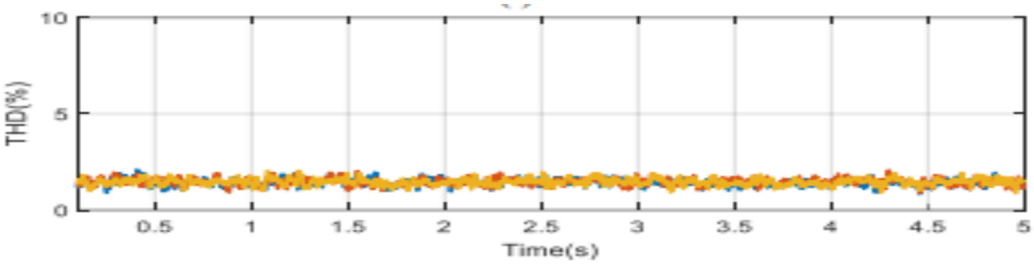
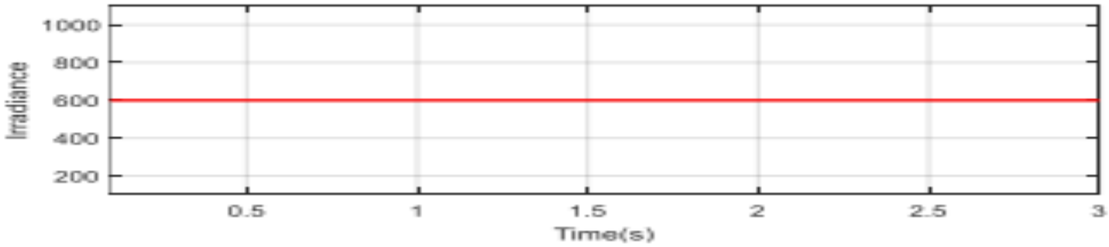
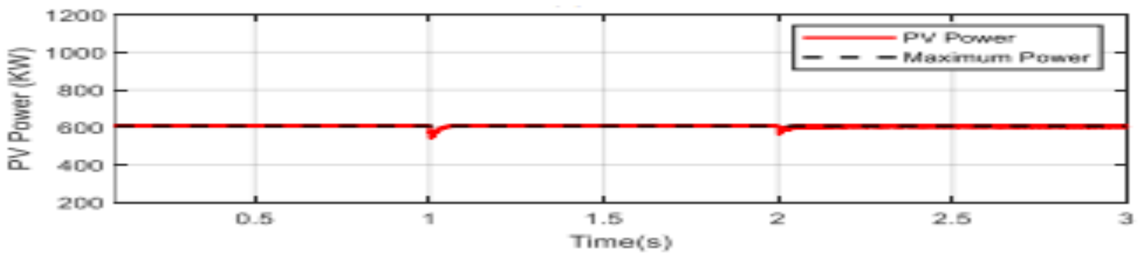


Figure 6: (a) Irradiance profile variation; (b) Generated PV power and theoretical maximum power; and (c) Irradiance profile variation. (c) The PV system's voltage distribution. (d) The current taken from the PV array varies. (e) The PV system's energy efficiency is measured in kilowatts per square metre of area. (f) Battery bank condition of charge (%), which shows the charging and discharging state of the battery bank; (g) Battery bank current variation; (h) The DC-voltage. Link's (I) The battery bank's power flow profile is depicted. (j) Three-phase voltage across a load (V3) The total instantaneous power given to the load, the current flowing through the load, and the total harmonic distortion (THD) in the output three phase voltage across the load are all measured in kilovolts.

