Autonomous Integrated Microgrid (AIMG) System: Review of Potential

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Abstract

The smart grid recently has been a vital research field among the global researchers and academia due to its significant transformation of the traditional, original and aging power grid networks. This paper reviews the state of the potentials of a smart distribution grid and highlights relevant areas of research problems that are related to the optimal sizing, unit commitment, and economic dispatch. The effect that this model will have in the power system operation targets and objectives as well as the effect that it might bring to the various types of consumers are x-rayed. The proposed system is expected to be a new electricity paradigm that aims to achieve sustainable, efficient, reliable and resilient type of electricity delivery system. The concept is expected to make significant advances towards the process of achieving the smart grid objectives and benefits as well. Finally, the paper proposes a study of an innovative model of smart grid network whereby many microgrids are integrated among each other to form an autonomous integrated microgrid (AIMG) model.

Keywords:

Integrated Microgrids; Distributed Energy Resources; Smart Distribution Network; Renewable Energy; Decentralized Power System; Autonomous Energy Systems

1. Introduction

The current power grids of most of the developed nations are getting old and aged. The century-long industry has gone through many transformations in the past. In addition, as development rates throughout the world increases tremendously, the dependency to reliable and efficient electricity became of paramount importance. The importance of having more reliable, efficient and self-healing systems are getting more public attention due to the heavy dependence of the world's economy of having extremely high quality power. The occurrence of several major blackouts in many different countries (such as the July 2012 India blackout, the 2003 Java-Bali blackout in Indonesia and the August 2003 blackout in the US) [1]and the need of having almost-complete-reliable electricity urged the researchers to rethink about the structure and the need to upgrade the current power systems in more sophisticated ways that can uphold the world's ever-increasing economies and technologies [2].

As the focus on developed countries goes on power quality and reliability (PQR) aspect, many developing nations are also in need to create low-cost, efficient, green-based power systems that have capabilities of growth [3,4]. Traditional and conventional power plants such as coal power plants are now considered to be less efficient, have very high investment costs and are polluting the environment. The solution for remote and rural areas was, for so long, the use of diesel generators in order to meet their electricity demand [5]. This again highlights the substantial need of new technologies that can suit the developing countries as well as rural and island areas.

On the other hand, there have been great achievements in the improvements of distributed energy resources (DERs). Great advancements have been carried out on solar, fuel and wind energy technologies among others. Additionally, many of these technologies have renewable energy production capabilities making them environment-friendly type of generation technologies. The topic of environmental protection itself is currently under the world's attention whereby the reduction of greenhouse gas (GHG) emissions is of great interest. These two aspects of the DERs –i.e. advancements of these technologies and their capability to reduce emission of GHGs – have compelled many power system decision makers to modernize the system by introducing these technologies massively in the present power grid.

Besides that, in the world major political discussions there have been huge discussions and ideas on how to mitigate the climate change problems as well as the effect that vulnerable oil prices have on the world's economy due to the political volatility of the oil-rich countries [6]. According to [7], environmental challenges (along with market/customer needs, infrastructure challenges, and innovative technologies) have been categorized as one of the main four factors that drive the need for future smart grids.

Due to the above mentioned problems, there is a conclusion that can be inferred from them. The most important learning points of these current world problems include the significant need to develop more reliable power systems, the need for energy autonomy and sustainability in electricity production and lastly, the need for new electricity markets. All these new needs force the researchers and power engineering experts to rethink their economic and technical approaches to deliver quality power to the customers. These new dimensions for electricity to operate are basically under the smart grid initiatives that have been under huge research discussions for the last couple of years.

In this paper, the authors propose a new approach that current power distribution systems could be modified through the systematic use of microgrids. By carrying out a relevant and extensive review, the paper proposes new dimensions of power system research that transforms the current distribution grid under the smart grid initiative. This new paradigm employs the large-scale use of microgrid technologies in either urban or rural distribution grid that is capable to have minimum reliance on the fossil-fuel-based power grid. The paper also analyses the effect this technology (i.e. AIMG system) can have, in terms of socio-economic aspects, at the community level. It looks at the possible applications that this technology could be deployed. Furthermore, the paper also emphasizes the suitability of the technology at the distribution grid by looking at the demand and supply.

2. Autonomous Integrated Microgrid System

It is one of the main objectives of this paper to propose a hypothesized power delivery system with the name of Autonomous Integrated Microgrid (abbreviated as AIMG) System. In order to properly define and describe it in detail, this section describes the system in a bottom-up approach by firstly, explaining about the

microgrids, followed by the integration of microgrids and lastly introducing the word autonomous to form what is known as the AIMG system.

2.1. Microgrid System

The traditional practices of the electricity sector are facing dramatic changes due to several reasons. Transferring power from the large-scale power plants which are close to the sources of energy (e.g. hydro dams) to consumers, causes considerable amounts of power loss which significantly affects the efficiency of the whole system. Besides, since the end of the last century, the deployment of the distributed generation (DG) technologies in the distribution systems have got widespread interest from electricity consumers in order to firstly increase their power reliability by installing backup generators, and secondly the increasing interest of the global energy policy makers to adopt the renewable energy technologies for the purpose of environmental issues. These acts have tremendously increased the penetration levels of DG technologies in general, thereby turning the original passive distribution networks into active systems that are able to operate bidirectional energy flow.

