IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received October 1, 2019, accepted October 19, 2019, date of publication November 4, 2019, date of current version November 20, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2951459

Overview of the Optimal Smart Energy Coordination for Microgrid Applications

NSILULU T. MBUNGU[1,3], RAJ M. NAIDOO[1], (Senior Member, IEEE),
RAMESH C. BANSAL[2], (Senior Member, IEEE),
AND VAHID VAHIDINASAB[3], (Senior Member, IEEE)
[1]Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria 0002, South Africa
[2]Department of Electrical Engineering, University of Sharjah, Sharjah 27272, UAE
[3]School of Engineering, Newcastle University, Newcastle upon Tyne NE1 7RU, U.K.

Corresponding author: Nsilulu T. Mbungu (mbungungunsilulu@gmail.com)

This work was supported in part by the Southern African Systems Analysis Center (SASAC), in part by the South Africa National Research Foundation (NRF), in part by the Newton Fund | British Council, and in part by the University of Pretoria; the first author thanks them for their sponsorships.

ABSTRACT This paper describes an overview of the optimal energy coordination/management approaches for microgrids. The article presents the smart grid environment in conjunction with their technologies into the applications of a microgrid when the energy coordination aims to create power flow stability between the generation and consumption of the electricity. This energy equilibrium is made regardless of a power grid complexity that can contain diverse load demands and distributed energy resources (DERs), including renewable energy system (RES), energy storage system (ESS), electric vehicle (EV), etc. A microgrid often contains an energy mix system that requires three control levels, namely primary, secondary and tertiary, to optimize the energy cost and behavior of the system operation and exploitation. Based on several DERs, a microgrid can operate in island mode or be connected to the main grid. The energy coordination for both features is to deal with the energy resources uncertainty, the climate impact, to reduce atmospheric pollution deriving from the conventional power grid, and the energy demand growth. Through the smart grid technology, the optimization approaches of this coordination have brought several improvements into the electrical system. Thus, an overview of an intelligent energy management system for microgrid applications is intensively detailed to structure the implementation strategies which aim to coordinate the energy flow of an electrical system optimally.

INDEX TERMS Energy efficiency, energy management, disturbed energy resources, optimal control, smart grid.

NOMENCLATURE

AC	Alternative Current
AFR	Air/Fuel Ratio
AMI	Advanced Metering Infrastructure
BAN	Building Area Network
COP21	The 21st yearly session of the Conference of the Parties
CPP	Critical Peak Pricing
DC	Direct Current
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management System
DES	Distributed Energy Storage
DG	Distributed Generation
DGR	Distributed Generation Resources
DMS	Distribution Management System
DNO	Distribution Network Operator
DR	Demand Response
DS	Distributed Storage
DSL	Digital Subscriber Line
DSM	Demand Side Management
DSO	Distribution System Operator
EE	Energy Efficiency
EGM	Energy Generation Management
EI	Energy Internet
ESS	Energy Storage System
EV	Electric Vehicle
FAN	Field Area Network
FLISR	Fault Location Isolation and Supply Restoration
FTTx	Fibre to the x "Neighborhood"

The associate editor coordinating the review of this manuscript and approving it for publication was Yang Li.

GC	Group of Customer
GIS	Geographic Information System
HAN	Home Area Network
HFC	Hybrid Fiber Coaxial
IAN	Industrial Area Network
IC	Individual Customer
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISO	Independent System Operators
LAN	Local Area Network
LV	Low Voltage
MAN	Metropolitan Area Network
MPC	Model Predictive Control
MR	Mobile Radio
MV	Medium Voltage
NAN	Neighborhood Area Network
OMS	Outage Management System
PAN	Personal Area Network
PC	Personal Computers
PLC	Power Line Communication
PQ	Active and Reactive Power
PV	Photovoltaic
RC	Radio Communication
RER	Renewable Energy Resource
RES	Renewable Energy System
RF	Radio Frequency
RMS	Root Means Square
RTP	Real-Time Pricing
SCADA	Supervisory Control and Data Acquisition
SR	Spinning Reserve
TOU	Time of Use
US	United State
V2G	Vehicle-to-Grid
VLC	Visible Light Communication.
VVC	Volt-Var Control
VVO	Volt/Var Optimisation.
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Line Area Network
WMAN	Wireless Metropolitan Access Network
WPAN	Wireless Personal Area Network

I. INTRODUCTION

SMART GRID technology is one of the key solutions to several problems of the conventional power network, from energy generation to the demand side. The "smart grid" consists of many improvements and innovations for the traditional power grid. While modern electrical networks introduce novel technologies based on real-time controlling and monitoring to ensure the stability and the quality of power flow in the electrical grid, a microgrid is a fundamental platform that effectively introduces the implementation for future intelligent networks. The microgrid allows integration of distributed generation (DG) or clean energy and energy storage system (ESS) to actively increase system efficiency between energy generation and power consumption [1].

The energy demand is increasing with population growth worldwide: more than 1.2 billion people do not have access to the electrical grid globally. This problem leads to an energy crisis due to the inadequacy of conventional power supply based on traditional energy generation, and the necessity for the implementation of the microgrid system [2]. The Paris agreement of holding the increase in the global average temperature well below 2 °C above pre-industrial levels means the ideal limit of the temperature increase is 1.5 °C. This agreement derives from the 2015 Paris Climate Summit, COP21 (United Nations Conference on Climate Change), that encouraged and promoted novel ideas and/or strategies, and green information and communications technologies to reduce the impact of climate change [3], [4].

Clean energy resources integration is one of the sustainable solutions to implement into the energy sector to minimize the impact of climate change [5], [6]. Besides, the global reserves of the conventional energy resources such as coal, natural gas, natural uranium fuel and oil will all be depleted in about 200 years [7]. Thus, the exploration and implementation of renewable energy resources (RERs) are considered to be the future development factors in power sectors to sustain the anticipated energy growth and can maintain the atmospheric temperature at its acceptable level. The wind power and photovoltaic (PV) systems are considered as the most effective clean energy resources to be used in the power sector [8]. Several developed nations, regarded as the most polluting countries, have been promoting power generation from resources which are sustainable and environmentally friendly [9].

The Microgrid is one of the leading platforms that permit the integration of distributed energy resources (DERs) into the power grid. Due to some design difficulties and lack of technologies, the microgrid has not yet matured into being commercialized into large-scale incorporation into the existing electrical networks [10]. There are several challenges regarding the random variation of RERs [11]–[14]. A microgrid can operate efficiently in island mode by actively controlling and driving system behavior from DERs. In the primary grid mode, the system requires zero or close to zero voltage and frequency differences between the grid and microgrid scheme. Smart grid technologies offer an opportunity to optimize the coordination of power flow into the microgrid system in real-time.

The energy management plays an essential role in the stability and operation performance of the microgrid structure due to their implementation physiology, which consists of optimizing the overall system behavior. As the electrical system is an orchestra of several components, optimally managing the power flow between the energy generation and consumption depends on the dynamic system behavior of the entire power grid. When the management is coordinated in terms of satisfying both the energy supply and demand, the overall cost of the electrical system can be optimized, and the entire power grid can be operated in the energy-saving mode. The energy management of a microgrid system optimizes the performance of the system operation and permits an efficient integration of DERs into the new generation of a power grid.

The requirements of grid-management depend on monitoring, controlling and optimization of the power system. This dependency aims to increase the efficiency of the power network by ensuring the system voltage and frequency stability, optimum power flow on the grid and an adaptable protection scheme. In a microgrid, energy coordination is mostly made with the hypothesis of having a system which respects all protection scheme requirements. Therefore, an overview of this work is as follows:

1) Describe the smart grid environment in the context of system design and implementation for energy management based on the technology of information and communication.
2) Present the scheme of the energy generation and supply management in the framework of intelligent system computation to state the system structure and an opportunity for DERs integration.
3) Analyze energy management behavior in conjunction with the smart system implementation and design to describe different demand coordination schemes that assist in minimizing the energy consumption cost.
4) Demonstrate the importance of microgrid design strategy in the context of optimal control energy management on how to coordinate DERs and utility grid effectively.

The remaining sections of this paper are divided as follows: in section II, a literature review on the smart grid system is presented. Section III describes the energy management structure from the energy generation to power demand. In section IV, an intelligent microgrid system is detailed, section V gives discussion on the future direction of the smart energy coordination of microgrid and section VI presents the conclusion.

