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The research on multi-agent system for microgrid control and optimization

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ABSTRACT

In modern era, the awareness of green energy technologies in the Microgrid (MG) is highly adopted in order to reduce the CO_2 emission and for a clean environment. The distributed energy resources, such as solar photo voltaic (PV), solar combine heat and power (CHP), diesel engines, small wind turbines and fuel cell technologies are evolving within the power system. The control and maintenance of this power have great effect on power systems. For optimal use of electric power in MGs, the Multi-Agent System (MAS) technology is adopted and has certain applications in the power systems. This research article mainly focuses on MAS technologies used for the control of MG, its optimization and market distribution. A fully controlled architecture of MG using MAS with different optimization techniques applied to renewable energy sources has been deliberate. Moreover, comparison of centralized and decentralized approach of a MG is also discussed in this article.

1. Introduction

Microgrid (MG), the low voltage network usually located at consumer's side, comprising of distributed generators, storage system and certain control units in order to provide clean and smooth electric power in the optimal way [1,2]. In recent years, as demand of electric power is increasing rapidly to fulfill the needs on daily basis, renewable energy sources are found very effective. Effective execution and control of distributed generation sources along their integration with power storage devices i.e. flywheel, capacitor bank, electrical battery, and controllable loads like water heater and air-conditioner is the key perception of MG [3,4].

In modern electric power grids, an increasing practice of small scale renewable sources is taken under consideration, because of the existing rising demand for electrical power and energy. The renewable energy sources are frequently used; because they are inexhaustible and environmental friendly [5,6]. Fast technological growth is carried out for the renewable energies, making the system more economical and leads to reduce the import of fossil fuels for under-developing countries. Renewable energy sources allow generating electrical energy at a lower price and improving the living standards without causing hazards to the environment. Moreover, it also plays a vital role in supporting the distributed electrical network in remote/rural areas [7]. In Fig. 1, it is depicted that investment rate of wind energy generation was significantly higher in 2010, though, next year a reduction occurred for a couple of years but maintained in the year 2015. In contrast, the same problem occurred in the investment rate of solar energy just after one year by wind power. Similarly, a reduction occurred in the investment rate of total renewable energy generation during 2009 and 2013, but maintained and was significantly higher in 2015. In spite of economic problems, various countries are funding several projects for connecting renewable energy sources to power grids in central and regional level [8]. MG has combination of different energy sources i.e. small wind turbines, photo voltaic (PV), fuel cells and other micro turbines integrated into storage devices, like batteries, capacitor banks and flywheels connected at low voltage systems. Different control/protection systems are usually installed at every feeder for safe distribution of electric power. The basic hybrid MG architecture is depicted in Fig. 2.

MGs generally operate while interconnected with central distribution grid; however switch to islanded mode when external faults occur. They can function autonomously in several conditions of the system; thus, advance control architecture is required to maintain high efficiency and reliability [9]. In [10], concept of MG is to undertake clusters of load and micro-source (MS), operating as controllable system, for providing power and heat to local areas. MG is controlled centrally through MG Central Controller (MGCC) connected to medium/low voltage (MV/LV) side. It manages key operations of MG. MGCC comprises of several key features including economic management functions, control exertions and it is head of classified control systems [11]. MGCC plays an important role in optimization of MG operations or on the other hand, it directly coordinates with local controllers installed in MG system, which are assumed to be responsible for optimization of MG [12]. In [10,13], several advantages of MG

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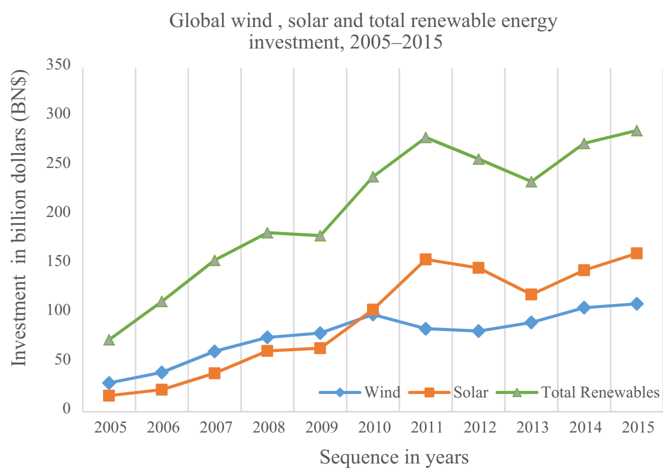

Fig. 1. Global wind, solar and total renewable energy investment, 2005–2015.

are presented, i.e. improving local reliability, reducing feeder losses, supporting medium and low voltages, increasing efficiency by using wasted heat, combining heat and power (CHP), smooth rectification of voltage, and providing uninterruptible power supply functions. Similarly, renewable energy power converters interlinked in parallel to grid for distributed power generation systems are demonstrated in [14]. These are distinguished through role in settling grid-voltage as well as grid-frequency. They are consequently categorized into three categories i.e. grid-supporting, grid-feeding and grid-forming. Furthermore, grid forming converters are ideal AC voltage sources having static frequency. Power converters designed for autonomous operation are generally used for power generators and loads balancing. For allocating definite active and reactive powers to an energized grid, grid-feeder power converters are designed, however, these converters don't contribute for balancing the grid power [15]. While grid-supporting power converters are proposed for controlling voltage of reactive powers plus frequency of active powers, either in stand-alone or associated grid. It allows to share energy for power balancing.

Multi-Agent System (MAS) technology is complex but very useful system, it is composed of numerous independent agents, having confined information and abilities, based on design and operation of the MG, while able to interact for accomplishing a comprehensive task [16]. Their ability for predictable control schemes, artificial intelligence techniques and expert system analysis becomes an additional advantage in adopting hybrid controllers in MGs. Communication amenities such as microwaves, fiber optics, GSM/GPRS and 3 G are now becoming amalgamated parts of power systems [17–19]. It makes easier, faster, reliable and comparatively more feasible to incorporate MAS into the power system applications. Several applications of MAS, especially in MG have various functionalities in power system. Interconnected MG operation optimization is carried out by enhancing the production of distributed generators (DG) and considering electric power exchange with the central distribution grid [20]. In MG control system, auxiliary intelligence and collective ability of agents perhaps provide appropriate results in optimum and active control of power system [21]. In [22], MAS are used, in energy management system, in order to fulfill the load demand of network and adjusting power along