On the other hand, the dramatic changes in the power industry are also affecting the energy markets and the way trading is carried out in the power industry in general. The deregulation policies imposed in many modern countries are expected to encourage the increased competition and market participants of the electricity industry.

Considering the above-mentioned significant improvements that the power industry has to go through, the power system engineers proposed the concept of microgrid. This concept has evolved to provide a new paradigm to revolutionize the current electricity industry by facilitating the above-mentioned new practices and solving some of the old industry's problems [8]. It is widely believed that microgrids are able to effectively control the deployment of the vast amounts of DGs in the distribution system [8-12].

A microgrid is generally a small-scale, self-contained, medium/low voltage electric power system that constitutes locally-grouped, distributed energy resources (DERs). DERs may include DG technologies, distributed storage (DS) systems, controllable and clustered loads and plug-in hybrid electric vehicles (PHEVs). Since microgrid elements are in close proximity, the optimization, grid integration or autonomous operation capabilities of the system are carried out locally.

Many researchers have either directly or indirectly focused in their research on the wider benefits that microgrids might bring to the electricity infrastructure. One important and very obvious advantage of the microgrids is its ability to provide a platform for the massive introduction of the renewable energy technologies into the power grid [8, 13-15]. Additionally, the microgrid's ability to provide significant improvement in the power reliability and hence increasing the resiliency of the system was heavily emphasized by many researchers including works published in[9,16-18]. This is because microgrids have the ability to island themselves from the grid (in case of emergency or planned maintenance) by using highly specialized control technologies.

Besides, the need to organize and utilize the massive adoption of the distributed generation technologies as well as the need to foster ways to integrate new generation technologies that are ever evolving was only able to be resolved by the implementation of the microgrid concept [8, 19]. The authors in [13]deeply debated in their paper the possible opportunities and advantages that microgrids might offer for the industry experts in relation to the centralized paradigm of the industry.

2.2. Integrated Microgrid System

The word integration primarily refers to the act of combining two or more things so that they work together effectively [20]. Applying this definition to a system that constitutes many microgrids, an integrated microgrid system implies the fact of combining the operations and the coordination of lots of microgrids to form a complete, low/medium voltage-based distribution system that works more efficiently, effectively and reliably than the current power distribution systems.

The integration of the microgrids so that they form a more robust and complete distribution system has got several advantages. Firstly, it enables the decentralized control and operations of the distribution system. This is mainly because the process of carrying out power system operations (such as demand management strategies) will be carried out in a more decentralized, site-specific manner that matches the suitability of the customers as well as that of the utility. For instance, when carrying out load shedding strategies, it is simpler and easier to identify and decide faster, which specific loads are suitable to be detached in a given crisis situation or planned case for a smaller system than for a large interconnected power system. On the other hand, for the large-scale systems, there is a lot to generalize the different situations and conditions of the utility customers so that a utility is able to carry out its load shedding strategies either for emergency or planned operation.

Besides, it is the authors' view that the greatest advantage of integrating microgrid systems into a self-reliant system lies in its ability to allow and ease the process of sharing resources generally. Some of the resources that could be shared include the excess of energy supply of a particular microgrid, reactive control devices, storage devices and others. The same view was presented in[14] in which the authors identify significant benefits that result from the use of integrated microgrid systems. The authors in [14] highlights that scalability is reduced if several microgrids are coupled together such that they are able to use each other's resources.

It can be realized that integrating microgrids leads to a similar concept of interconnection in traditional large-scale power systems. From this point, it is evident that some of the advantages that initially led the utilities to interconnect large power systems – such as improved power system reliability with reserve sharing, enhanced security of supply through mutual assistance, coordination of generation and distribution expansion, and development of regional markets for electricity – are similarly applicable (if not more so) in relatively smaller integrated microgrid systems. On a small scale, the above-mentioned advantages translate into microgrids level such that integration between the microgrids will lead to the improvement of the specific reliability of individual microgrids with reserve sharing, enhanced security of supply through mutual assistance of the microgrids, coordination of distribution system expansion, and development of retail markets that are suitable in a much smaller scale that suits each community's interests and situations.

Integrating microgrids solves the need for complex control systems to control the massive deployment of DERs in the distribution system. It is otherwise, needed to dispatch and control each and every DER separately. This task is tedious and requires very complex control systems. This can be solved by coupling several DERs into a microgrid and then only designing a control system that controls and coordinates the operations of several clusters of DERs (microgrids)[16].

2.3. Autonomous Integrated Microgrid System

In the literature, energy autonomy is properly defined by [21] by looking at both the literal meaning of the word autonomy as well as the notion of the word energy autonomy. The authors in [21] state that energy autonomy is meant to be "…… the ability of the energy system to function (or have the ability to function) fully, without the need of external support in the form of energy imports through its own local energy generation, storage and distribution systems". Referring back the statement of 'autonomous integrated microgrid system', it could be explained that the word autonomous is used due to the fact that the interconnected microgrids are independent of the fossil fuel-based power grid that might be available in the locality that AIMG system is situated.