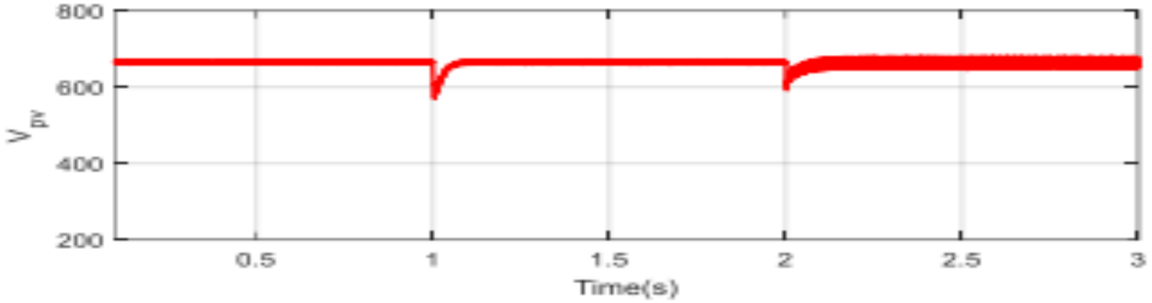
In the simulation study of the proposed MG with a variable load and a maximum value of 60% irradiation for the PV system, B Case 2 was employed. This example demonstrates the effectiveness of the proposed method in effectively absorbing load fluctuations. The load over MG in this simulation investigation increased by 400KW, i.e. throughout the simulated time, load over 0f 0-1sec 400KW was connected to MG. Over MG, an extra 400KW of load is added at 1sec and 2sec. Thus, the entire load over MG was 800KW during the first 1-2 seconds of simulation time, and the total load over MG was 1-3 seconds of simulation time.



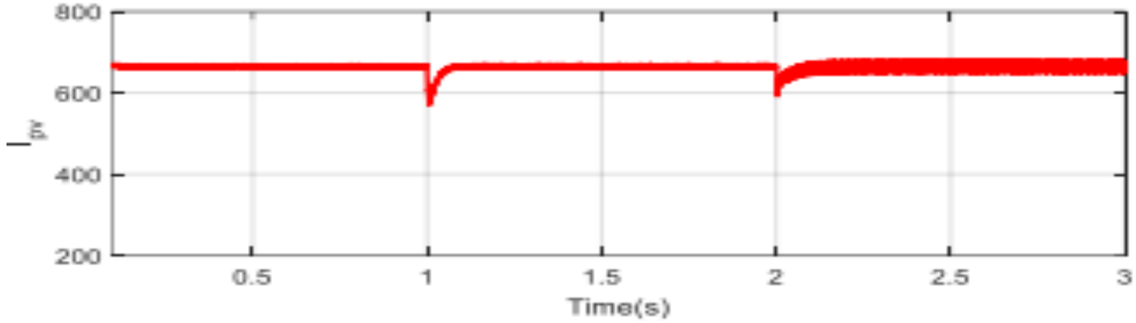
(a)


PV Power (KW)
1200
1000
800
600
400
200
PV Power
Maximum Power
0.5
1
1.5
2
2.5
3
Time(s)

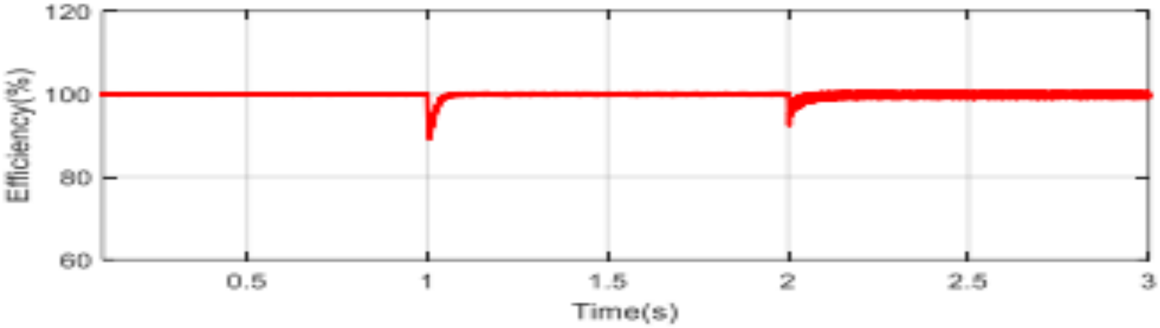
(b)


V_{pv}
800
600
400
200
0.5
1
1.5
2
2.5
3
Time(s)

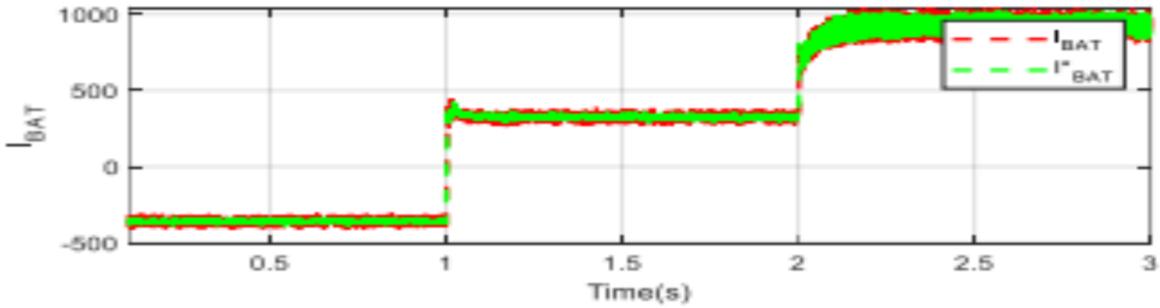
(c)