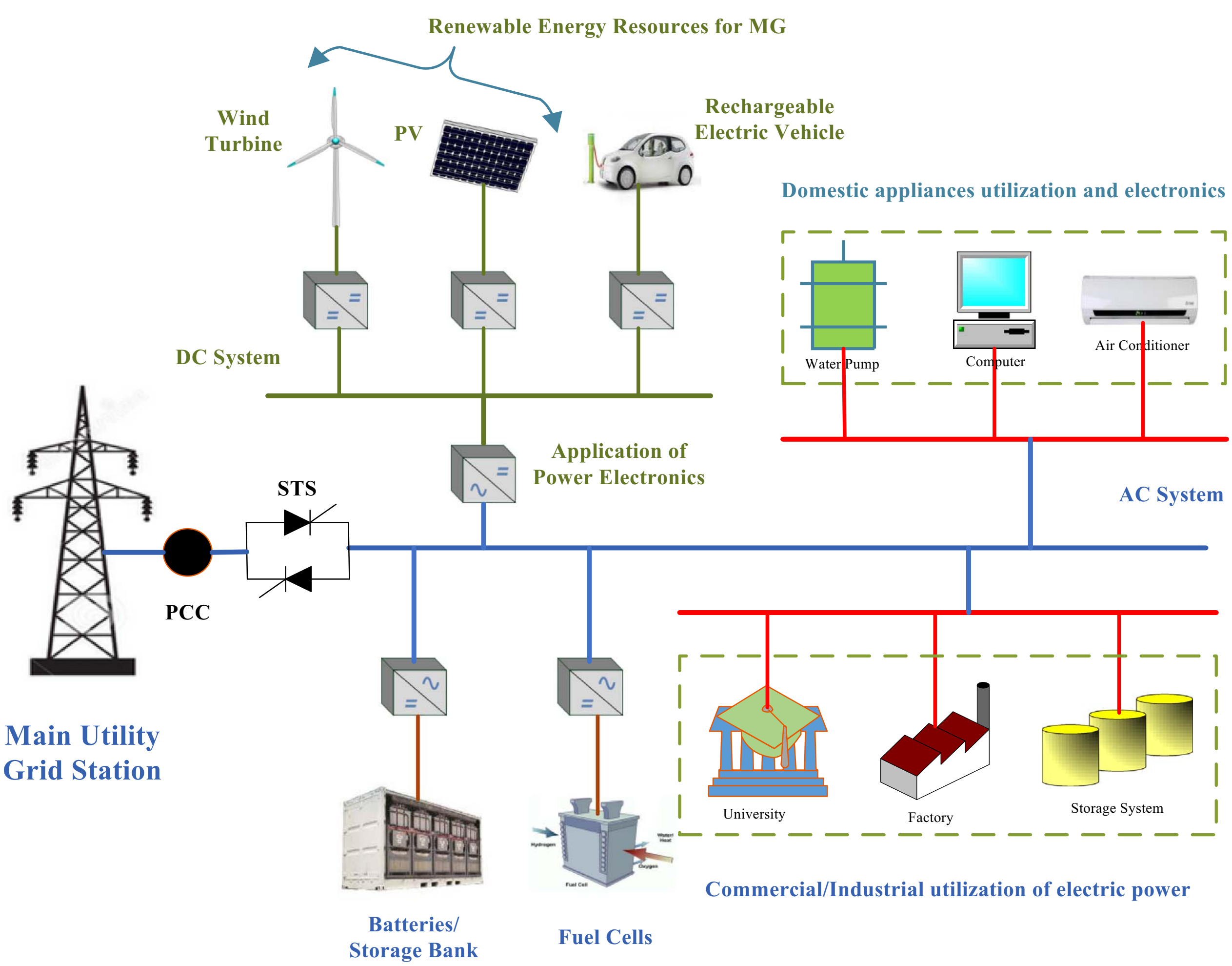

Fig. 2. Basic architecture of hybrid MG.

with its surplus and shortage information. It chooses from several available options, i.e. coordination with power grids, battery storage system, controllable distributed generation plant, regulating variable power and growing or declining production of controllable generating units. Similarly, in [23], decentralized control architecture based on MAS is established for controlling multifaceted energy management of distributed generation system. A non-cooperative game theory plays vital role in interlinking MAS to the system. System was evaluated through simulation, in renewable resource variations, cyclic load demands and network disturbances; it was proved to offer comparatively high performance controls and more robustness to that of conventional centralized energy management systems. Likewise, MAS based smart restoration structure is applied to a distribution system simulated using an open distribution system simulator. The novelty of the agent system includes minimizing the grid losses while reinstating the service to the loads as per their priority without disturbing the network impediments [24].

Energy management through MAS for implementing a hybrid system at high altitude is discussed in [25,26]. Based on local information, to accomplish effective and stable system operation, DG sources inside MG are regulated by an energy management system. Correspondingly, virtual bidding is applied for scheduling system process and capability reserve; established on shift, impediment, reduction or rise on the power demand from one or numerous controllable consumption sources of the system. Moreover, through predictive and droop control in real-time power dispatch, power generation, load demand, power sharing and cost in the MG is maintained [27,28].

Some papers also addressed reliability of MG by distributed power control for distributed energy resources (DER), based on network, MAS, with communication delay technologies having effective skills for distributed demand management [29,30]. This mechanism supports consumers to participate in grid support deprived of distressing level of gratification. In paper [31,32] a new communication algorithm for MAS based on peer to peer communication is discussed in order to reduce communication steps, reduce load on the agents, and has a rapid response time compare to other existing architectures. Some papers also deal with the fault protection coordination under both normal and short-circuit fault situations. By the use of MAS, the protection coordination can be planned and control actions can be performed properly, isolate the fault area and protect the MG system in real time under varying conditions [33].

The main concept of this manuscript is to review research and study based on MG control and optimization by using MAS technology to handle the multifaceted tasks within the MG by an efficient way. General organization of this paper includes: In Section 2, an overview of MAS, its capabilities along with application requirements are discussed in details. In addition, technical description of MAS implementation and operational cycles within MG is also focused in this section. Section 3, provides architecture of the MG along with control system, inverters and its safe operation within the MG, while energy storage devices and optimal operation of load are also discussed in this section. Optimization methods for different renewable energy sources, their design objectives for MG are conferred in Section 4. Meanwhile, comparison of a MG between centralized and decentralized approach is presented in Section 5 and finally the Section 6 includes conclusion.

2. Concept of multi-agent system

2.1. Agent system

An Agent is considered to be a system, located in an environment, having capability for performing actions, autonomously in the environment in order to encounter the design objective of the system. Agents perform their jobs totally in different way from other comparable software or hardware systems due to the strong intelligence and flexible behavior. Some significant traits to gratify an intelligent agent design aims that discriminate an agent from modest controllers are as follows [23,34–37].

- *Reactivity:* This refers, to help the agent to respond to any deviations happen within the environment through the use of intelligence system without directly influencing the environment.
- *Autonomy:* The capability of an agent for performing his tasks independently in the network without exterior interference by other agents or humans. These attributes lead to protect the interior states of an agent from exterior influences and isolating agent against instability instigated through exterior disturbance.
- *Inferential ability:* Ability of an agent to operate in intellectual goal stipulations i.e. inferring observation by simplifying information. This may be done through manipulating suitable contents of existing information.
- *Responsiveness:* The aptitude of an agent to fully observe the current state of an environment and respond to it in a possibly minimum time to make changes in the environment. This ability has high importance in real-time applications of the system.
- *Pro-activeness:* An agent must show a positive retort offered by immediate conditions without reference to a general behavior. This is in order which supports the agent to enhance actions towards its defined goals in spited of being responsive to a specific variation in the atmosphere.
- *Social behavior:* Even though the agents must have the ability to take decision independently, but for achieving a specific goal, it is very important that agent have a capability of interacting/communicating with external sources which may be other agents, human or controlling units in the environment. This helps the agent to cooperate, negotiate or compete with other agents.