II. SMART GRID TECHNOLOGY

The smart grid refers to a novel electrical network that acts intelligently to accommodate clean energy, electric power management, grid modernization and consumer participation in an energy-efficient manner [15]–[18]. The intelligent electrical grid also assists the improvement of power operation that minimises power disruptions, which can guarantee a proper network control scheme [19], [20] and a good protection philosophy [18], [21]. Through a communication network, the combination of these four goals of a smart grid, namely RERs, electrical power management or energy management, grid modernization and consumer participation [15] reduce the harmful greenhouse gas emissions of the electrical power industry [15]–[17]. The most popularly clear energy resources used in the smart grid, are wind and solar powers, geothermal, small hydro, biomass and biogas, fuel cells and combined heat and power EV [15], [16]. The energy market, dynamic pricing (time of use (TOU), critical peak pricing (CPP) and real-time pricing (RTP)) assist in improving the energy management of a smart grid. The energy management approaches will further be discussed in section III. Moreover, these strategies are considered as the schemes that allow the consumer to participate in the fulfilment of the smart grid goals [9], [22]–[27].

In December 2007, the United States Government in their Energy Independence and Security frameworks defined ten great characterizations to describe a Smart Grid better [28]. These features derive from looking at novel strategies to support the modernization of the country's power grid from generation to consumption. This model aims to maintain a reliable and secure electricity infrastructure that can cover energy growth and to state the defined smart grid characterization. These characteristics are listed as follows:

1) Create the ability to increase the use of digital information and control technology that can enhance the efficiency, reliability and security of the electric power grid.
2) Through communicative technology networks, introduce full cyber-security that can guarantee dynamic optimization of grid operations and resources.
3) Ensure the deployment and integration of distributed resources and generation, including RERs.
4) Assist in the development and incorporation of demand response (DR), demand-side resources, and energy-efficiency (EE) resources.
5) Deploy intelligent technology approaches, such as real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices, for metering, communications concerning grid operations and status, and distribution automation.
6) Ensure the integration of "smart" appliances and consumer devices.
7) Guarantee the deployment and integration of advanced ESS and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.
8) Give to energy consumers an opportunity to have the appropriate information and diverse control options.
9) Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the network.
10) Assist the identification and lowering of unreasonable or unnecessary barriers to adoption of Smart Grid technologies, practices, and services.

Fig. 1 describes the different domains or components of power grids [15], from a conventional electrical network to a smart grid. It is observed that the smart grid has four more domains added to the system. One domain consists of integrating the DERs and three other domains are based on the communication networks. The DG on the smart grid

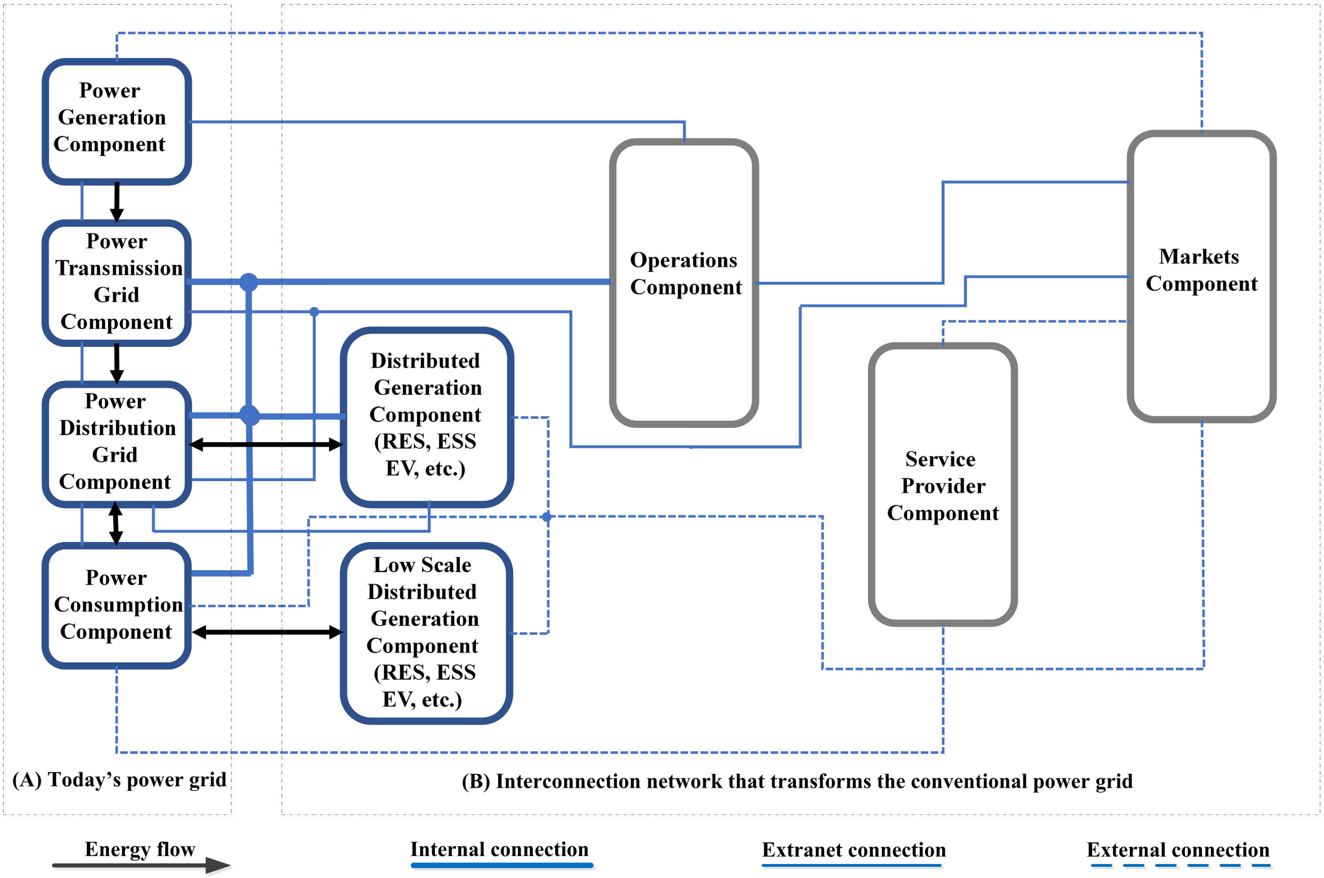

FIGURE 1. Overall layout of future power grid environment.

TABLE 1. Electrical grids comparison [7].

Smart grid	Conventional grid
Adaptive and islanding	Failures and blackouts
Digital	Electromechanical
Distributed generation	Centralised generation
Many customer choices	Few customer choices
Network	Hierarchical
Pervasive control	Limited control
Self-healing	Manual restoration
Self-monitoring	Manual monitoring
Sensors throughout	Few sensors
Remote check/test	Manual check/test
Two-way communication	One-way communication

environment is integrated in to two principal components. It is important to note that the power generation component can be considered as a combination of traditional and RERs. For today's grid, it can be seen that the energy producer cannot satisfy the expanding energy demand. However, for the future electrical networks, the introduction of DG brings more satisfaction on the consumer side and less stress on the supplier side. Table 1 gives a brief overview of a comparison between the smart grid and the existing grid [7].

The layout of future power grid also gives the energy flow on the electrical network from generation to consumption. By isolating the conventional power grid of the described layout for the future electrical network, it is essential to note that the energy flow on the electrical system between a distribution and the consumption can only flow in one direction. Nevertheless, this flow has a bidirectional flow, as described in Fig.1, because the system representation is based on the evolution of the electrical grid. Thus, the future electrical network has a flexible energy flow system where the consumers and the distribution system operators (DSOs) can operate effectively, as shown in Fig.1, the energy flow between power distribution grid, power consumption and DG (both a large and a low scale) component. The distribution network operators (DNOs) which consist of several DSOs mostly operates in transmission and/or generation level of the hierarchical architecture of the electrical network as described in the future layout of power grid. In microgird application, the DNO is, therefore, considered to be at the transmission-level which can be called a network of microgrid. The DSO can also be constituted of a group of several isolated microgrids.

According to the IEEE's Vision for intelligent grid communications, the smart grid interconnection network from the power generation to the power consumption is devised in four principal networks [29], namely Home Area Network (HAN) or Local Area Network (LAN), Neighbourhood Area Network (NAN) or Field Area Network (FAN), Metropolitan

TABLE 2. Smart grid communication networks: Wireless technology.