In many previous research works, the main focus is such that the single microgrid system that is proposed or implemented by the research work is operated either in a grid-connected mode or used the grid as a backup power generation resource. This view is also shared by [14] and the authors also hope that if the power system planners target to operate the integrated microgrid system in an autonomous way while at the same time avoiding to use the utility grid as a backup power generation, then each microgrid system that constitutes the smart distribution network will target to install as many renewable energy technologies (RETs) as possible since the surplus of energy can be used to supply other microgrids within the integrated system. Hence, this approach of developing future power systems is seen as an environment-friendly, renewable-based and community-owned-type of power system that targets sustainable future.

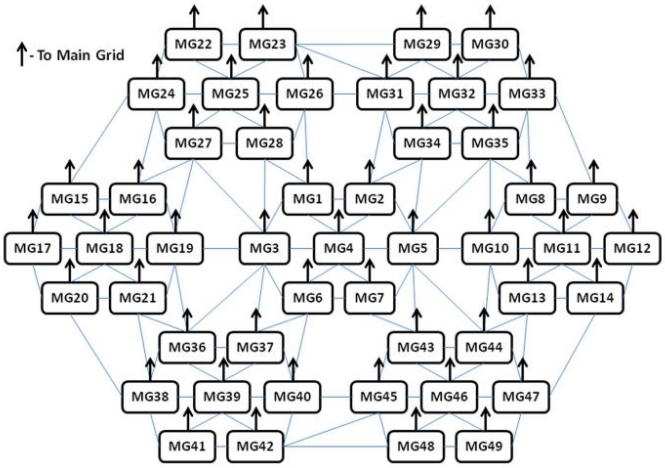

Fig.1. An outlook of how the autonomous integrated micro-grid(AIMG) system model will look like. Adapted from [23].

It is worth-mentioning to describe the AIMG system as a system that makes the path for the strategic deployment of microgrids as was the case of microgrids introduction in the power grid in which they provided the platform for the DGs to be deployed strategically without incurring any significant sacrifices into the distribution systems. Fig. 1 indicates the outlook of many microgrids being interconnected among each other forming the autonomous integrated microgrid (AIMG) model. The arrow pointing outward of each microgrid indicates that all microgrids are connected to the same distribution grid forming a smart distribution grid in a given locality.

Additionally, it is also worth-notable to highlight that the word autonomous does not stand for the meaning understood from the word “stand-alone” as quite often proposed when discussing microgrids. The meaning of the word “stand-alone” is true to those single microgrids as they act individual small systems as described in [23]. In contrast, the fact that the AIMG system constitutes many microgrids that are integrated among each other proves that the word stand-alone in microgrid scenario cannot be used interchangeably with the word autonomous as in the case of AIMG system. The independence in supply sufficiency aspired in the AIMG model is the fact that the whole system comprising the many microgrids is able to self-sustain itself with no or minimum reliance to the existing distribution grids. Hence, the new model is expected to offer a third dimension to the existing two dimensions, i.e. grid-connected and stand-alone microgrid systems.

3. System Operations

It is the belief of the authors that only very few studies have focused on the system operations of this particular power grid system i.e. the autonomous integrated microgrid system (AIMG). This view is also shared by [14]. So in this review paper, the authors look at the ways that the normal power system operations could be extended into an AIMG level which is higher than the microgrid level that many authors have focused on in recent years. Therefore, in this section, several power system operations are highlighted. It is firstly looked at what other microgrid researchers have written about each operation and then these ideas are argued such that they are elevated into a higher level of AIMG system that stands for one large distribution grid that is able to perform better in many ways than the existing distribution grids.

3.1. Optimal Sizing of Distributed Energy Resources

There has been a huge research in respect to the optimal selection and sizing of distributed energy resources (DERs) within the microgrid level in the literature. This is mainly due to the fact that many electricity consumers such as high rise buildings and industrial facilities want to integrate the combined heat and power (CHP) technology with some of the renewable technologies. It is highly efficient if consumers have the ability to utilize the CHP technology on-site as there is high demand of cooling and heating in the high-rise business-oriented buildings. Because of these reasons, and because of the increased demand of electricity from the rural areas, this topic of optimal selection and sizing of DERs has been under significant research focus.

In the literature, many techniques have been proposed for the optimum design of stand-alone hybrid power systems which are generally reviewed in [24]. The authors of that review paper showcase the most common techniques/software used in the recent literature. They highlighted the use of commercially-available software tools as well as the bio-inspired optimization techniques. In their comparison, HOMER, genetic algorithm (GA), particle swarm optimization (PSO) and simulated annealing (SA) were some of the most common tools/techniques used in the recent literature. Some of the issues that these methods optimize include the determination of the optimal configuration and location, type and size of the generation units so that the system meets the demand of the customers at the least cost possible. Additionally, some researches that are conducted earlier on employ other techniques that do not utilize the optimization techniques to set the sizes of these hybrid systems as presented in the literature [25].