2.2. Capabilities of MAS

MAS are an advanced form of conventional distributed control system having abilities to control huge and multifaceted entities. A significant feature, that distinguishes MAS from classical distributed control systems, is a local intelligence embedded in the software of each agent. Each agent performs his tasks locally and independently in the system by using its intelligences. Agents aren't swapping modest values individually through "on/off signals" but correspondingly have the aptitude to follow information, instructions, beliefs, and measures through the language environment of the system. For illustration, load agent, for controlling load, can contribute in local MG market, by conveying an edifying request message for all DER agents, declaring power consumption and amount of the required energy [4].

MAS is capable of responding to the computational challenges owing its omnipresent, intelligent, autonomous, human-oriented and supportive attributes which are fixed with abilities, such as decomposing classification into recyclable, redistributable and autonomous communicating mechanisms. Such characteristics and aptitudes improve the system extendibility and flexibility by permitting system reconfiguration and incorporation through accepting common agent communication technologies [38]. Moreover, object-oriented comportment of ontology and facts abstraction, permits every single agent for handling essential or permissible knowledge and data. Furthermore, MAS improves robustness and reliability of the system because of the ability to tolerate uncertainties, fixed by using some redundant agents in the instance of any failures in the system environment. MAS have also a capability to improve the efficiency of computations by directing contemporaneous computation in data processing or at the stage of decision making of solving the specified problem. Furthermore, when there is necessity for MAS to be extendible, modular MAS allows increasing number and capabilities of the agents. This ability also empowers MAS to be flexible in establishing or in reusing of the agents. Moreover, modularity of MAS contributes in system preserving by handling local inconsistency where they are not circulated to other modules in the system. Five main attributes outlined for the capabilities of MAS, dealing with largeness and complexity, extendibility and flexibility, intelligence and autonomy, modularity, and handling distributed data in the MG [38,39].

2.3. Application requirements for MAS

For using MAS there are many requirements which are essential to be considered, such as development platform (analysis, design methodology and development), toolset for MAS implementation, and operational mechanism of MAS as discussed below.

2.3.1. Development platform of MAS

An agent development environment is required for constructing MAS, which supports some phases of MAS conceptual proposal development procedure. An inclusive description, new analysis, and design methodology for creating MAS is beyond the approach of this article, but for the development of MAS, [40] described a four phases generic platform development process including; Analysis, design, development and deployment.

In the analysis stage, it concerns with modeling of the agent's roles and behaviors. This leads to easily identify the domain and problem of the application. The design stage is more important for identifying complex problems and handles it through a better way identified in the initial stage. The development stage is concerned with the goals of the programming agents, ontology and proper functionality of these agents for the operation of the system. While the last stage launching the generated MAS, run-time management of the agents, messaging processing with the DER and processing of the data.

2.3.2. Implementation of MAS

MG plays vital role in power system; it compresses large number of methodical parameters and specifics. Controlling MG is possible in different ways: one possibility is creating a multifaceted classical model having full description of all elements, while consequently; it needs a communication system capable of exchanging huge quantity of information along intricate algorithms. Second way is making a basic description of system and extract optimal results. In MAS technology, detailed model of the system is generated. Different agents can be used in this model and every agent uses an exact concerning portion of information. Therefore, it is essential to take a formal way of unfolding data and delivering to each agent in suitable way.

A number of individual autonomous intelligent agent's approaches are available in the existing literature with numerous degrees of *Reactivity, Autonomy Inferential, Responsiveness, Pro-activeness and Social ability* to implement MAS. Examples of such type of anatomies are agents having layered architectures, model-based programming agent's implementation, reactive agents and belief desire and intention (BDI) agents. Moreover, for implementing MAS, there are some mainly using tools such as JADE, JANUS, ZEUS, VOLTTRON, Netlogo, or Skeleton agent which offers functionalities to enable programming via using MAS [41]. Table 1, provides significant key points among the most widely using platforms for implementing MAS.

The expansion of such application is in docility to standards anticipated by international Foundation of Intelligent Physical Agents (FIPA) [42]. The intention of organization is standardized growth of such techniques, particularly in the region of communication among different agents and group of MAS.

Java Agent DEvelopment Framework (JADE), java based tool for implementation of MAS [43]. Latest updated tool of JADE 4.4 platform can be used for creating new systems. JADE offers simple and commanding task implementation along composition model, peer-to-peer agent interface based on asynchronous communication standards, a yellow pages services subsidizing publish subscribe discovery tech-

Table 1
Significant key points among the most widely using platforms for implementing MAS.

S. No.	Properties	JADE	JANUS	ZEUS	VOLTTRON
1	Open and freely acceptable source	√	√	√	√
2	FIPA compliant assent	√	x	√	x
3	Reusable semantic memory	√	√	√	√
4	Publishing supervisor	Command line	XML Mining	GUI	Command line
5	Platform provision	Existing actively. Upgraded to 4.4, December 2015	Existing actively. Upgraded to v4.0.51.0, September 2016	Obsolete	Existing actively. Updated April 2015
6	Software design language	JAVA Built	Ordinary language process	JAVA Built	Self-determining programming language
7	Ideal application	Scalable MGs	Building automation	Quick prototyping	Domestic/LV energy management
8	Accuracy and efficiency	High	High	Medium	High
9	Merits	Stable platform for considerable high duration	Software tools, architecture design and modeling at advanced level	Ideal for user having developing skills	Supports platform services, such as, messaging, mobility and application, support hard-drives
10	Demerits	Implementation for new users are clear challenge	Semi-automatic derivation	Hard to use, documentation is extremely weak	Inadequate industrial implementations

nique and several other advance features, which facilitates expansion of distributed systems. To support debugging and development phases, foremost feature of FIPA specifications compliant is MAS platform, using Agent Communication Language (ACL) having high level ontologies [44]. For different systems, different ontologies can be presented according to the needs of system. The JADE platform runs best library for implementing behaviors by consuming a simple object called Behavior. Moreover, the platform offers different classes that spread elementary object behavior, such as:

1) CompositeBehavior;
2) SimpleBehavior;
3) OneShotBehavior;
4) CyclicBehavior;
5) FSMBehavior;
6) SequentialBehavior;
7) ParallelBehavior.

JADE provides a technique for operating mentioned Behaviors. Comprehensive explanation of these functions can be found in [45].

2.3.3. Operation of MAS

Operation of MAS is very important task in the environment of the system. It consists of three stages, such as:

- Perception: It is done via gathering data in the environment either by monitoring current operational situation of the system or by predicting tasks to be done in future.
- Decision-making: By intelligent cognitive it conducts and changing environment autonomously. It might be possible that the decision-making progression directed either online or offline
- Action. Action of the agents affects environment either physically or non-physically (hardware/software actions)

2.3.4. Discussion

Several MAS platforms and studies have been carried out for optimal operation of MG connected with distributed systems, but due to lack of updating; recently they are not widely use in the power system actively. This research work mainly focuses on MAS for hybrid MG control and optimization of the power system. The paper arguments validate MAS is adaptable with hybrid MG; therefore, an appropriate tool such as, MAS is recommended for scrutinizing, modeling, controlling and monitoring developments in different power categories. In most huge and multifaceted modern power systems where enormous data intelligent processing is essential, the necessity of MAS abilities becomes evident with cooperating modules and subsystems for supervision such complex modern power systems. In addition, complex power systems involve multi-operational cycles which need quick response, decision making and fast reaction to any unexpected events to protect the power system from any blackout or any other technical issue. So, the use of several autonomous agents in the system could assure such type of better response continuously. Moreover, flexibility and extendibility of MAS permits to deal with power system variations dynamically, therefore MAS also allow dealing with such dynamic systems in efficient way.