I_{pv}
800
600
400
200
0.5
1
1.5
2
2.5
3
Time(s)

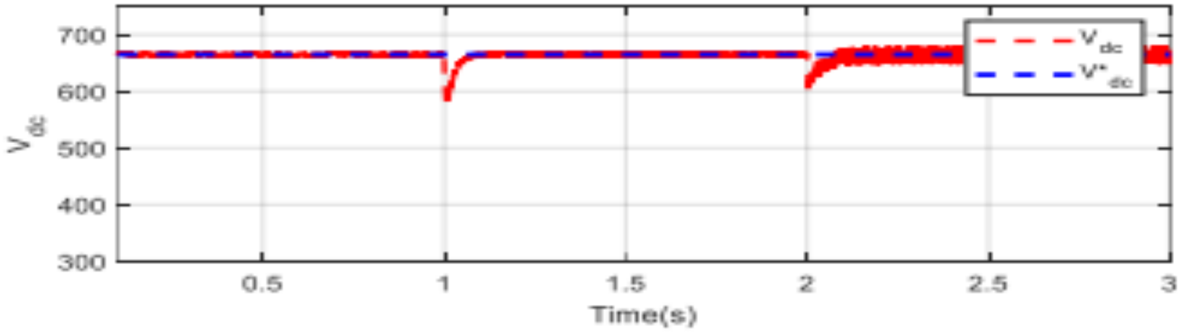
(d)


Efficiency(%)
120
100
80
60
0.5
1
1.5
2
2.5
3
Time(s)

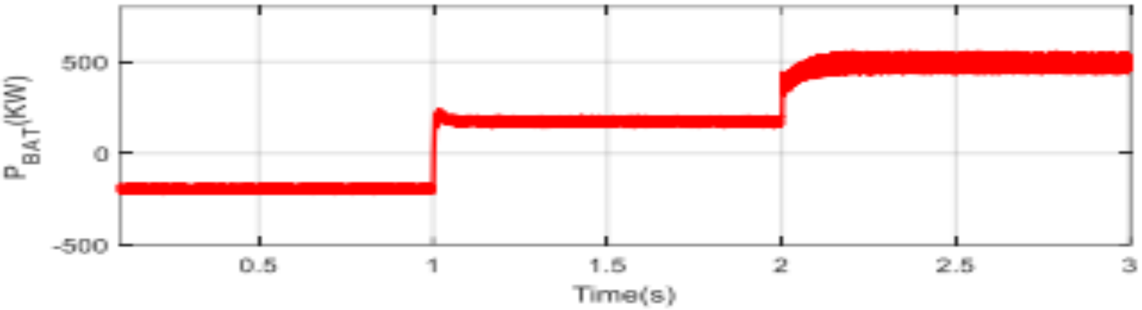
(e)


I_{BAT}
1000
500
0
-500
I_{BAT}
I^*_{BAT}
0.5
1
1.5
2
2.5
3
Time(s)

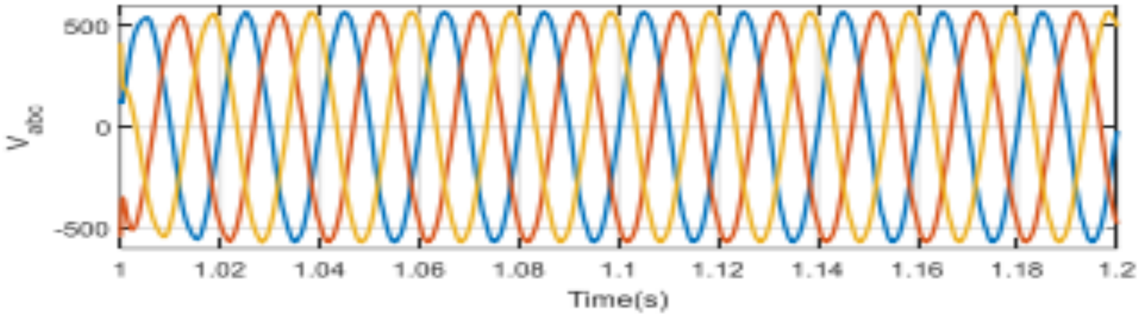
(f)