As far as the authors are aware, there is only one reported literature that has raised the optimal sizing problem into an integrated microgrid level. The authors of [26] presented detail studies on optimal sizing of DERs for integrated microgrids using evolutionary strategy. The optimal sizing problem is formulated as

nonlinear mixed integer minimization problem which minimizes the capital and annual operational costs of DERs while considering several systems and unit constraints. In addition to the cost minimization objective of the method, the system is expected to operate reliably at the cheapest cost possible. It is one of the main contributions of [26] that it proposes a methodology that is capable of sizing the DERs within an integrated microgrid distribution network. However, the work also has got deficiencies since it does not address the optimization of the proposed network architecture. Besides, the authors also claim that their method is flexible to accept many more DERs being contributed in each microgrid. However, a question in regard to significant increase in not only the number of DERs within microgrids but also the number of microgrids joining in the AIMG system is of great concern since the concept of AIMG targets massive deployment of both DERs within microgrids and many microgrids joining up together to form the required AIMG system.

In addition, it is very important that all the research related to AIMG concept should consider the multi-objective optimization techniques by looking at several important constraints such as the minimization of the total cost involved in the AIMG, the minimization of environmental emissions as well as the maximization of the total efficiency of the system. However, it is also essential to emphasize the point of having high *quality/price ratio*. This is because introducing new technologies definitely comes with the price of high investment costs but these additional costs should guarantee the desired quality to sustain better service and a more sustainable economy that benefits all.

3.2. Economic Dispatch and Unit Commitment

It is one of the main targets of the AIMG system to have at least minimum or no reliance to the power grid network. It also targets to vastly adopt the new generation technologies with renewable energy technologies as the main sources of power. Some of the units that might involve include energy sources such as: solar, wind, biomass, fuel cells, micro-turbines, diesel engines, small hydro and many other new technologies that are under extensive research work for efficiency enhancement programs. Other units also include the distributed storage technologies which are similarly facing under significant efficiency and life-cycle enhancements. Some of these are batteries, flywheel energy storage, ultra-capacitors for storage and many others. All these units require proper strategies to be dispatched so that the optimal system operations in terms of both cost and emissions are achieved simultaneously. Due to these facts, the old electricity industry's problems – i.e. economic dispatch and unit commitment problems - comes into a serious consideration from the industry experts and its researchers as well.

Although there is quite a good research in terms of energy resource scheduling of microgrids in general [27-29], most of these research works consider microgrids as either standalone systems or grid-connected mode. Some of the techniques used include: linear programming optimization technique [28,29], Lagrangian Relaxation (LR), Genetic Algorithm (GA) and a hybrid algorithm of LR and GA combined to form LRGA algorithm [27,30]. All of their research works have a high potential to be extended into the AIMG level. This reality is supported by the fact that the work in [30] – which is the only work reported in the literature that carries out resource scheduling of microgrids and DERs in an AIMG environment – is an extension of the work presented in [27]. Additionally, researchers can explore ways that could use the normal optimization techniques that are commonly applied to the centralized power generation so that these techniques are able to dispatch the very many small units of DERs that constitute an AIMG system.

On the other hand, the proposed method in [30] uses the multi-agent system (MAS) algorithm to achieve the objective. The algorithm proposed schedules each microgrid individually, at first, so that the internal demand of the microgrid is met. The second stage of the process of the algorithm finds the best possible bids to

exchange power in the AIMG network so that competition is possible in a wholesale energy market. The last stage involves by rescheduling each microgrid individually in order to meet the total demand of the system which is the addition of all loads that are present in the AIMG system.

Considering the limitations that could be observed in [30], the MAS method possesses some technical challenges and problems. Since the method is getting recent attention from the power engineering researchers, there are still lots of challenges on how to entirely model and adopt it in the power system applications. Therefore, it can be assumed that the method poses difficulty in applying it. Besides, the load model used in the algorithm is considered as a lumped load. In reality, the loads are separated into each specific site and controlled by their owners as the loads also vary from several categories such as residential, industrial and commercial loads.

Another interesting phenomena that can be observed from the literature is the fact that the proposed algorithms for energy scheduling, unit commitment and economic dispatch problems are tailored in such a way that the algorithm fits the control system that is adopted in the given power system. For example, in [30], the control system adopted is a hierarchal control system that divides the control system into three different levels (i.e. load controllers and micro-source controllers in the lowest level, followed by microgrid controllers and lastly distribution management system control which is operated by the distribution operators). Following the control action, the unit commitment problem is also solved considering the three levels of the control action of the AIMG system.

4. Features and Characteristics of the AIMG System

This paper indicates the need for adequate and suitable methods and models that are essential tools to support actions and researches towards new and more efficient local energy systems. It is expected that AIMG system might provide an answer towards the need for this particular model and method to achieve the envisioned target of the authors in [31]. As the authors argue, any new model should encompass the basics of the expected future technologies to be incorporated in any visionary models. This fact is primarily and vitally clear in the adoption of the AIMG system model that uses the microgrid technology, which has been identified as the one of the first and most important technologies that might cater future electricity paradigm. Microgrid technology provides the fundamentals of the AIMG system.