There are some mainly widely using tools for MAS such as, JADE, ZEUS and VOLTTRON and also has different MAS platforms which are not widely using in the power domain and have not considered in the comparison because of the poor updating activity like; Aglets and Skeleton Agent [46,47]. JADE is the most widely used platform, for the development of MAS, carried out in the studies and majority of articles reviewed and surveyed.

ZEUS is, another reveal source agent development platform, in association to FIPA, applied in Java programming language. It usually suggests graphical-user interface (GUI) with runtime free environment for users, having ACL provision intended for agent exchange messages in FIPA acquiescence. ZEUS, provisions knowledge query and manipulation language (KQML) created communications, along entire phases of conceptual MAS design development. It is openly obtainable for study purposes. Commonly in management systems, ZEUS permits the roles of modeling agent, using combination of predefined roles and class diagrams. In addition, although there are numerous advantages of ZEUS, however, producing novel applications via ZEUS platform brings challenges for new users due to weak documentation. Some examples related to development of MAS for MG by using ZEUS platform can be found in [48,49].

VOLTTRON [50] is an executive distributed agent framework, specifically used for electrical power systems; it is designed by Pacific North West National Laboratory (PNNL). The Open Foundation and Modular Platform are envisioned to facilitate the transactions between network units over the grid. Through central message bus, communication between different entities is established in the form of topics/sub-topics. The fully control architecture of VOLTTRON is demonstrated by means of hierarchy for three-level agent classes like, cloud, control and passive agents. From a remote zone (to and from) it publishes data, communicate with different installed devices within the system and interrelate with intelligent devices and manipulate recorded data respectively. Number of agent classes would be vigorous for deriving various agents and VOLTTRON expansion folio, GitHub offers pure examples [51]. Although VOLTTRON original execution is offered in Python, programming language platform is agnostic.

JADE is FIPA associated open source agent development foundation software for constructing MAS. For creating distributable agents JADE offers challenges for multiple hosts, though, it supports events for consistent and concurrent agent. JADE support conceptual design and deployment stages for MAS, providing freedom to computer programmers to extract designed agent. Moreover, JADE, usually executed in programming language of Java and integrated through GUI tool intended for restoring. It is prevailing for download and research purpose. MATLAB/Simulink tools as well as JADE environment tools are easily accessible for the same purpose. MAS for development of MGs using JADE agent platform can be found in [52–54].

Overall, FIPA associated open source agent development foundation software “JADE” is highly suitable for innovative designers for building scalable and stable MAS control for MGs. JADE offers commanding task implementation through composition model, peer-to-peer agent communication; based on asynchronous message passing paradigm and several other advance features that facilitates development of distributed system. ZEUS may be superlative, employed by innovative designers, for swift prototyping and MAS perception for MG control. Because, in most common management systems, ZEUS permits role of modeling agent, mostly using a multiple of predefined roles and class illustrations. VOLTTRON can be better, utilize by facilitators also building supervisors, for supervision intelligent devices, publishing a remote data and manipulating instrumentation data within the system. The open foundation and integrated platform are envisioned to provision communications among interacted units in the network.

2.4. Use of MAS within MG

In modern power system, the use of MAS technology is widely adopting and has a number of advantages and leads to solve numerous operational problems within the MG. Initially, as discussed later in Section 4, the centralized control is more complicated than that of the decentralized control. Hence, for the small DER units they have different local controllers that can take local decisions and have a certain degree of local intelligence to operate the MG within the need of the market. Besides this, DER is not only responsible to sell electric power but also attain other important tasks, i.e. produce heat for local installations, maintain voltage level and to provide enough backup power in case of black out of the MG or increase the need of the market. Moreover, it has also a capability to maintain the load shedding and on/off the grid in emergency, (see [12,20,55]). These tasks increase control of the distribution and autonomous operation of a MG. In [55] four kind of agents are proposed: MGCC agent, generation, consumption and power system agent. Main responsibility of MGCC agent is coordinating tasks with local controllers, it also declares commencement and culmination of conciliation period for specific time and records final power exchanging among agents at each period. However, in market, three types of control stages are renowned.

- Distribution network operator (DNO) along market operator (MO) at MV level
- Central controller for MG
- Local controllers (LC) that would either be MS controllers (MSC) or load controllers.

DNO carries out technical operation in medium as well as low voltage areas, having more than one MG. Moreover, one or more MOs are authorized for souk ploy at this area. However, these dual objects don't best fit to MG, although they remain agents of grid.

Key interface among MG and MO is MGCC. It is mainly accountable for optimized operation of MG; otherwise, it directs with LCs and assumed to take major responsibility for this optimization. Whereas [20] deliberates primary utilities essential for MGCC, for future involvement of MG in real-time markets having different strategies.

2.5. Operational cycle of MAS within MG

In [12], Dimeas Aris and Hatziargyriou Nikos presented the operational cycle of MAS in the market environment. The operational cycle steps for agents given below are also shown in the flow chart in Fig. 3.

- The MGCC initialize start of market period.
- Power venders evaluate authentic production abilities and produce suitable measure of power vender market agents (MA).
- Actual loads evaluate real demand for generating appropriate amount of power consumers MA.
- Agent of power system is dependent on total number of vender's agents and consumers, creates agents with adequate measure for making network symmetrical. Subsequent, analyzes total quantity "n" of venders (or consumers), produces an additional set of venders "n" and consumers "n". This consent a generating entity to sell electricity directly to MG or give capability to prime agent to directly purchase from the system.
- Subsequently, MGCC declares the commencement of a next conciliation sequence.
- Electricity market venders and consumer's agents start bidding in market, conferring defined procedure.
- MGCC declares end of contemporary negotiation.
- Venders and consumers agents declare their parent agent, after this task they terminate themselves.
- Responsible unit MGCC terminate energy souk period and publicizes new start point.

3. Architecture of MG with MAS

Power generation, its control and safe operational strategies within power system are essential task and to well-establish these tasks, it increase reliability of power system. Control and energy management policies adopted for MG are mainly determined based on DER technology, load requirement and operational cycle.