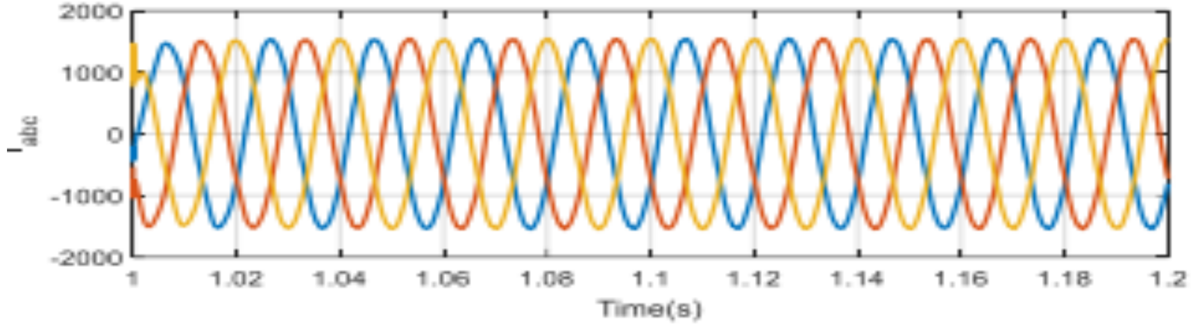
(g)



(i)



(j)



(k)

Figure 7: (a) Irradiation constant throughout the PV system; (b) Generated PV power and theoretical maximum power; and (c) Total energy generated by the PV system (c) The PV system's voltage distribution. (d) The current taken from the PV array varies. The PV system's energy efficiency is measured in kilowatts per square metre of area. (f) Battery bank condition of charge (%), which shows the charging and discharging state of the battery bank; (g) Battery bank current variation; (h) The DC-Link I's voltage. (I) Three phase voltage across load, (j) Power flow profile from battery bank, and (k) Power flow profile from battery bank Total instantaneous power to load (l), load current (m), and total instantaneous power to load.

6 Commercial Planning of Microgrid

To market a microgrid as a commercial product, various difficulties must be addressed. A microgrid may not function politically because the local utility does not recognise the value of replacing the macrogrid with microgrids. Microgrids may take longer to establish themselves as major power supply agents. Wires and transmission components, after all, are still owned by utility corporations. Transferring electricity over the macrogrid requires permission from utilities. Furthermore, utility companies see the microgrid as a competitor and have begun to spend in improving macrogrid stability. Furthermore, current grid codes must be updated to include microgrid considerations. Localized electricity would benefit users, energy, and the environment, but utility firms do not see it that way politically. The status of the industry is through a revolution and thorough examination until all essential issues are addressed and judgments are taken. Utility companies are already sluggish to adopt new technologies, but microgrids will not be financially viable until they relinquish ownership and management of equipment. Still, additional study is needed to address a number of crucial challenges, as well as to promote and support microgrids from suppliers to municipal and federal governments.

7. Conclusion

Alarms about global warming, pollution, and carbon footprint emissions are now causing concern about this issue. Microgrid systems make distant applications possible, provide pollution-free electricity, and encourage the use of renewable energy sources. A microgrid is also one of the greatest options in the case of a power grid outage. As the need for energy continues to climb, renewable energy technologies aid in the generation of clean and sustainable energy. However, there are a number of obstacles that must be overcome in order to enable the RES that may be utilised to accomplish potential. Renewable resources are widely scattered, and because to the intermittent nature of electricity, such a new distributed system may be supplied by a variety of generating ways in order to maximise the sources' potential energy. The purpose of this survey article is to define the microgrid term and draw out the conceptual components for several research domains. The potential research directions that are necessary for the future development of microgrids have been anticipated. The MAS has been used to describe the centralised and decentralised hierarchical controls of microgrids. Decentralized control has various benefits, such as plug-and-play functionality. Microgrid communication, stability, and control difficulties have been discussed. Finally, the expansion of the global distributed generation sector has been used to demonstrate the potential features of future microgrids.

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