4.1. Main Characteristics of the AIMG System

Many authors have highlighted the characteristics of the future electric power systems many of them describe them under the broad topic of smart grid [7]. In this paper, the authors have tried to visualize what characteristics that the proposed system might introduce in a given application. Here are five important characters, among many others, that the AIMG system is able to display after the successful implementation of the system.

1. **Resilient:** The AIMG model is expected to provide secure and reliable power to its customers in case of internal and external disturbances or hazards. It is able to recover from: attacks, natural disasters, blackouts or network component failures. The fact that the building blocks of the system are DERs grouped into microgrids that are able to interact among each other makes the whole system a reliability-based system in such a way that the problems occurring in certain places are contained within DER units or at a microgrid level if it is enormous. The resiliency of the system in terms of security of supply is also guaranteed by the fact that the system will have a large diversification of energy sources varying from

different types of renewable energies (i.e. solar, wind, biomass, geothermal etc) to the different types of non-renewable sources such as fuel cells, diesel engines, micro-turbines, and storage units. In the future, electric vehicles are also expected to contribute back to the supply of the demand in case of emergencies.

2. **Sustainable and Autonomy-Oriented:** The AIMG model is expected to be an environment-friendly (as it acts as the platform of the distribution system to integrate renewable energy technologies in massive amounts), self-sufficient (as it seeks to achieve complete self-reliance), and efficiency (as it brings generation sources closer to where demand is actually needed). It is highly important, however, to balance between the need to obtain a sustainable and green-based power system with the need to achieve energy autonomy and high security of supply. RETs have intermittent characteristics that might endanger the need of continuous supply. Therefore, it is highly important for the system designers to provide the optimal diversification of energy sources while achieving the optimal sustainability, and reliability needed.
3. **Customization**: Since the AIMG model is primarily based on microgrids, each microgrid is expected to be designed within the needs and the expectations of the given customers. This makes the AIMG system to be client-tailored for the operator's convenience without loss of its functions and interoperability.
4. **Flexibility**: The AIMG system is to be: (1) adaptable to different communities, geographical areas, and applications (2) easily expandable depending on the future needs (3) adaptable to different market needs of the particular users and/or customers.
5. **Community-based**: The system is expected to be community-based where applicable. This is to encourage community awareness in the wake of their energy usage so that customers are able to help up the utilities to cater the growing demand of electricity particularly during the peak demand occurrences. It is important to have community-based system so that the demand-side management strategies that deal with customer participation in the sector are properly executed.

Table 1
Vision of future energy systems – features and concepts

Feature	Concept
Integrated	Integration between different energy sources, generation technologies and ICT
Interactive	Interaction between customers and markets ("internet model")
Optimized	Optimization of economic performance, energy performance, environmental performance, reliability and availability of energy services
Resilient	Resilience with respect to disruptions and attacks
Adaptive	Adaptation to rapidly changing conditions
Predictive	Prediction of loads, RES production, market trading, possible outages and determination of maintenance scheduling based on operational data

Other researchers have identified several key characteristics of future energy/electrical systems [32], [7]. Table 1 shows a description presented in [32] that shows how future energy systems would be expected to operate. In another aspect, it is evident that many policy makers aim for their energy policies to target three main objectives, namely, sustainability, security of supply and competitiveness. According to [33], security of supply (SoS) implies two meanings: (1) decreasing the import dependency of a particular region to another region, (2) diversification of energy supply. These requirements are easily foreseeable for the autonomous integrated microgrid system as explained above.

5. Reality-Based Deployment of the AIMG System

This section of the paper looks at the other possible factors that need to be considered so that the possibility of reasonable deployment of this new technology (i.e. AIMG system) is achieved in the near future. Since this type of power system is applicable in urban areas, whereby there is the availability of many DERs owners in a given locality. It is firstly looked at the community-based power systems that are able to suit this proposed system model. It then looks at the degree and scale of autonomy that is possible within the framework of AIMG system. Besides, other subsections also include the possible and suitable arrangements of microgrids in a given urban environment and other suitable applications that could suit the AIMG deployment.

5.1. Community-based Power Systems

Many researchers have highlighted the need for a possible future framework that solves the community level energy sustainability needs [31],[34,35]. It is a common theme in the literature that the need for the sustainable framework in a community level should not be postponed, in particular in the fastest growing countries and contemporary cities. The need to accelerate the transition to sustainable energy systems, as highlighted in [36], will be realized and catered accordingly by proposing suitable models and systems that favour sustainability. In addition, nowadays, it is realized that achieving sustainable community objectives cannot only be achieved through lots of technological innovations and enhancements, but also through the improvement of many other factors that depend on the community at large. This view is supported by [21, 37].