A fully controlled architecture of hybrid MG is depicted in Fig. 4; including different micro generation sources such as, wind turbine, photovoltaic generation, fuel cells and backup system in the form of

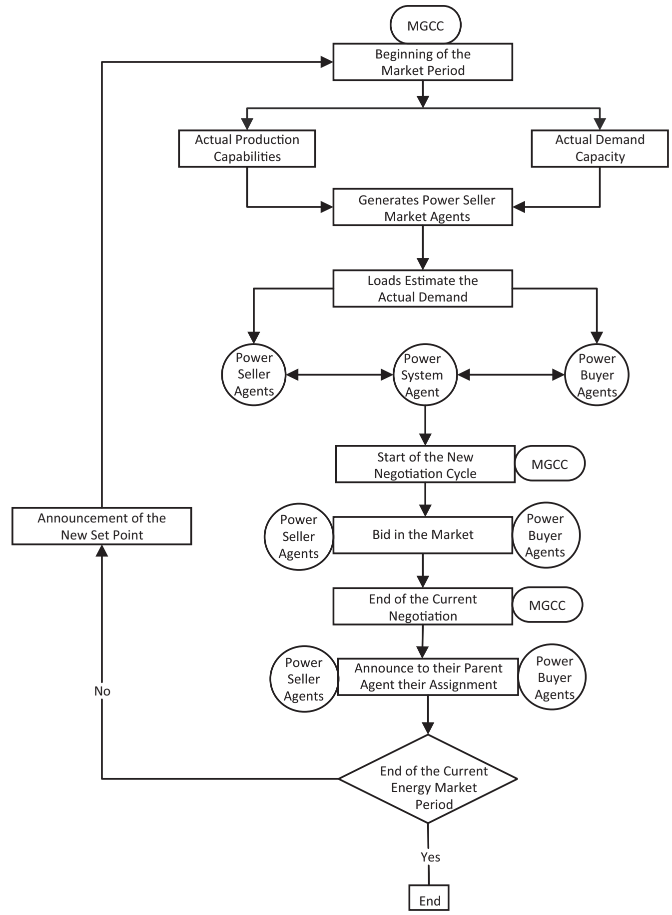

Fig. 3. Flow chart of the operational cycle of agents.

batteries and flywheel. This system provides both ac and dc power to the consumers with full controlled features. So, converters have been used in order to get the desired results. Power system is connected to distribution system for fulfilling consumers need through a static switch, a kind of separation switch, known as point of common coupling (PCC). Each generation module consists of a circuit breaker, a converter and a power flow controller in order to make system operational, reliable and safe.

The MGCC is the central controller of this control system. While LC and MSC are the sub controlled level controllers which directly coordinate with MGCC in order for the smooth operation of the MG. Coordination of MSC and LC with MGCC is very important for control operation of MG, they exchange different information with each other such as; MGCC send information request about different voltage levels, management of apparent power beside controlling switching of MG. The LC and the MSC take the decisions locally and exchange the information's only with the MGCC.

3.1. Controlling of the MG

The control of distributed energy system within a MG is resolute by nature of interaction to the system. Core control function of DER unit is to control voltage and frequency along with active and reactive powers. However, power export policy frequently controls DER output power flow in voltage and frequency limits as determined by MG [56]. Framework of hierarchical MAS is discussed in [57,58]. Lower part control agents are considered as a hybrid agent, which consists of reactive and deliberative layer. Reactive layer is demarcated as "perception and action", for responding fast in difficulties of surroundings and deliberative layer is clear as "belief, aspiration and aim" having great aptitude for adjusting or formation behaviors of agent.

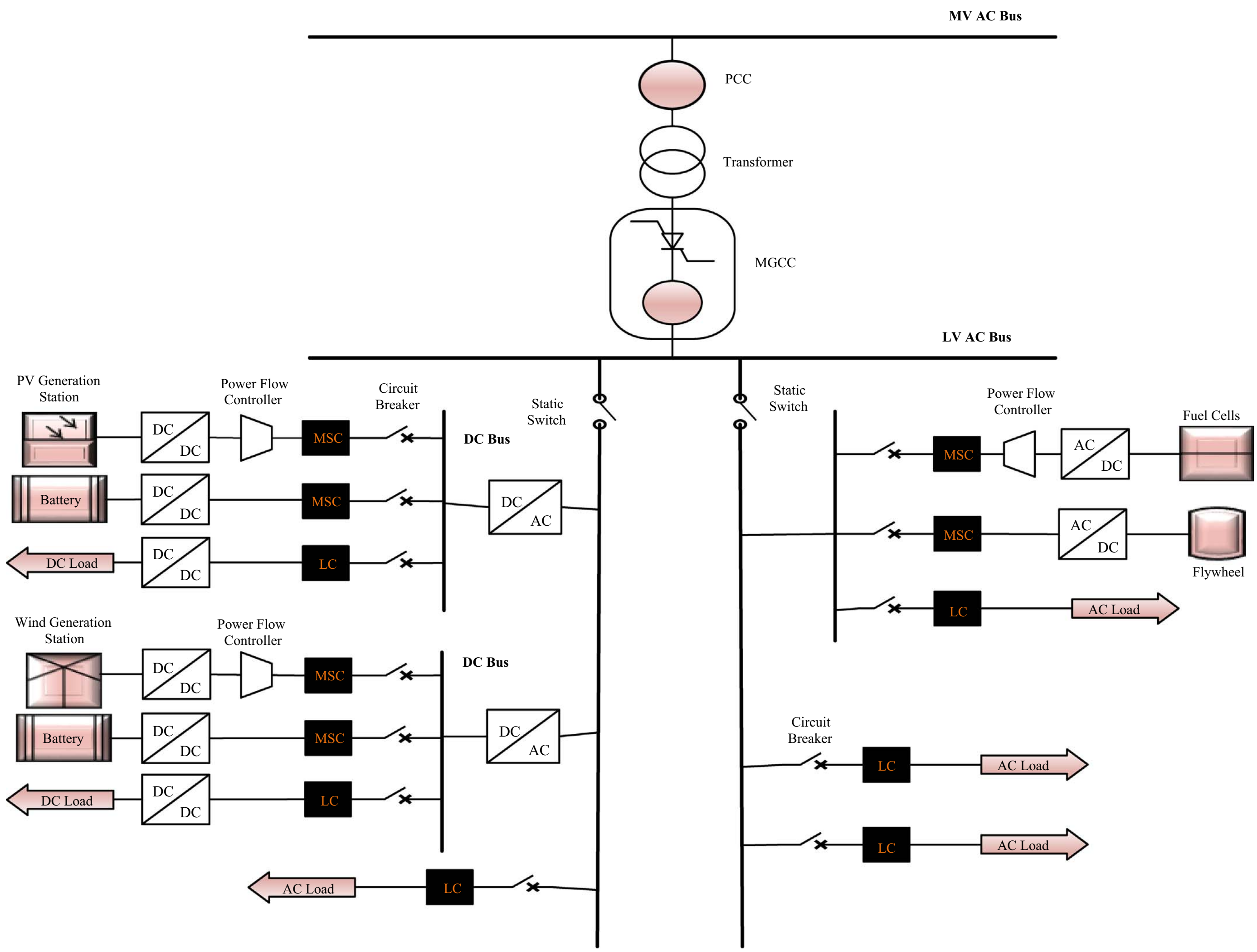

Fig. 4. Architecture of the MG with different control agents.