Types	Application	References	Types	Applications	References
Wi-Fi (WLAN)	AMI; NAN; BAN; IAN; HAN; WAN	[32]–[37]	WiMax	MAN; WMAN; HAN; AMI; FAN	[38]–[41]
ZigBee	HAN; PAN; AMI; BAN; IAN	[36]–[39], [42]–[50]	RC	HAN; AMI; NAN; FAN; WAN	[51]–[58]
WirelessHart	HAN; BAN; IAN; AMI	[39], [49]	MR	HAN; AMI; NAN; FAN; WAN,	[59]–[74]
6LoWPAN	WPAN	[38]–[41]	Satellite	AMI; WAN	[35], [75]–[77]
Bleutooth	HAN	[36], [41]	RF	PAN	[78]–[80]
Z-Wave	HAN	[81]–[83]	VLC	HAN; PAN	[84]–[86]

Area Network (MAN), and Wide Area Network (WAN). This vision is set until 2030 and beyond roadmap. Some of the researches separate the NAN and FAN, and this is mostly caused by the interconnection network space problem and communication technology. It is important to note that all DG components, as described in Fig. 1, can contain EV, energy storage, PV, wind power, and others energy generation [8], [30], [31]. The future power grid environment also uses the smart metering infrastructure to measure the energy flow on the system.

However, the IEEE vision gives a different explanation that resolves this ambiguity and serves as a guideline to engineering design. This explanation assumes that the HAN is related to autonomous power consumer, NAN or FAN is based on power distribution and consumption; MAN refers to power distribution and transmission, and WAN is similar to power transmission and generation. The HAN can be seen as a controversial network from the consumer side because there are several types of consumers. Therefore, on the consumer side in the modern power grid, the area networks are referenced for different kinds of consumers. These are HAN for residential applications, Building Area Network (BAN) for commercial applications, and Industrial Area Network (IAN) for industrial load demand. In residential usage, there is also a Personal Area Network (PAN), which can be implemented inside HAN.

A. COMMUNICATION TECHNOLOGY

One of the main advantages of the smart grid is its ability to embed the power grid and the communication networks efficiently [134]. Thus, communication technology is the key support of a smart grid environment, which aims to achieve the informatisation, automation and interactivity of a smart power system through the reliability of data transmission [118], [134]. In the context of energy consumption, the smart grid improves the interaction between power supplies and demands in a real-time environment [9], [15]–[17], [22]–[24], [28], [50], [118], [130], [134]–[137]. It is observed in terms of enhancing comprehensive service capabilities of a power grid, improvement of EE, and promotion of power conservation as well as the release of green gas in the atmosphere [118].

There are two principal types of communication technologies used in the smart grid, namely the wireless and wireline communication [134], [135]. Different communication technologies that can be deployed in a smart grid environment are detailed in [29], [138]–[150]. Tables 2 and 3 describe different applications of communication technologies used in the smart grid environment from generation to demand. Thus, the wire-line communication structures are mostly used in low frequency (in the range of less than 500 kHz [137]) and often in short distance of smart grid technology [135]; while the wireless system is used on the high-frequency communication network in smart grids and for long distances. In contrast, the equipment of wire-line technology in the smart grid communication network is more expensive compared to wireless equipment [134]. Thus, wireless is also suggested for a few interfaces for short distance of smart grid design [9], [22], [23], [135].

As shown in Fig. 1, it is worth noticing that the smart grid is the new power grid which brings several revolutions in terms of DERs, communication technologies and services [134]. This novelty can be found through the integration of a smart system in control center, where the power generation becomes the combination of conventional and RERs, and consumers can also integrate the distributed generation resources (DGRs). It is made possible by a system monitoring, remote control and optimal management. In the transmission line, a WAN is based on wireless networks and/or wire-line networks, which can be assured through the integration of smart sensors and controllers.

In Table 2, conventional wireless communication technologies that can be implemented in a smart grid environment are presented. WLAN is Wireless Line Area Network, Wi-Fi is the wireless fidelity, and WPAN is Wireless Personal Area Network. ZigBee, WirelessHart, 6LoWPAN, Bluetooth and Z-Ware are also some wireless technologies that can be implemented in the smart grid environment as described in Table 2. WiMax is Worldwide interoperability for microwave access, RC is Radio Communication, MR is Mobile Radio, RF is Radio Frequency, and VLC is Visible light communication. While in Table 3, most used wire-line communication technologies are set. It is important to notice that DSL is the acronym of the digital subscriber line, FTTx defines fibre to the x (where x can be Neighborhood, building, home and office), and PLC represents power line communication.

TABLE 3. Smart grid communication networks: Wired technology.

Types	Application	References	Types	Applications	References
Ethernet	HAN, BAN, IAN, NAN	[87]–[97]	Coaxial cable	HAN; NAN; FAN	[98]–[100]
DSL	HAN; MAN; WAN	[101]–[105]	Twisted pair cable	HAN; NAN	[100], [106], [107]
Optical Fiber	WAN	[105], [108]–[111]	FTTx	HAN; BAH; NAN;	[112]–[114]
Telephone line	HAN	[115], [116]	PLC	AMR; AMI; HAN; NAN;	[117]–[133]

The Ethernet communication technology can be employed either in wired or wireless sectors [87]. It has been observed that the power line communication network is the most employed wired technology in HAN due to its several advantages. Some of the techniques can be combining with the wireless to form a hybrid communication strategy. This hybridization depends on the specific requirements of the system design and the achievement of communication stability and flexibility in the smart grid. There is also a hybrid communication technology in the wired system such as HFC (Hybrid Fiber Coaxial) network, which combines both fiber and coaxial technologies. Due to the large size of the electrical grid, in the smart grid environment (from power generation domain to energy consumption sector), it is not possible to use only one communication technology network. It is also important to notice that the power engineers tend to avoid latency from communication networks wherever possible as it adds to the point of failure and can reduce the reliability of the power system [29].

Additionally, in power distribution lines, the smart grid system has allowed the integration of DG (PV, Wind power and battery storage), to form a Microgrid area. This system operates under NAN or FAN, which can operate either in Wireless Networks and/or wire-line Networks that are supported by sensors, controllers, intelligent electronic devices and smart meters. On the demand side, Advanced Metering Infrastructure (AMI) ensures the communication between the DSO and the consumers (residential, commercial, industrial and public lights [15]). While the power consumption becomes the combining of DERs (EVs, renewable energies and battery storage) with the dynamic energy demand system that contains some smart appliances. This structure is made possible through a premises communication technology that is based on HAN, BAN and IAN [134].

B. SMART METERING

From power generation to energy consumption, the smart metering is a fundamental element of the communication network in the smart grid. Several concepts are used in the smart grid to express intelligent metering technology. The most frequently smart measurement strategies are based on AMI [151], which can be seen in the form of smart sensor devices and smart meter devices. The intelligent sensors are mostly used in power generation, transmission lines and power distributions, while the smart meter devices are applied in power distributions and power consumptions [134], [152]. The AMI system architecture has three significant levels, which are smart meters, communication network and data center [153]. The communication infrastructure of intelligent metering is based on WAN, FAN, LAN and HAN [154], [155].

Some high energy demand consumers (industrial and commercial demands, even in residential sectors) can also use the smart sensor for specific applications. It is necessary to note that intelligent meters constitute several sensors with the ability to store data and communicate with the entire power grid [151]. The use of the smart meter has provided some opportunities in the electrical system with its ability to transfer big data. These include instantaneous voltage, current, apparent power, real power and reactive power; peak voltage and current; root means square (RMS) voltage and current; phase displacement, system frequency, energy use and production, harmonic voltage distortion and total harmonic distortion [151], [156]. The opportunities are load forecasting, fault detection and demand-side management (DSM) [156].

The smart metering allows better control and/or monitoring of the new generation electrical power grid. It is also considered as a data generation point that enhances the two-way communication between the consumer and the supply [157]. Through adequate security of a smart grid deployment, the combination of intelligent metering and a proper control system philosophy, it can guarantee grid stability, minimization of utility fraud as well the loss of user information and data [158], [159]. The combining of these two schemes is well structured in [158], which has four main components, namely utility company, substation/data concentrator, HAN, smart meter and a third party.

Recently voltage and frequency regulation and power quality monitoring and control of the electrical grid, are ensured through smart meter devices [160]–[163]. Additionally, the smart metering system can also assist the DSO to detect and locate all non-technical losses in distribution networks. These are the data attacks, smart meter attacks (device ripped off the wall or smashed) and electricity theft [159], [164], [165]. Some researchers use the smart metering features to create an energy-efficient system [9], [22]–[24], [135], [154], [166]–[168]. Mbungu *et al.* [26] have proposed an optimal single-phase intelligent metering system that can optimally coordinate the energy flow in the residential sector.

It has been found that through the implementation of AMIs, the conventional power system can be transformed into the new generation of electrical network industry [151].