Many researchers highlight the benefits of community based power systems [38]. One important aspect of these systems is the community ownership power system model whereby members of the community own some or all of the parts of the community's power system such that its ownership reaches diverse members of the community. This type of ownership model is successfully implemented in many European countries. One successful example to look at is Denmark, where 80% of wind energy production resources are some sort of community based ownerships [21]. As a result, the massive production of electricity based on wind energy exploitation has dramatically increased in Denmark, making Denmark one of the world's leaders in wind energy use. On the other hand, the Danish case has proven that "… the ability to act as a society has been possible despite conflicts with representatives of the old technologies" as explained in detail in [39]. The Danish experience is a valuable one for all as they have worked to achieve their energy targets for more than three consecutive decades.

There are also many lessons learned from the Dutch electricity whereby sustainability became an important issue for politicians and research scientists. The lessons learned are explained in [40]. Another important example is presented in [38] whereby the researchers have carried out a survey in a community-based wind power system in Japan in which the initial cost was funded by the community members. The study has revealed that it is possible to collect large-sums of funds from the community members alone, thus paving the way for the possibility of this type of business model.

The ownerships that are based on community levels offer many advantages in their own localities as well as the national energy targets (such as emission and energy autonomy targets). It firstly creates a sense of belonging and ownership of power system resources hence increasing the awareness of the importance of having very reliable, quality-oriented power system [21] among the community members. This view is also indicated in the study presented in [38]. Perhaps more significantly, the benefits of community ownership

can be realized in terms of both social and economic benefits through job creation, financial rewards, reduced problems of health, increased efficiency and improved security of supply. Under the community-based power system concept coupled with microgrid systems, normal households are able to replace the traditional central heating boilers with micro-CHP units. This procedure is acknowledged in [17] whereby the authors stressed that this type of replacement could bring economic benefits to the communities adopting this technique.

Addressing this need of having community-based power systems, the autonomous integrated microgrid (AIMG) framework is seen by the authors that it is one of the most viable options to cater these needs at a community level. It is also perceived that this proposed AIMG framework has the capabilities to provide the platform to address the synergistic requirements of the community's need for a paradigm shift in terms of energy efficiency, carbon reduction and renewable energy integration. It provides the mechanism to initiate community ownership power system models. For communities to involve the bi-directional flow of information envisioned in the smart grid, the energy and electricity use awareness in the normal households at a community level could be raised by the adoption of suggested model. Besides, by encouraging the AIMG system deployment through the community ownership models, the competitiveness of the electricity market will be increased that could bring reduced electricity costs.

5.2. Degree and Scale of Autonomy

The large-scale, centralized electricity industry is a century-long and well established way of obtaining power for our modern world. It is very hard to abandon this well-established technology in the market and all of a sudden propose a new model without considering the old way. Proposing and recommending the new electricity model, however, does not abandon the large-scale power system's use and applicability in the industry. The main objective of the AIMG framework is to create a new paradigm for the electricity investors to look at and consider when the advantages and benefits outweigh the old traditional way of getting the electricity grid to our homes. It is a step that puts us closer to concepts that need to be emphasized deeply; concepts such as energy autonomy, sustainable energy use and decentralized power systems. As was previously the case, the options available for the electricity industry experts were one-sided in such a way that, no large-scale electricity production meant that investors have to incur large expenses in installing their own isolated power systems or otherwise no power is available to be utilized in a given scenario.

It is one of the main targets of a community to realize energy autonomy in their daily energy use requirements. However, according to [37], the energy autonomy is not all about changing from fossil fuel-based power generations to renewable-based ones, but also requires an extensive strategy that encompasses many other factors that reach different levels of a community starting from individuals to businesses, cities up to the state and national levels.

A system that has complete autonomy and can operate in a perfect self-sustainable environment is the main cause of this new paradigm, i.e. autonomous integrated microgrid system (AIMG). Because this model is based on microgrids as its basic building blocks, it is firstly targeted to achieve internal autonomy of each participating microgrid in the system. This target proved to be a feasible mechanism that can be realized in today's power grid as explained in [17]. The analysis presented in the paper which has been applied to residential consumers illustrates "… that the electricity demand in a microgrid can be supplied by micro-CHP generators with penetration ratio of one for every second household, together with a photovoltaic array of about 1.5 kWp and energy storage corresponding to about 2.7 kWh per household (four industrial lead-acid batteries). This would then deliver an energy service independent of the grid network."

Realizing this vision of almost non-reliance to the grid has significant advantages for both the consumers (in a community level) as well as the utility operators. It is evident that when this objective is realized, the new energy (including electricity) model is able to cover some of the ever-growing demand. In return, this leads to the reduced need of constructing new transmission and distribution networks that would also lead to large savings in operation and investment in the long run according to the argument explained in [17]. Additionally, by combining other energy saving strategies and appliances with microgrids' energy supply system further reduces the domestic and other commercial energy demand and GHG emissions.