Central layer coordinated control agent is considered as a premeditated agent, for synchronized switching of operational modes for upholding secure voltages. A particle swarm optimizer (PSO) is prepared up of a central coordinator-agent and various local controller-agents. Central coordinator-agents are responsible for synchronizing all LCs and local controller-agents, and they are categorized into three parts, 1) local temperature controller-agent, 2) local illumination controller-agent, and 3) local air quality controller-agent created on their diverse control operations. They are responsible for controlling temperature, illumination and CO_2 concentration in MG [59]. Droop control technique is implemented for increasing cooperation concerning power electronics inverters for improving voltage variations and load dispatching [60]. Disparity of voltage in MGs central bus bar is considered as altering load condition, as an alternate power production of converters, for enhancing reaction time of control system.

In MGs, secondary voltage and frequency control scheme, established on distributed supportive control of MAS, is executed via communication system for improvement in system reliability. Moreover, a three-layer MAS is established on hierarchical coordinated control strategy for stabilizing MAS's voltage and balancing power [61,62]. In [63], authors discussed voltage and frequency control of MGs through droop control technique. For voltage and frequency maintenance, storage system such as battery system is primary control unit. It is operated when MG shifts to islanding mode. In islanding mode, batteries coordinate directly to local DERs through a central controller, which leads to power system reliability.

Sugihara et al., in [64], anticipated central control method and distribution system operators (DSO), at consumer's side, having direct access for controlling distributed storage (DS) systems. This approach takes an advantage for reactive power compensation abilities in storage converters. Access is granted for exchanging subsidy for storage system. In this proposed method, voltage control, assisted to active power control is not involved. Correspondingly as in other control schemes, decision is based on characterization of grid via calculation of load flow. Authors believe that mentioned technique allows DSO to preserve appropriate voltage level on inexpensive base compared to other methods. Control architecture in MG without central controller agent is given in [65], in order to resolve mismatch of real and reactive power.

A multi-MG control system (MMCS) is proposed in [66,67], anticipated control scheme is used for communication and control between multi adjacent MGs. MAS is responsible for monitoring available power for local DERs operating within its own region but also have capability to communicate with MMCS region. In addition, three different modes consist of normal, restoration and emergency modes are discussed. Under normal operation, reliability of power supply increases, consequences, in case of line fault are improved and upgraded power quality is provided.

3.1.1. Primary, secondary and tertiary control

- *Primary Control*

Main responsibility of primary control and/or droop control is to improve system reliability, stability and performance for local voltage control by regulating frequency and output voltage in order to get interior current and voltage control loop; and for guaranteeing some proper active/reactive powers distribution among DG units [14,68]. Reduction of error and output voltage recovery operations are enhanced by sharing error reduction technique, actuated by low-bandwidth synchronization signals, leading to decrease error and stabilizing amplitude of output voltage [69]. For reliability reasons, communication is frequently avoided, since primary control is based on a local quantity. Parallel inverter controls in DG systems are discussed in [70], while maintaining system stability and linear/non-linear control loops can control performance and also has capability to supervise inductor/capacitor current of output filter to obtain rapid and dynamic reaction of system.

- *Secondary Control*

  Secondary control performs the job to control the frequency, voltage restoration and also synchronization of MG to main grid before accomplishment of the inter connection. It restores the amplitude deviations of the output voltages formed by virtual inertias and output virtual impedance. It simply measures the parameters (amplitude and frequency) of MG and compare with reference one, after comparing error value, send it to all units for restoring output voltage of the system [8,71,72]. Likewise, to synchronize MG phase, the phase between MG and grid is measured and send to all modules to attain synchronization.
- *Tertiary Control*

  Tertiary control performs import/export of energy within MG; it controls power flow to and from the MG. It controls the power flow (import/export of energy) between MG and grid through a PCC. Through a power flow solver, it provides load balancing in an optimal way. Therefore, Active and reactive (PQ) powers' import/export can be performed independently [8,73,74].

3.1.2. Inverter controller within MG

Most of technologies installed in MGs are not appropriate for directly connected electrical network because of energy production feature and load requirements of consumers. Therefore, interfacing of power electronics components; (dc/ac or ac/dc/ac) is essential. Thus, inverter control has wide applications within the MG. Peças Lopes et al., [75], discussed dual control approaches for activating an inverter. Although, Model of inverter is subsequent, conferring to next control approach; PQ inverter controls technique: inverter feeds given active and reactive powers set-points. Voltage source inverter (VSI) control: Inverter is controlling "provender" load through pre-defined standards for voltage and frequency. Depending on load, actual and reactive powers output of VSI are elaborated. MG connected VSI is proposed in [76], power distribution controller is used for generating magnitude and frequency of essential output voltage permitting to droop characteristics, by matching operation of conventional synchronous generator. Voltage controller is used to create reference filter–inductor current vector; and current controller is implemented to produce command voltage vector to be synthesized by pulse width modulation (PWM) segment. Coupling inductor shapes output impedance of inverter thus, active and reactive power coupling is minimized.

Inverter based control for real and reactive power is discussed in [10], which contain three fundamental features i.e. prime mover, dc interface and VSI. Linking to power system is organized by an inductor. VSI offers control for both magnitude and phase of output voltage, the vector relationship between inverter voltage and the system voltage, along with inductor reactance, controls flow of PQ power from the MS to system.

In [77], Bailu, et al., presented modular cascaded H-bridge multilevel PV inverter for single/three phase grid-connected applications. Modular cascaded multi-level topology advantages to increase effectiveness and flexibility of PV systems. In [78], multi-level voltage from a single dc source are proposed, it reduces amount of switches, not demonstrating slightly voltage balancing problem. This inverter is also able to increase input voltage without any extra boost circuitry.

3.2. Energy storage devices

For smooth operation of power system, storage of electric energy is very much important, having a wide range of benefits to the electric power companies. The electric energy within the MG can be stored by several forms, such as; batteries, super-capacitors and fly wheels etc.

In [76], it is described that large time constant response of some micro sources, i.e. fuel-cells, micro turbines and storage devices, would be capable of providing amount of power essential to stable system disturbances in major load changes. Considering time duration, for examining MG dynamic performance, storing devices such as flywheels and batteries are validated at constant dc voltage using power electronic interfaces coupled with electrical set-up (ac/dc/ac converters for flywheels and dc/ac inverters for batteries).

Venkataramanan and Illindala in [79], illustrated that lead acid batteries are more appropriate in MG energy storage applications. These batteries can provide large currents for short interval of time. In [63], for voltage and frequency maintenance in MGs, storage system, i.e. batteries system, is primary control unit. It is operated as MG shifts to islanded mode. In islanded mode, batteries are directly coordinating with local DERs over central controller, leading to reliability of power system. In [60,80], an innovative control approach is designed for stabilizing MGs on several process modes. Battery storage system is used to address slow response difficulty of MSs to load variations. However, for balancing load burdens, power is generated in islanded mode of MGs.

During peak hours/higher demand of electricity, energy storage devices takes the responsibility to supply energy to the distribution system. The major necessity scenarios for power supply during peak hours are;

- The disturbances such as, lower inertia of the DGs the energy storage devices insure power balancing in a MG in spite of load variations and transients.
- During dynamic variations in the alternative renewable energy sources in the MG, the storage system provides proper power delivery capabilities and tolerates the DGs to work as a dispatch able units.
- Fulfilling energy requirements for continuous conversion between grids connected "to and from" islanded operation of MGs.