C. DATA MANAGEMENT

One of the principal purposes that make smart grid technology attractive in the new generation of power system industry is its ability to collect large-scale data. However, to manage this massive amount of the information can create considerable pressure among control and planning engineers in terms of the transmission and storage of data [156]. The smart grid application and deployment through faster metering big data transfer assists the reduction of this pressure. Thus, the characteristics of electric power grid, big data management, are volume, velocity, variety and value [151], [156], [169]. While the challenges of this scheme are multi-source data fusion, data analysis and security and privacy protection of electrical power big data [156]. Through a proper data management philosophy, these challenges can be resolved. In [169], authors have presented the problems of smart grid data transfer from energy generation to energy consumption, which are scalability, real-time, security, data access and sharing of information, storage and processing issues, heterogeneous data, and reliability. Some of these challenges are seen as the smart grid's big data core components [170].

Liu *et al.* [171] have proposed the graph data model and computing technology-based power flow as a promising tool that can handle the data management challenges in the smart grid environment. In [157], secure and scalable data communication protocol for intelligent data management is presented to minimize the time of data collection. This procedure operates under a hierarchical architecture where data collectors or relay nodes securely collect and convey data from measurement points to the power operator. The system combines secure data with an objective function of time minimization to optimize the transfer time. In [170], a framework that covers the life-cycle data behavior and deals with smart grid big data structure proposed under visual analytic schemes. The system operates under a dynamic DR that coordinates big data components (data generation, data acquisition, distributed data storage, data processing, data querying, and data analytics) for visual monitoring.

In [169], a data management model for smart grid environment is proposed. This model consists of an adaptive big data application structure in the smart grid where the combination of a situation (events), customers (facilities) and equipment (sensors) collaborate to ingest data. In [172], a smart wireless sensor network based on the infrastructure framework for quick transactions, namely SWIFT architecture, is proposed to provide a big data solution for the intelligent environment. The designed SWIFT aims to coordinate the operation, monitoring, controlling and managing activities in smart cities. The overall system architecture is based on three steps, which are the deployment of various equipment for monitoring, controlling and auditing, such as sensors/devices, data collection, and data preprocessing and processing.

In [173], a centralized false data injection detection is presented as structured learning that can ensure the integrity of data in the smart grid environment. The objective of this scheme is to guarantee the accurate data in the robustness of control and management manner, which can protect the electrical grid against any attack, and provide a platform to monitor and control the power grids. The approach applies a Markov graph on the network bus phase angles where the conditional covariance test is utilized to structure the electrical grid. As a statistical strategy, it can ensure better management, monitor and control of Data.

Recently, in [174], a random metric theory, namely RMT, is introduced as the mathematical foundations that can map the smart grid system containing big data technology. Through this proper procedure, the authors have proposed a high-dimensional statistic, mean spectral radius, to indicate the data correlations. The method did more concise strategy, which was considered as the first attempt to apply big data technology into smart grids. The approach is employed in the different periods of power system backgrounds and foundations, which involves the management modes, data flows and energy flows.

D. PRIVACY ON SMART GRID

The big data and the internet of things (IoT) are considered as the new privacy challenges in a smart grid technology [151]. It is also important to note that from the end-user side, personal data in the intelligent metering application has led to privacy concerns because this can be destroyed by a simple miss monitoring of diverse appliances [175]. Thus, data privacy in the smart grid requires proper design features and communication technologies. On the other hand, the security goals in an intelligent network are based on authentication, usage data confidentiality, usage data integrity, consumer privacy and forward secrecy [176].

In [177], a privacy-preserving scheme is proposed to hold the incentive-based DR programs. This structure is considered as the first strategy to be addressed in the smart grid technology. The method develops the requirements of fine-grained metering data to analyze individual demand curtailments and preserve customer privacy and efficiency during the DR reward and billing process. The strategy combines several cryptographic primitives, such as identity-committable signatures and partially blind signatures. In [178], privacy under dynamic pricing is addressed based on the billing system in the smart grid. The method uses symmetric fundamental cryptographic primitives as the hash function and single-pass lightweight that is based on authenticated encryption to ensure security and privacy-preserving data aggregation structure.

In [176], an efficient data aggregation scheme that combines dynamic pricing based billing and DR strategy is proposed. The approach aims to guarantee a privacy-friendly and suitable data aggregation structure. As a novel strategy, this proposed design offers better privacy protection for electric meter reading aggregation and computational efficiency.

The proposed scheme contributes to an efficient authentication and key establishment scheme, computational efficiency, novel data aggregation method, and provides a higher degree efficiency.

In [179], it is stated that the efficiency and effectiveness of smart grids depend on the consumer data collection, process and analysis, which can be used for billing, monitoring and prediction. Therefore, the authors have proposed the masking method based on the privacy-aware approach for spatiotemporal aggregation of time series data, which can protect individual privacy and provide sufficient error-resilience and reliability. In [175], the impact of data granularity on smart metering approach is addressed to present potential privacy implication in intelligent metering to the consumer or to the DSO. The edge detection methods are used as the first step in non-intrusive load monitoring algorithms. One-versus-rest ossification modelling is applied so that the F-scores can evaluate the ability to detect an appliance's use.

Proper privacy of the smart grid environment is made under an excellent combination of communication, metering and data security or management. This scheme ensures the efficiency of the power grid and assists engineers to monitor, control and design future power grids.

III. ENERGY COORDINATION APPROACHES

The coordination of energy from generation to demand-side aims to ensure an optimum flowing of the electric power in the network. The structure is called energy management. This scheme is observed in three steps of the electrical power grid (generation, distribution and consumption of energies) and several concepts of the application strategies [180]. Energy management suggests economic methods and/or an opportunity to satisfy both the power suppliers and consumers. On the generation side, energy management reduces the stress on equipment and power resources and also assists the planning engineers to coordinate better power generations and supplies that can avoid the energy crisis.

This energy management is seen as a cost-effective approach that is vital to national security, economic productivity and environmental welfare. Controversially, the implementation of any given energy management strategy sounds costly in all levels of the power grid, namely generations, distribution and consumption. However, it has tremendous added value in the future for energy stakeholders.

In the smart grid environment, as the principal goal is to transfer data between the different components of the power grid as described in Fig. 1, some different decisions can be made in each element. In the context of big data for smart grid management, the whole process decision that supports the power grid efficiency can be seen as [181]:

1) For the generation side, the primary decision support strategies are generator planning and optimization, economic load dispatch, power generation efficiency improvement, renewable energy planning and management.
2) The transmission line can contain power grid planning, grid loss identification, fault detection, outage detection and restoration, and asset management.
3) In the power distribution and transformation level, real-time sensing, voltage optimization, transformer health, fault detection, outage detection and restoration, and asset management are seen as the principal strategies that can be made.
4) In the DSM, the critical decision can be the DR, load forecasting, load classification and customer segmentation, dynamic pricing, real-time interaction and energy saving, and revenue protection and theft detection.

It is worth noticing that this list of strategies is not exhaustive. In this section, only the three principal components that play directly in the energy management strategy are considered, namely generation, distribution and consumption.

A. ENERGY GENERATION MANAGEMENT

The energy management in the generation side, namely energy generation management (EGM), consists of securing the power production. This method is not necessarily looking for the cheapest energy that is generated but for the reliability and availability of the power generation. The mixing of energy production aims to secure the power flow from the generation side and to ensure satisfaction on the demand side. Through energy generation management, the power and/or planner engineers work to find a better alternative energy resources, which are always available regardless of their prices and seasonal variations.

The energy generation originates from several energy resources which can be in the form of conventional (non-renewable) and renewable. The conventional or traditional power resources are coal, natural gas, fossil fuel, and oil. The renewable resources are biomass (wood and wood waste, municipal solid waste, landfill gas and biogas), biofuels (ethanol and biodiesel), hydro, geothermal, wind, solar and energy storage. Some resources like natural uranium and hydro are considered RERs, but in some scenarios, these are seen as traditional resources.

The leading causes of most of blackout and load-shedding are a lack of structuring the coordination of power generation, which can be observed in the context of the energy management, and proper long-term planning philosophy in the production side. This stress situation often derives from a low quantity of energy resources, due to diverse reasons, such as socio-economic and environmental problems.

In the power system, the generation planning procedure is a function of the operation planning perspective, which depends on a cyclic process of the basic plan for electricity supply and demand, power system screening and analysis, and investment plans [182]. The cycle consists of a better consideration to plan the power system operation and integrate DERs so that the efficiency of the power grid can be at its acceptable level.

In Zhang *et al.* [183], a distributed algorithm model is presented to address the intrinsically stochastic availability

TABLE 4. Evolution of distribution management system.