5.3. Possible Applications

As far as the microgrid applications are concerned, microgrids are generally considered technologies that are able to be deployed both in the advanced economy (AE) countries as well as in the developing (DE) world as highlighted in Fig.2. It is arguable to propose that AIMG systems could be implemented in any country within the three divisions (i.e. developing economies (DE), emerging economies (EE) and the advanced economies (AE) countries) provided in Fig.2. The possibility of having many microgrids established in closer areas leads to the AIMG realization in a given locality. This boosts the system's applicability in a global scale.

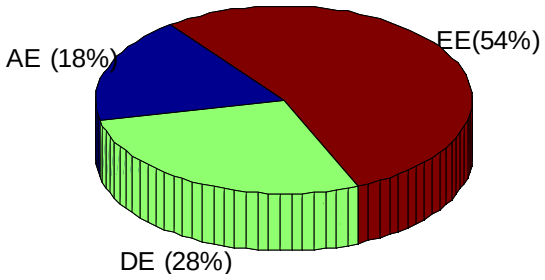

Fig. 2. Micro-grids could be deployed in different parts of the world irrespective of their economic standing providing different advantages in each area. The classification of the world economies inherent to this figure is based on the International Monetary Fund (IMF) World Economy Outlook 2010. Adapted from [31]

Since the need of each specific society differs in different countries, it is perhaps easier to look at two different standpoints and these are the advanced and emerging economies countries perspective and that of the developing countries along with communities living in rural and island areas.

5.3.1. Advanced and Emerging Economies Countries

For those countries that have well-established power grids (and particularly the advanced economies countries whereby most of their residents receive high quality power supplies unlike their emerging economies counterparts), the main drivers that encourage the consideration of new paradigms of electricity or energy deliver in general constitute several important factors. Many nations want to achieve energy sustainability in their own premises. This energy sustainability includes the exploitation of the renewable natural resources that are available to them and the vision of achieving energy autonomy with negligible environmental impacts. Achieving diversification of the energy mix is also considered one of the main

concerns. This is normally seen as a need for attaining energy security in the long run and to reduce the heavy dependency of imported fossil fuel resources of the specific nations.

In addition, as innovation in the technologies grows, the electricity sector is expected to go along with the technology growth by opening up the industry markets for new market players and innovative technologies. This step is usually favored in the industry as it also increases competition in the industry resulting in reduced electricity costs to the consumers. Most significantly, the need of getting an almost-complete reliable and very high quality power is getting expressively essential necessity for most of the developed nations. This is because a short blackout in a very industrialized area might lead to significant economic losses as the industries seek more and more reliable power supplies due to their significant improvements of technologies in use in their premises.

Having mentioned that, AIMG systems seem to offer a considerable option for the industry experts to consider. This is mainly due to the fact this type of system is primarily based on microgrid technology. There are noteworthy indications of the microgrid deployments in many real life applications particularly in the developed countries. Service sectors (such as hospitals, university/school campuses, airports and public buildings etc.) are seen potential zones in the modern urban centers that can suit microgrid applications in their own compounds.

Other notable examples can be driven from net-zero energy building concept that encourages buildings to install their own energy systems to achieve sustainability in their own backyards [41]. Such examples include commercial buildings (such as shopping malls, office parks, commercial high-rise buildings, etc.) that can install solar panels combined with generation and tri-generation technologies that also provide not only electricity but also cooling and heating needs of the buildings. Another important application for the microgrids include residential areas that could install their own rooftops, wind farms (such as the case in the suburban areas), biomass technologies and other cogeneration and tri-generation technologies. Each district could be arranged into a self-sustaining microgrid that is able to integrate itself into the rest of the system that constitute the AIMG system. Lastly, military microgrids are also identified as a top microgrid application and in which several of them have already been established mainly by US military both inside the country and outside where there are current military operations such as the case in Afghanistan[42].

All these areas put together makes the microgrid deployment too vast and wide in the future. Therefore, considering all these factors, the integration of these microgrid systems becomes of paramount importance for the distribution grid operators as well as the microgrid participants or owners, as this view was also supported by the authors in [43].

There have been several reviews being carried out by other researchers that summarize the list of world's existing microgrid test beds that are either operational for research or normal use[11],[44,45]. One very good example of a microgrid system that could be looked at is the project carried out at the Illinois Institute of Technology (IIT) in the United States. The researchers at the university have gone from just proposing ideas to also implementing the microgrid installation in the whole campus [46]. The varsity demonstrated that microgrid deployment at the campus has provided three main advantages and these are better efficiency, resiliency, and sustainability. The authors of the article further discuss the other initiatives that the university went on in regard with the smart grid concept realization. The vast deployment of microgrids in many distributed campuses and compounds leads to the integration of all these microgrids and hence paving the way for the autonomous integrated microgrid concept that is illustrated in detail in this research work.

Looking in a bigger scale than those above-mentioned microgrid applications, the AIMG system could be easily and more systematically implemented in a more careful and well-designed way to all those upcoming low-carbon new cities that aim to achieve sustainability in the long run. There are several notable smart city projects that are underway in different parts of the world. One such example is the Masdar City in the UAE that aims to create the world's first carbon-neutral city according to [47]. The significance of these projects is that these cities could be used as test beds for new emerging energy (particularly electricity) generation paradigms such as, in this case, the autonomous integrated microgrid system model. This objective is similarly shared by researchers involved in the Masdar project who claim that the city acts as a living laboratory for sustainable energy systems development on a large scale. The benefits that AIMG system offers suit the expectations of these major projects.