3.3. Safe operation of the MG

MGs are composed of multiple electrical components, for safe and consistent process of MG, for controlling variables to remain within standard tolerances. In [81], two methods: preventive ones and predictive ones are discussed. Preventive ones, established on knowledge accumulated from skills, while predictive ones depend on actual data acquisition and handling. Both must avoid potential problems. As in [82], in view of fault events, system must have capability to detect and recover its normal behavior called self-healing of system. For power system, self- healing comprises three significant phases: identifying complications quickly, perform tasks for minimizing any opposing effects from fault events, and recover system rapidly to steady state operational mode [83,84].

Two operational modes define MG: Grid connected and islanded mode. MG connected to main grid exchanges power with each other (upper level/MV level of the MG). Power exchange, among grid, maintains power balance between energy demand and supply. While in islanded mode; there is no power exchange between MG and main grid while MG operates autonomously, as they are isolated electrically from each other and have no connections [85,86].

In [87], Huang et al., deliberated two methods for dealing with islanded operation of MG. Primary method is interrelated to control modes of inverter. By means of MGs are inverter dominated grids, voltage/frequency are controlled in islanded mode through inverters. However, second method closely follows conventional synchronous machine control.

3.4. Optimal operation of load

For fulfilling seasonal load demand, combinations of PV, wind, micro-hydro and diesel systems are proposed in [88]. Authors focused on multiple optimum combinations of hybrid renewable energy system for resort island based on actual production side energy auditing, including load distribution, profiles of seasonal load and load types as well as an investigation of local load development arrangements. Diesel is used as primary source of energy but due to degradation of environment, high generating, operational and maintenance cost, the authors proposed hybrid combination of diesel and renewable energy system for optimal operation and seasonal load management. Therefore, proposed hybrid system minimizes generation as well as operation and maintenance cost along obtaining a significant reduction in CO_2 emission and efficient energy sharing to distributed system.

In [89], three categories of demands i.e. fixed, transferable and user-action load are deliberated. It is assumed that quantity of estimated power, for every category of load, can be increased through several electronic devices. Fixed Load (FL) directs minimum power needed by customers at each time period and predict it by historical data usage. Transferable Load (TL) transfers original time interval to different interval. It is required to change power requirements to economical time interval for minimizing charge. In [90], authors presented DS system; DS can store left-over power from existing power and amount of power desired at each time interval. DS can sell power to power grid and buy from it, depends on state of charge (SOC) in batteries for safe and reliable operation of MG. DS can also hold power required for user-action load. As it charges or discharges power, DS experiences charging or discharging loss, respectively to increase optimization of MG.

In [91], author focuses on advancement for new energy management system created on application of multi agent-based hybrid for MG with centralized and decentralized energy control functions. On mentioned outline, three-level hierarchical energy controlling approaches are accessible in which cooperation method, for convention net protocol and multifactor valuation mechanisms, is applied. Corresponding energy managing framework, comprehended by arrangement of autonomous control for resident DERs, at resident level, coupled to synchronized energy control at central level of MG.

In [92], author presented a technique for building MGs, having reduced cost and effective supervision for production and storage devices, associated to a LV set-up for reliable operation. Implemented supervision system includes several functions to satisfy several objectives in MG i.e. data acquisition, management for load shifting at demand side, load limitation and scheduling generation. Secondary control of production and storage devices is established on this basis for coping active power involvement of entities, rendering to self-adjustments, when load varies, to boost up optimization of MG.

4. Optimization and designing objectives of the MG

4.1. Optimization methods applied to renewable energy sources

In this section, different optimization approaches are explained for solving hindrances against different renewable energy units within MG. Multi objective approaches are specified for solving complications in renewable energy systems and few of them suggest them to be applied in the MG. Upgrade deferment and reduction in energy cost in the grid as well as reliability and efficiency developments have made utilities prevail on to afford investment on storage and maintenance costs. In this regard, optimum sizing and placement of storages has become the emphasis of the recent researches to deliver an adjustment between investment and maintenance costs and expected benefits from storage systems in the MG [93].

Different tutorial describes generic algorithm (GA) development which is very important for problems with multi objectives. The fresh method applied for MG optimization of renewable energy sources is GA. It has a capability to solve large scale optimization complications within a MG. In [94] an enhanced GA is illustrated among different candidate locations for optimal placement of hybrid wind-PV system. By considering operation of hybrid RE system during its lifetime, an enhanced GA is settled for attaining optimization targets in a MG. Sizing problem along with design, control and cost strategies has a great impact on MG. In [95,96] demonstrated economic analysis and optimal sizing of hybrid wind turbine and PV-battery scheme consuming GAs for lessening overall expense of system. Likewise, for solar–wind–battery hybrid structure optimized sizing through multi objective GA are discussed in [97]. They mainly focused on two primary objectives for optimal operation of a MG; minimizing overall cost and power loss supply probability in the system. Standalone optimal sizing of wind-PV generator, formations of hybrid wind-solar system using battery banks, optimal sizing method for analyzing finest system configuration that can accomplish customer's essential power source loss probability with possible least charge of system, are also focused in [98,99]. Two-layer enhanced typical consensus algorithm for MAS is offered, distributed cost is optimized in this technique for load management of an islanded MG. Two-layer approach is adopted by the authors, global facts exposed in first layer of enhanced average consensus algorithm while distributed expenses optimization of load management can be fulfill via synchronization processing of improved average consensus algorithm in second layer [28].

PSO is also widely using in recent research work for the optimization of MG in different aspects such as, optimal designing and sizing of a MG, coordination among different renewable energy resources and minimizing overall cost of the system. For solving wind–PV capability coordination in industrial period of user, an evolutionary PSO approach is offered in [100,101], benefit cost ratio is employed for e industrial user to measure economic benefit capitalizing wind-PV generation systems. In [102] progressive variation of PSO process is used for optimum design of reliable hydrogen-based stand-alone wind–PV power producing system, optimization part is focused for reliable flow of energy, if demanded. Minimization of hybrid system cost in MG, system costs include; replacements, investments, operation and maintenance along with loss of load costs. In addition, for optimal operation of MG, [103] discussed an improved proficient multi-objective adaptive PSO of a typical MG with renewable energy resources accompanied by a backup hybrid micro turbine-fuel cell–battery power source with purpose to level the mismatch or to store the left-over energy when it is required. For improving the MG optimization process, a PSO hybrid algorithm built on a fuzzy self-adaptive and chaotic local search mechanism structure was applied.

Banos et al., [104] studied existing state of art in computational optimization approaches, for renewable and sustainable energy, determined that certain researchers have explained problems of multi-objective associated to renewable energy schemes via pareto-optimization approaches. Moreover, studying present investigation on finest sizing of stand-alone hybrid wind-solar power generating systems using graphical building technique, artificial intelligence method, iterative approach, probabilistic approach and familiarized multiple software tools for designing of hybrid renewable energy systems in a MG i.e. General Algebraic Modeling System (GAMS), Hybrid Optimization Model for Electric Renewable (HOMER), HYBRID2, HOGA, RETSCREEN and HYBRIDS [105]. In addition to optimization techniques of MG, some researchers also have focused on triple multi-objective scheme remote hybrid systems for minimizing entire cost of MG during installation and emissions of harm-gases like CO_2 [106].