Generation	Computing System	Performance Goals	Technologies	Application	References
First Generation (1980)	Mini computers	Improve reliability and efficiency of legacy systems	Specialized and unique needs, i.e, no communication or coordination	SCADA, VVC for individual components	[188]–[193]
Second Generation (1990)	Standard personal Computers (PCs)	System wide enchanced efficiency and reliability	Integration and coordnation of functions to improve operator effectiveness	Coordinated SCADA	[194]–[196]
Third Generation (2000 "dawn of smart grid")	Network of power PCs, sever farms	Security, safety, reduced cost, customer interface	Smart meters/AMI, DERs, RERs	GIS, model based FLISR, AFR, VVC and switch plans	[197]–[205]
Advanced Third Generation (2010)	Improved networkig, mobile and cloud computing	Real-time situational awareness, enhanced customer interface, resiliency, enhanced PQ	Higher penetration of solar and wind, EVs, storage, microgrids	DERMS, OMS, VVO control and protection, microgrid operation	[205]–[215]
Fourth generation (2020)	Mobile cloud computing	DER integration, integrated performance improvements, environmental goals	Higher penetration of DERs, EVs, storage and retail market mechanism into distribution domain	Optimisation, decision support, etc.	[216]–[222],

of RERs with battery storage. Through a robust optimisation scheme, a novel power scheduling strategy is developed. The system aims to coordinate an economic dispatch, energy management and DERs that contain the DG and distributed storage (DS). The approach is considered as a robust energy management formulation that can minimise the overall cost for microgrids when a high penetration of RERs is taken into consideration.

A simulated annealing approach under an intelligent energy resource management to consider Vehicle-to-Grid is designed in [184]. The proposed model develops a virtual power player to address energy resources management in the smart grid manner. The system contains a large number of DGRs. It is observed that through the proposed strategy, excellent solutions are obtained in a lapse of times, which can provide proper decisions in terms of energy resources management.

In Quijano *et al.* [185], active network management was proposed to improve the system EE. Though the capacity of variable DG, the proposed model formulates linear optimal power flow scheme to handle a multi-period and multi-objective optimisation algorithm. This strategy consists of two-stage stochastic assessment based on the multi-objective problem, which consists of optimisation and coordination of the operation voltage and the management of RERs.

Sohn [186] has developed mixed-integer linear programming to deal with the generation applications package based on DERs. The structure aims to increase the total EE by combining the heat power with a microgrid energy management system, which can be connected to the grid or operating in island mode. The economic dispatch and generation scheduling are the principal strategies used here to formulate and solve the forecasting problems of heat load and PV generation.

A macro multi-agent solution is presented in detail to formulate the overall optimisation function based on Java Agent development in [187]. The optimisation model is designed for hybrid renewable energy generation system. Through the purpose of energy management, the multi-agent solution approach is considered as a suitable solution, which aims to coordinate the energy flow of the distributed hybrid PV-wind generation system with storage on a small scale. Moreover, the development model can reorganise the RERs in respect of environmental changes, compromise the system power performance and cost, and provide optimal use of the system's components.

B. UTILITY SIDE MANAGEMENT

The energy coordination in the utility side consists of looking at the strategies to maintain the quality of power flow between the generation and demand for energy. It is the main reason for integrating DGRs into the power grid, as described in Fig. 1. Thus, the energy management system approaches developed in [182]–[187] can also be considered as some of the applied strategies in the utility side.

The first designed energy management system was the principal centre of utility grid management, which was based on centralised command and control system. Currently, the decentralised management scheme has been introduced to deal with the large size of the utility where independent system operators (ISOs) can be found. The primary objective of energy management in the utility side is to measure in real-time the grid behaviour that can pro-actively assist in the monitoring of current grid conditions [223].

At the distribution level, the management system aims to improve operator effectiveness through an advanced automation scheme by integrating sensing, monitoring, control and protection. Table 4 describes the genealogy of the distribution management system (DMS) that has been designed since the appearance of novel technologies [224]. This model gives a brief overview of the most relevant strategy that can be applied in the utility grid. Where AFR defines the air/fuel ratio, DER is distributed energy resource, and DERMS means distributed energy resource management system. Besides, FLISR means fault location isolation and supply restoration.

TABLE 5. DSM techniques.

Techniques	References
Night-time heating with load switching	[230], [231]
Direct-load control	[232]
Load limiters	[233]
Commercial/industrial programs	[22], [9], [234]
Frequency regulation	[162]
TOU pricing	[23], [235]
Demand bidding	[236], [237], [238], [239]
Smart metering and appliances	[24], [26], [240]

GIS is geographic information system, and OMS is outage management system; PQ means active and reactive power, SCADA is the supervisory control and data acquisition, VVC is volt-var control, and VVO is volt/var optimisation.

In most cases, managing the energy at the utility side depends on the coordination philosophy that has been applied in the demand side. Thus, it can become challenging to state if the energy managing pattern was previously designed for demand or the utility side. This ambiguity is caused by the fact that most of the improvements made in the utility side in the works of literature found are based on the demand management manner. Therefore, the following subsection III-C describes energy coordination on the consumer side.

C. DEMAND SIDE MANAGEMENT

The principal feature of smart grid systems is based on the DSM [225]. The DSM depends on the timing and the impact that can apply on the process quality, which is categorised by a spinning reserve (SR), DR, TOU, and EE [226], [227]. The implementation of the DSM on the energy system offers several benefits and future opportunities in terms of reducing the generation margin, improving distribution and transmission grids investment and operation efficiency, managing the demand-supply balance in the system with intermittent renewable energies, and integrating large-scale distributed power system [228].

In 1985, Gellings [229] stated the concept of DSM for the DSO, are planning and implementation schemes that influence consumer behaviour. This method consists of load shape objectives based on flexible load shape, load shifting, peak clipping, strategic conservation, strategic load growth, and valley filling. Recently in 2011 [226], it was confirmed that a dynamic DSM does not lead necessarily to the reduction of energy consumption, but instead influences the energy pattern.

Table 5 summarises the different techniques that can be applied in DSM planning and implementation. Notwithstanding it is a new concept with diverse technologies, the application of DSM faces several challenges, which include: lack of information and communications technology (ICT) infrastructure, inappropriate market structure and incentives, and understanding of the benefits of DSM solutions. Furthermore, the increase in the systems' operation complexity cannot often compete with conventional strategies [228].

It is observed in Table 5 that the DR approach is not listed as one of the applied techniques of DSM. In [226], the authors have summarised DR as one of the DSM approaches that can be implemented in several methods, as described in Table 5. The DR program has two types which are incentive-based programs (including demand bidding and buyback, direct load control, emergency DR, interruptible load, load as capacity resource, non-SR, regulation service and SR), and time-based programs (including CPP with control, CPP, peak time rebate, RTP, TOU, and system peak response transmission tariff) [226], [227], [241], [242]. It is worth noticing that through smart metering techniques, all time-based DR programs can be designed [24], [26], [155]. The DR strategy offers an opportunity for several sampling intervals for a dynamic control scheme in order to find optimal satisfaction for both supplier and consumer. The advantage of DR is its facility to coordinate a closed-loop control structure that can optimally manage the energy flow of the electrical system [243].

Adika and Wang [244] have proposed a smart appliance scheduling strategy based on DSM for household energy management in the framework of the microgrid environment. The system integrated RERs in the form of wind and solar microgrids interact with the primary grid and the consumers DSM in a real-time manner. The designed model ensures the efficiency of the energy flow of the microgrid system through the used of DR strategy that assists to also deal with diverse uncertainty of DER. The optimal energy management system of the electrical grid operates with the coordination of uncertainties when DSM interacts with utility management effectively.

D. INTEGRATED DEMAND RESPONSE

The integrated demand response (IDR) is an advanced scheme of the traditional power system DR. The IDR aims to change the energy pattern benefits by considering the interconnection relationship of multi-energy networks that participate in DR programmes. The IDR can contain electricity, heat, natural gas and any other form of the energy resources on the system [245]. The structure of multi-energy systems which operate in the same fashion of management is also called integrated energy coordination system [246]. This scheme introduces the concepts of the energy internet (EI). The IE has for features internet thinking to reshape the energy networks by creating a synergy of multi-energy systems, internet methodologies (such as cloud computing, big data, IoT, blockchains, etc.), and new business models and energy markets. It is essential to notice that the integrated energy coordination system is the brain of the EI.

Through the consideration of IDR strategy, the energy trilemma can be adequately addressed to ensure security, sustainability and affordability of the energy system [247]. The energy coordination using the IDR scheme brings a win-win situation for both energy multi-energy operator and factories and also eliminate some computational difficulties and conflict of interest between power system stakeholders.

TABLE 6. Classification of microgrid systems by size and applications.

Type	Voltage level	Maximum Power	Applications	Reference
Picogrid	Low voltage (LV) level	$\leq$ 10 kVA (kilovolt-ampere)	Feeder segment (Individual customers)	[261]
Nanogrid	LV level (microgrid at secondary side)	$\leq$ 100 kVA	Feeder segment (Individual and/or GC (group of customers))	[252]
Microgrid	LV level (microgrid at secondary side)	$\leq$ 1 MVA (megavolt-ampere)	Feeder segment (small commercial and/or large of GC)	[235]
Minigrid (Milligrid)	Medium voltage (MV) distribution level (microgrid at primary)	About 10s of MVA	Distribution substation	[262]
Megagrid	$\geq$ 120 kV	about 100s of MVA	Large windfarm with storage	[19], [263]

One of the essential advantages of considering IDR scheme is to have more flexibility and lower interactive compensation with more adjustable energy resources. The benefit of implementing coordination strategy can be shared to both the power generation and consumption [248]. Thus, the following section IV analyzes the optimal energy management strategies for microgrids.

IV. MICROGRID SYSTEM

A controversy of definition can be found between the smart grid and microgrid. Some researchers have stated that a microgrid is a part of the smart grid while some argue that a microgrid is an entirely apart system. As described in Fig. 1, it can be seen that a microgrid is a combination of two components in a smart grid environment. This is expressed in the forms of power consumption and DG components, in large scale (distribution level) and low scale (consumption level).

According to the US Department of Energy and the Electric Power Institute, a microgrid is a section of a distribution system that contains loads and multiple DERs, such as controllable loads, DG (wind power, PV, etc.), and ESS. The network can be operated in a controlled and/or coordinated manner concerning the power grid requirement where it can be either connected to the main grid or operated in island-mode [249]. The first constructed power plant by Thomas Edison in 1882 was a microgrid. This concept is made because, at that time, the centralized grid was not yet developed [250]. Thus, the evolution of the microgrid has a long history [251].

A microgrid is categorized into three types depending on purpose, supply system, and size. The microgrids by use are customer or true microgrids, utility or community microgrids (namely milligrids), virtual microgrids, and remote power systems (namely island microgrids). The supply features of microgrids are an alternative current (AC) microgrid, direct current (DC) microgrid, hybrid microgrids and network (or meshed) microgrid. Table 6 describes different types of microgrids according to their size (power and system voltage) and applications [252]–[254].

The energy coordination for different structures of microgrids can use the same strategy for AC microgrid, DC microgrid, AC/DC hybrid microgrid and microgrid cluster. However, the system will be of lower power efficiency for AC microgrid compared to DC microgrid, which has high power system efficiency with a considerable initial cost, the unfamiliarity of the structure and lack of incentives [255], [256]. The hybrid AC/DC microgrid offers several benefits to the entire electrical system from power generation to consumption [257]. Due to system improvement, the hybrid structure can be flexible and provide more efficiency on the system but can have a complex architecture which is caused by different voltage system and power configuration [20], [258]. Besides, a microgrid clustering architecture is considered as an advanced hybrid microgrid which contains multiple microgrids within a specific range of distance with one or different power configuration [259], [260].

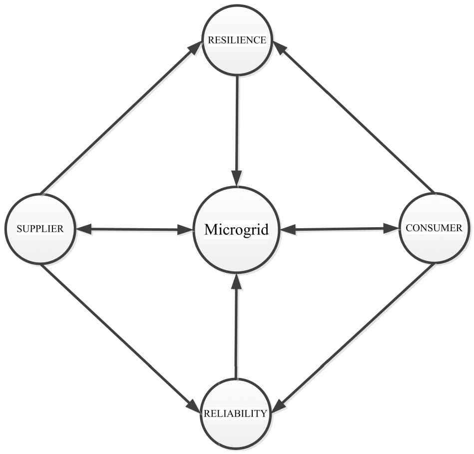

FIGURE 2. Microgrid goals: relationship between supplier and consumer.

Based on the different sizes of the microgrid, as shown in Table 6, some local/regional or national networks can also be considered as a microgrid (or meshed microgrid). This assumption depends on the classification level and the engineering consideration point of view. As the future electrical grid consists of interconnecting several independent power grids intelligently, the next power grid will be the combination of several microgrids in a quick manner.

From the customers to the energy generation, microgrid employment introduces several benefits into the electrical network. The benefits of microgrids are autonomy, compatibility, cost-effectiveness, efficiency, flexibility, peer-to-peer modelling, scalability, and stability [252]. The operational power behavior for a microgrid has four key benefits, which are reliability, resiliency improvement, efficiency, and environmental impact minimization [264]. The first two key benefits (resilience and reliability) improve the flexibility between the supply and demand of energy. Thus, the reliability and resilience of a microgrid bring efficiency into the power system and reduce the environmental impact by controlling and monitoring in real-time the electrical network and by providing more DERs.

Figure 2 presents the operational relationship that exists between the supplier (or DSO) and the consumer in the term of resilience and reliability. This scheme represents the primary goal of a microgrid. Suppose the middle circle represents a microgrid environment that does not exist; it can be seen that there is a separate connection between the consumer and the DSO. It means that if the DSO is looking to achieve the resilience relationship between the energy supply and consumption, the system is losing its reliability. On the other hand, when the consumer is concerned about its authenticity with the supplier, there is no more resilience between energy demand and supply.

However, when the microgrid environment is introduced, as depicted in Fig. 2, resilience and reliability both converge to the same circle of the microgrid. Thus, the supplier and the consumer can operate in the better comfort of the electrical system where the efficiency of the power grid increases. It is important to note that the resilience and the reliability between the consumer and the utility supplier are seen in the context of the energy flow, voltage regulation, and load frequency control. From these characteristics, resilience and reliability between the energy demand and supply, several features can be derived into microgrid applications.

The advantage of clustering resilience and reliability in a microgrid environment, as described in Fig. 2, deals with several uncertainty events which can be derived either from load demand or DERs. The strategy of reaching microgrid's principle goal operates effectively when the energy management approach is added to coordinate the power flow pattern. From DERMS to DSM, the microgrid architecture brings satisfaction to both DSO and consumer. It is necessary to notice that when the microgrid is operating in islanded mode, the microgrid goal as described in Fig. 2, will not contain the supplier circle from the DSO. However, the electrical system will be more efficient in terms of meeting the system goals which is based on resilience and reliability of the energy flow pattern.

A. CONVENTIONAL MICROGRID

The traditional microgrid is a mini-electrical system, as described in Table 6, that does not contain the communication interconnection network as described in Fig. 1. The system can conventionally hold three hierarchical control levels of an operating microgrid as presented in [265]. Microgrid control levels are structured as follows: primary, secondary and tertiary. These control steps serve to design and model a dynamic performance of the microgrid system whether connected to the main grid mode or in island mode. All those control levels are implemented in all types of supply microgrids, namely AC, DC, and hybrid. For a DC microgrid, the electrical network frequency is not considered.

The primary control scheme aims: (i) to stabilize the system voltage provision and preserve the frequency stability, (ii) to offer plug and play capability of DGs by assuring a proper share of active and reactive power on the system (this is made possible without any communication scheme), (iii) to guarantee right-through capability of the circulating current among DGs by preventing the system damage and avoiding the overcurrent phenomenon. This control is designed into the internal behavior of each DG connected to the microgrid.

The second control step is the secondary control. This aims to restore the voltage and frequency of a microgrid and to compensate for the voltage and frequency deviations due to primary control. This level is considered as a centralized controller that is designed for slower dynamic response compared to the central control.

The tertiary control step plays a vital role between the main grid and the microgrid. This level is the last control step that contains optimal operation strategy and manages the energy flow between the primary network and the microgrid. All these processes are made available by controlling the amplitude and frequency of DG for AC microgrid type. While for DC supply, the tertiary control assures the stability of bidirectional power flow and the system voltage that must follow up the reference voltage of microgrid.

Based on the microgrid's controller structure, as described in [265], the developed control level system has four principal objectives to create an optimal operation cost regarding the load's system, DERs, and/or the main grid. Dealing with the conventional microgrid energy management system requires coordination technologies and strategies that do not contain the communication network as presented in Tables 2 and 3.