4.2. Designing objectives of the MG

Initial installation cost of solar/wind or hybrid renewable energy system along with storage devices is higher than that of diesel engine generator having equivalent sizes, but operation and maintenance cost for renewable energy generation system is usually lesser as compared to diesel engine generator. Energy storage devices can easily operate and obtain mismatches between peak demand and generation at time of uncertainty. Main problem usually occur in MG is due to the designer's optimization and installation planning of renewable resources. Reliability of renewable energy sources and costs requirement should be stable in design approaches.

Several dynamic aspects like the spot location, temperature variations, uncertainties and quality requirements of various renewable energy sources arrangements along with supply security related aspects in a MG have an impact on the decision strategies [107]. By considering all these parameters in the designing stage will lead to an efficient and optimal installation of MG. Energy storage devices has great impact on MG for reliable power distribution and now developed an essential part of hybrid renewable energy sources. Choice of renewable energy sources in MG depends seriously on financial assessment metrics such as, energy charge arbitrage (buying and selling of energy in markets in order to take advantage of differing prices for the same asset), reducing energy transmission access cost, deferring investment facility, cost of investment in system, energy production expenses, operational and maintenance costs, plant balancing costs, power prices, increasing overall efficiency and lifetime of system [108–110].

Three-layer control unit is considered in designing of MG for optimal and reliable operation having minimum power loss. Each unit has capability for independent operation and performing their tasks individually for MG optimization as shown in Fig. 5.

1) MGCC is central controllable unit within system; it is installed at MV/LV side and also manages the key operation within MG. It is mainly responsible for optimal operation of the MG. The MGCC comprises of several key features including economic control and management jobs, it is classified control arrangements. Main operations of MGCC is given below,

- MG central power management system
- Overall power control within MG
- Optimal operation during islanding mode
- Emergency control during instant fault condition

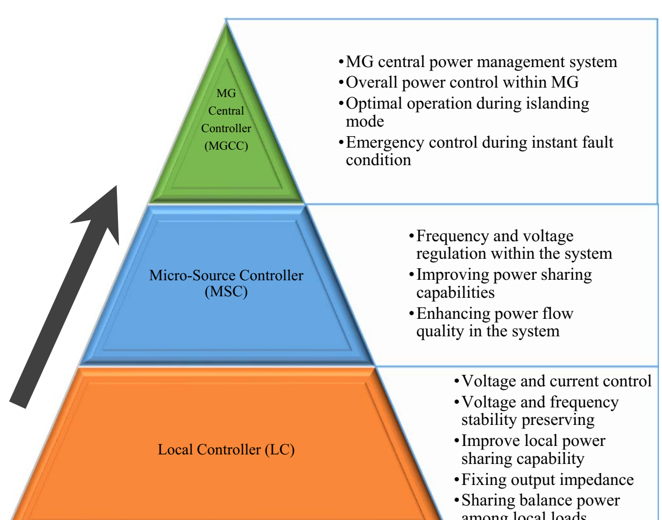

Fig. 5. Three-layer optimal control unit for designing of MG.

2) MSC is linked with each MS generation sectors at different renewable energy source and mainly responsible for the energy optimization and sharing of energy with the main bus bars. The main responsibilities of MSC are;

- Frequency and voltage regulation within the system
- Improving power sharing capability
- Enhancing power flow quality in the system

3) LC could either be MS controllers or load controllers having following functions;

- Voltage and current control
- Voltage and frequency stability preserving
- Improvement of local power sharing capabilities among different local loads
- Fixing output impedance
- Sharing balance power among local loads

Overall, optimization techniques are extensively applied for effective distribution of energy among different loads and storage systems in designing procedure. They are mostly analyzed on basis of their performance parameters, efficiency and economic metrics. However, effects of energy values and demand uncertainties in the market on optimal design, still configuration is essential to be considered for several storing systems for renewable energy in the MG.

5. Comparison of a MG between centralized and decentralized approach

Earlier centralized control techniques for power systems were very common. These were realistic as grid was developed for limited number of controllable and monitoring units. As requirement for electric power consumption increases, system gets more complicated rapidly; central control system is highly multifaceted and very costly. Complex decision making for large power systems, that can be centrally controlled, can be computationally exhaustive, bulky, and require a wide range of technical and communicational challenges for smooth and safe operation of system [111]. For centralized control system, the MGCC may responsible and takes decisions about the set points of each local installed unit [112]. However, for confined power systems, i.e. in modern ships, multiple-objective optimization methods are observed to be more effective [113]. On the other hand, the authors showed their interest in decentralized real time control techniques, applied to MGs. In practical however, it is not so easy for MGCC to access all existing information. In example, it is very intricate for MGCC to identify and handle the operation of a circuit breaker and temperature of battery for a specific power storage unit. Likewise, further details can be found in literature mentioned in [114]. Presently centralized and decentralized systems are well-matched to MG operations but decentralized methods seem to be more suitable; MGs have autonomous power system infrastructure components having capability of continuous operation and limited need for peripheral communication. They may be controlled independently from external utility grid network in such manners, although, local controllers can take decisions accordingly. In decentralized control concept, authors seek to avoid central controller for MG itself and decentralized decision making technique in MG.

However, it is comparatively harder to implement a centralized system at reasonable cost that can bid in the market regularly, for an hour, and at the same time, it has the ability to black out a MG or shut down a specific load or making adjustment of a specific unit set point, in case of unsteady operation within next short time interval [115]. A related issue concerns data communication infrastructure. For smooth and safe operation of MG, a simple local network/local controller for swapping information in limited way is essential within a MG.

Implementing decentralized approach permits every producer of DER units and loads for inserting programmable agent in controller of equipment, according to rules, providing “plug and play” capability for future DER units and loads. On the other hand, in centralized system, installation of any new module also needs extra programming in central controller and perhaps exchanging whole system for its implementation [12,116].

6. Conclusion

A MG is small in size and complex in operations. In this paper, a MAS system for MG control and optimization is presented, which concludes that use of MG systems with local generating units and loads, plays key role in improving operations in power system's reliability and efficiency. MAS is a tool, not only used for providing intelligence for performing operations associated to complex tasks, but also facilitate management in design and operation of system. Furthermore, a large amount of research work is carried out on MG by using MASs like market modeling, power system distributed control, optimization and quick restoration of the system. Similarly, MG architecture, with backup devices, inverters and controlling system for smooth and safe operation of MG, is offered with several aspects.

However, performance of MAS is stimulating and synchronized to new functions i.e., scheduling of electric power, storage/backup and emergency islanding. However, some challenges still need to be in consideration for improvement, such as, stability of voltage and frequency along increase scheduling duration are few foremost significant tasks for optimal operation of MG. Moreover, optimization methods, applied to different renewable energy sources and designing objectives, were discussed in details and finally comparison of MG through centralized and decentralized control is also presented.

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