In [266] an energy management strategy of the PV system and the diesel generator is presented to assist a microgrid operator cost reduction. The proposed model uses the battery energy management system to deal with the intermittent nature of PV power resources and unpredictable demand profile. The strategy uses several operational modes on the battery management system that can decrease the diesel generator operating hours, reduce the fluctuations in the intermittent PV power and increase the batteries' lifetime. It was recommended for further study to maximize the reliability of the islanded microgrid and minimize the operation cost through the reduction of using a diesel generator. Kant *et al.* [267] have used a diesel generator set and battery ESS to maintain the reliability of a standalone microgrid.

Ultimately, it is difficult to find the energy coordination of a microgrid system that does not operate either in a smart grid environment or as an isolated intelligent system. As represented in Tables 4 and 5, most techniques of DMS, and from third to the fourth generation of DMS, some researchers have currently implemented smartly using these methodologies [8]. It is observed that the intelligent system is prone to these applications. Furthermore, the objective of microgrid deployments is to increase the electrical system efficiency and to reduce the atmospheric pollution from the energy generation by the traditional resources. The intelligent system through real-time communication can effectively assist to meet this requirement by monitoring and controlling the DERs' uncertainty.

B. SMART MICROGRID

When the standard microgrid can operate an interconnection network of a communication system as presented in Tables 2 and 3, this becomes a smart microgrid. Dispute of communication system, one of the most significant differences between a traditional microgrid and an intelligent microgrid resides in atmospheric pollution reduction. This minimization looks to bypass the diesel generation by promoting the usage of DERs and creating an environmentally friendly energy utilization system. In the context of energy coordination for a smart microgrid, the system structure can be intelligently implemented using the microgrid control levels. The scheme has to respect the necessary fundamental principles, such as integration of at least one DER, deployment of the high capacity ESS, creation of the different forms to distribute the electricity (heating and cooling), enabling self-use energy systems for the consumer, and incorporation of the optimum energy management strategy into the microgrid [268].

In [235] an optimal control strategy is designed at tertiary and secondary levels using a predictive model control under time-based DR programs that include TOU and real-time electricity pricing for commercial buildings. The model was developed combining the DMS with the advanced third generation of DMS to minimize the system operation cost and reduce the consumption cost from the DSO. Through the proposed energy management technique, real-time electricity pricing is presented as a new implementation perspective for both end-user and DSO. The advantage of this technique consists of a design scheme that considers the system electricity pricing structures from DSO and DER in a real-time manner.

Some researchers [8] have developed the third, advanced third and or fourth generation technologies as described in Table 4. However, the designed strategies do not specify the involvement of communication networks, as presented in Tables 2 and 3. This lack of precision does not disqualify the designed electrical system from being a smart microgrid. The fact of knowing the electrical system structure, the intelligent grid behavior and the evolution of DMS (as described in Table 4) allows defining of any given microgrid operating in a smart grid environment or not.

Chaouachi *et al.* [269] have designed the multiobjective smart energy coordination that contains fuzzy logic and neural network ensemble; each is based on battery scheduling and a short-term forecasting process, for microgrids. The system deals effectively with DERs and the load demands, which are sensitive and non-sensitive types. The model consists of a generalized formulation of a microgrid using artificial intelligence techniques combined with a linear programming-based multiobjective optimization approach. The designed model investigates the possibility of online energy management to minimize the operation cost and emissions. Compared with the traditional neural network, the proposed model brings several improvements regarding high forecasting accuracy of DERs.

In [270], an optimization strategy for a microgrid energy management system in the smart grid framework is implemented. The designed approach uses the full advantage of DGs and power generation planning evolution to set an urban microgrid operation that includes renewable energy and a storage system. The energy management scheme is implemented through SCADA by using practical methods and two design stages that consider the environmental and economic aspects. Compared with the evolution of DMS as described in Table 4, the application of SCADA is for the first and second generation, which are not under the smart grid environment. However, this developed model operates as an intelligent microgrid due to the implementation of a smart metering system and communication network. This approach assists in improving the EE of the electrical system and reduces the atmospheric emission.

An active power control approach is implemented under smart grid framework using model predictive control (MPC) to coordinate the energy flow of two interconnected microgrids [162]. This system aims to actively control the RERs and the storage ability so that the deviation of active power and frequency in the tie-line of the electrical system as a whole can be minimized. The results of dynamic predictive control are compared with the open-loop based on optimal control theory to draw the energy coordination improvement of closed-loop based on MPC.

In [1], an energy cost optimization based on an off-line strategy through an online algorithm method is implemented to manage the DS and renewable energy for a single intelligent microgrid connected to the main grid. The proposed model aims to minimize the total energy costs of the conventional power grid by investigating real-time power flow coordination problems to manage the storage system, DERs and an aggregated load. The off-line approach uses infinite-horizon real-time energy storage scheduling to optimally coordinate the battery storage system charging and discharging at any time, which is subject to practical load and storage constraints. The proposed method is considered as a novel approach to smartly integrating RERs to the grid and managing the energy storage for the microgrid system.

Corchero *et al.* [271] have proposed smart optimal management of vehicle-to-grid (V2G), load demand and renewable generation (PV and wind) for a residential microgrid system based on tertiary control. One of the critical problems here similar to [1] is vehicle battery management to ensure the energy storage capacity during the driving period. Thus, the model was implemented through a realistic strategy involving owner performance based on the novel concept, namely, range anxiety. This system is incorporated into the objective function employing a penalty parameter as a possible policy to deal with the fear of running out of energy before the final destination. Through the flexibility offered by the smart grid system, potential savings were observed with the integration of V2G. The system also uses the DSM to shift the sensible load to the off-peak time so that the model can produce a substantial saving in the total energy costs.

As a stable and self-sustainable power network, microgrids are considered as independent energy systems which can be connected to the primary grid, and deal with the different uncertainties. These unexpected events can be derived from various energy resources and load demand [272]. Thus, the work has designed an adaptable energy management system to minimize the operation cost and load disconnections. The proposed architecture uses the fourth generation of DMS as described in Table 4 to coordinate the interaction of measurement, forecasting and optimization of systems by creating an online energy management system. The model is tested in two types of supply microgrids, namely connected to the primary grid and islanded mode. The online energy management strategy that is based on power generation dispatch to forecast the generation and load adequately has enhanced the performance of microgrids.

The integration of ESS has seen to be one of the promising strategies that have challenged the various uncertainties from DG and power consumption in the smart grid environment. In [273], a techno-economic evaluation framework of DER is presented for a better understanding of energy mix system and load demand coordination of a microgrid connected to the primary grid. Due to the vital consideration of ESS integration, the proposed approach guarantees a proper power balancing of the entire microgrid and deals wisely with the several system uncertainties. Regardless of the advantages of the proposed model, the designed strategy does not emphasize on the feature of smart grid energy coordination. However, as the resilience and reliability between the consumer and supplier can be guaranteed, as described in Fig. 2, it can be assumed that the system is implemented in a smart grid environment.

In [14] an optimal control strategy that uses the distributed energy storage (DES) to ensure the frequency equilibrium of microgrid is proposed. The system configuration used the smart microgrid approach to grantee an optimal load frequency deviation of the entire microgrid system. The proposed model deals with the uncertainty in demand-side while insuring an optimal control that can coordinate the energy flow of a microgrid. In [25], smart energy coordination based on DES approach is implemented under the DR scheme to deal with the bi-directional energy flow between the consumer et the utility grid. The model is flexibly designed to handle different uncertainty of a microgrid. The proposed approach also operates effectively through an optimal control scheme under a DR strategy to ensure both the resilience and reliability of the entire microgrid system.

Li *et al.* [274] have recently proposed optimal scheduling of an isolated microgrid that consists of dealing with the uncertainty of energy demand and DERs. The implementation strategy of the proposed energy management scheme is based on coordinating three hierarchical models, including model building, model conversion and model solving. The first step is to model the uncertainty of the microgrid and generate optimal scheduling model with Chance constrained programming. The second step looks at the strategy to create the system parameters, which has to be resolved in the third step. The designed model uses solvable mixed-integer linear programming formulation based on a general algebraic modeling system. The scheme fully uses ESS so that spinning reserve services can be provided. Thus, the ESS when it is implemented under the DR scheme can deal with different uncertainty of the system component of a microgrid [243].

It is observed that the proposed model in [274] uses the smart grid approach to schedule the energy management of a microgrid. The same dispatch scheme to coordinate the energy flow of an isolated microgrid has been developed in [275]. This system used a multi-objective model to provide the spinning with the reserve services of microgrid, and in [276] through a bi-level programming approach via real-time pricing is designed to coordinate the swapping station in multi-stakeholder scenarios. In [275], the dynamic optimal dispatch strategy uses a robust heuristic optimization algorithm to organize the economy, environmental protection and user experience of isolated microgrids. The research work [276] formulates two levels of sub-problems that constitutes upper-level and lower-level based on-DRs schemes. The model consists of first minimizing the isolated microgrid net costs and then maximizing the profits of ESSs.

V. DISCUSSION ON THE FUTURE DIRECTION

The advantages of coordinating the energy flow into a microgrid provides the opportunity of grid integration that improves the use of RERs regardless of divers uncertainty, which derives from the instability of RES. Most of the technologies in these applications are based on an optimal control strategy to manage different patterns of the power flow on the energy system by integrating DES. All approaches that provide the smart grid environment from energy consumption to power generation can be implemented throughout the energy coordination. According to particular microgrid behavior, the system improvement requirement depends on an adequate designed structure and better system modelling. Thus, coordinating the energy flow on a specific microgrid required a suitable philosophy of the dynamic system as a whole. This depends on the prosumer's evolution and different energy generation resources (such as RES, ESS, and traditional resources). Besides, the smart grid can offer a better design technology through the knowledge of power system dynamic components of a given microgrid. The main goal is to improve the energy coordination efficiency while creating an acceptable power quality on the electrical system.

A smart microgrid has a robust ability to deal with different uncertainties of the electrical system which can come from diverse sources, such as energy demand and/or DERs. The scheme approach with the system uncertainty operates effectively when energy management can respect microgrid goals, as described in Fig. 2. The relationship between supplier and consumer of the energy brings more benefits when it is implemented in contexts of DSM, DMS and EGM. This combination is more fashioned in the framework of DR applications that deal effectively with different behavior of the system energy pattern. For microgrid technologies in the framework of the smart grid implementation, the concept of EI and IoT for energy coordination system is one of the future trends that needs more investigation. The actual electrical network looks for the short and long term solutions to solve the trilemma aspects of the energy sector.

The implementation of microgrid when it is connected to the utility grid, as described in Fig. 1, must always follow the network operator requirements either in the distribution or consumption level. The microgrid implementation can face several challenges in terms of the business model and energy markets. Thus, dealing with the synergy of the multi-energy system is one of the perspective research works which needs several investigations in the future development trends of a smart microgrid. Multi vector energy coordination system of a microgrid has introduced the IDR concepts that works effectively to deal with the trilemma issues that come from power industries. Either for EI or IDR concept, each one of this scheme can be promptly developed by using the energy coordination approaches of the smart grid based on DSM, DMS and EGM for microgrid applications. The combination of DSM, DMS and EGM provides an opportunity to secure an optimal operation and energy flow on the electrical system that can handle the synergy of multi-energy system.

The future trends will focus on the energy management strategies for the microgrid, which considers the EI concept for a multi-energy system that aims to guarantee the equilibrium of energy sector trilemma. It is also essential to notice that looks on the advantages and efficiency of a smart microgrid in terms of energy flow pattern, voltage regulation and frequency deviation is also one the future tend that can be developed through the use of the EI strategy or others optimal control approaches to ensure the microgrid goals.

VI. CONCLUSION

The coordination of the energy pattern in the microgrid system consists of structuring a proper philosophy that can manage the power flow between the DERs and the demand side as well as supplier. On the other hand, the DMS does not reduce energy consumption; however, it transforms the structure of the energy profile. Coordinating the power flow of the electrical system smartly for microgrid application provides an opportunity to minimize the energy consumption and to forecast the DERs. Some researchers have implemented microgrids that do not detail the implication of the intelligent system. However, the designed strategy and methodology used to describe those specific systems, present them as a smart microgrid. Concerning technologies and system modelling, managing the power flow intelligently of a microgrid can create EE performance in the electrical grid. This structure aims to design an optimal control behavior that can actively enhance DSM, DMS and EGM in the presence of various uncertainties of the system, and minimize the overall operation cost. It is observed that the energy coordination of the microgrid in a smart manner optimizes the integration of DERs and creates saving for both the energy supplier and consumer.

Highlights of this review paper can be listed as follows:

1) Smart energy coordination and technology to be implemented in terms of communications of the electrical grid are analysed for the design of the intelligent microgrid.
2) The energy coordination of several components of the electrical grid effectively assists in dealing with the diverse issues on the power system and brings more efficiency and proactive to the microgrid system.
3) The DER and energy demand uncertainties can be resolved on the implementation of the smart grid, which respects the resilience and reliability relationship between the supplier and consumer.
4) DR and/or IDR technologies need to be considered as main strategies that have revolutionized the design of the smart microgrid energy management.
5) The EI has the novel approach that seems to be more promoting on the effectiveness of the multi-energy system for microgrid implementation.

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NSILULU T. MBUNGU received the bachelor's degree in civil engineering in electromechanical engineering from the University of Lubumbashi, Democratic Republic of Congo (DRC), and the B.Eng. degree (Hons.) and the M.Eng. degree in electrical engineering from the University of Pretoria (UP), South Africa. He is currently an Engineer and Researcher with more than 10 years' working experience, which includes teaching and research, consulting services, maintenance, and engineering project management. For his master's degree, he developed a novel approach of controlling and optimizing the energy consumption of the electrical system in the framework of real-time electricity pricing for commercial buildings. He is a member of the South Africa Institute of Electrical Engineering (SAIEE). His Ph.D. research at UP, in collaboration with the School of Engineering, Newcastle University, is focused on a novel approach for optimizing and coordinating future electrical systems when distributed energy resources are integrated for microgrid applications. He is also a Reviewer of many reputed journals.

RAJ M. NAIDOO received the Ph.D. degree in electrical engineering from the University of Cape Town, South Africa, in 2008. He has more than 20 years of teaching, research, and industrial experience. He is currently an Associate Professor with the Department of Electrical, Electronic, and Computer Engineering, University of Pretoria, South Africa. He was previously the CEO and Founder of Enermatics Energy and a board member of Stellenbosch Wind Energy Technologies. He has worked and consulted several blue chip companies. He is also the Director of EWYZE. He has published many research articles in various journals and conferences and has diversified research interests in the areas of the smart grid, renewable energy, and power systems.

RAMESH C. BANSAL has more than 25 years of teaching, research, academic leadership, and industrial experience. He is currently a Professor with the Department of Electrical Engineering, University of Sharjah, UAE. In previous postings, he was a Professor and the Group Head (Power) of the Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa, and worked with The University of Queensland, Australia; University of the South Pacific, Fiji; Birla Institute of Technology and Science, Pilani, India; and Civil Construction Wing, All India Radio. He has published over 300 articles in journals, conferences, and contributed several books and book chapters. He has Google citations of over 7800 and h-index of 40. He has supervised 18 Ph.D., four Post Doctorates, and currently supervising seven Ph.D. students. He has diversified research interests in the areas of renewable energy and power systems which include wind, PV, microgrid, distributed generation, grid integration of renewable energy, power systems' analysis (reactive power/voltage control, stability, faults, power quality, and protection), and smart grid. He is an Editor/Associate Editor of many reputed journals, including the IEEE Systems Journal, the *IET-Renewable Power Generation*, the *Technology and Economics of Smart Grids and Sustainable Energy* and the *Electric Power Components and Systems*. He is a Fellow, and CP Engg IET-U.K., a Fellow of Engineers Australia, and a Fellow Institution of Engineers, India.

VAHID VAHIDINASAB (M'10–SM'17) received the B.Sc. degree from the K. N. Toosi University of Technology, Tehran, Iran, in 2004, and the M.Sc. and Ph.D. degrees from the Iran University of Science and Technology, Tehran, in 2006 and 2010, respectively, all in electrical engineering.

Since 2010, he has been with the Department of Electrical Engineering, Shahid Beheshti University (SBU). He has also initiated and managed SOHA Smart Energy Systems Laboratory, SBU. He has demonstrated a consistent track record of attracting external fund and has managed several industrial projects and closely worked with several large complex national/international projects. Since 2018, he has been with the School of Engineering, Newcastle University, and manages and collaborates on the inteGRIDy as an EU Horizon 2020 project. He was considered as one of the Outstanding Reviewers of the IEEE Transactions on Sustainable Energy, in 2018, and top 1% reviewers in engineering according to Publons Peer Review Awards, in 2018. His research interests are oriented to different research and technology aspects of energy systems integration, smart grids/microgrids/nanogrids design, operation and economics, and application of machine learning and optimization methods in energy system studies (modeling, forecasting, and optimization). He is an author/coauthor of more than 90 articles in top rank and peer-reviewed journals as well as national/international conferences.

Dr. Vahidinasab is a member of the IEEE Power and Energy Society (PES) as well as the IEEE Smart Grid Society. He is also an Associate Editor of the *IET Generation, Transmission & Distribution* and the *IET Smart Grid*.

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