5.3.2. Developing Economies Countries, Rural Areas and Islands

With significant numbers of off-grid communities living around the world and as much as 45% of the global population are living in rural areas [48], there is a huge technology need that is capable to easily provide proper electrification to all these communities. Proposing the technology that best suits these kinds of needs is becoming a paramount importance for electricity industry experts, researchers, policy makers and aid donors. Generally, microgrids seem very cost-effective approach of the power delivery system with respect to the developing world's need of quality power. Microgrids also provide shortcuts to the vision of the developing countries in order to achieve national electricity grid that substitutes the diesel-based power systems that are very inefficient, unreliable and have very high costs compared to the developed countries centralized grid.

A. Developing countries:

Given the fact that many developing countries suffer from low electrification rates and hence very poor development standards in their respective countries, microgrids can provide the ultimate solution for those countries and areas [17],[49-53]. Constructing community-based or industry compound-based microgrids could be easily established in the developing countries in residential and commercial facilities to encourage economic growth and development. As more and more microgrids emerge, these microgrids could be integrated to form the AIMG concept that might favor more reliable system for all. This concept is also highlighted in [50]. The authors indicate that by starting electrification from microgrids to mini-grids (the look that the mini-grids are expected to be is what this paper strives to explain in detail which is the concept of autonomous integrated microgrid system) and ultimately to national grids. This approach is basically offering three different levels of setting the ultimate national power grid visions of developing countries. The authors argued that the microgrid owners who started the electrification process could, eventually, still have some role in providing electricity and hence suggesting that national grids and microgrids could still co-exist in the future smart grid vision.

B. Rural Areas:

The analysis presented in [17]suggests the fact that it is possible to create microgrids that are independent from national electricity networks by combining PV, micro-CHP and very small battery makes this approach very favourable for remote communities. It highlights that it is essential to reduce the high costs associated with the construction of the transmission cables and hence reducing significant costs of installation of these networks. Additionally, the autonomous microgrid construction also removes other distribution costs outside the requirements of the microgrid. Consequently, the deployment of microgrids offers an option for cheap

electrification in the rural communities as significant social gains are realized. As communities grow, the need for many microgrids also grows and hence integrating them into the AIMG model becomes the suitable option to realize the sustainable and energy autonomy needs of these communities.

C. Island areas:

Island electrification has also seemed to be one of the top applications that microgrids are expected to flourish in the nearby future [49]. It is very common in many parts of the world that many islands lack proper electricity infrastructure due to the requirements of the heavy investments for transmission line construction costs and some other parts the problems become immense due to technical problems present in the area. The authors in [49] detailed the issues related to the electrification of islands focusing more into the Indian perspective and taking the Kythnosisland in Greece as a case study. There are also many other research works focusing different parts of island electrification.

Another example of island electrification by using microgrids is proposed in [54]. The authors exhibit that the fact that Indonesia is a country of thousands of islands whereby people are scattered all around the many islands makes the interconnection of large-scale power system between the islands very expensive and an imaginable to accomplish. Consequently, the authors argue that microgrid deployment could be a viable option for the nation to resort to.

It is worth-mentioning that it is not the focus of this paper to discuss about the pros and cons related to the use of microgrids as a means to increase electrification in developing, rural or island areas. However, in this sub-section, it is important to highlight that if microgrids are considered in the electrification of these areas, hence the concept of autonomous integrated microgrid system is the most desirable and viable option for constructing a well-functioning distribution system that is able to meet the major concerns of energy related issues in this modern world including energy autonomy, energy sustainability, power quality and reliability, cheap electricity and energy use and the others.

6. Conclusion

This paper has presented a new approach that could be constructed (or even turned the existing distribution grids) the future distribution systems. The concept of autonomous integrated microgrid system was introduced whereby the notion of many microgrids being integrated into a signal robust smart distribution system was proposed. The model aims to encourage the use of microgrids (the new approach of achieving a sustainable decentralized power system) to achieve an affordable, reliable, and sustainable delivery of electricity (or energy in general).

Whilst the existence of significant research related to the different aspects of microgrid issues, this paper has highlighted a new dimension that researchers might look at in regard to AIMG model which emphasizes the need to design and plan for a coordinated system of lots of microgrids. The power system planning and design issues such as optimal sizing of individual DERs, the optimal sizing of microgrids, the economic dispatch of the dispatchable DER units in the system and the unit commitment issues have been proposed as some of the future research issues that could be focused on in the near future. It has also been put forward the expected characteristics that this new system might bring to the electricity and the energy industry at large.

The recommendation and the argument presented in this paper are expected to add up the existing discussions of the smart grid vision and how the future of the electricity as well as the energy delivery systems will look like. It has been shown that the AIMG system could be deployed in many places because of many different reasons and requirements that largely depend on the availability of resources, geography, policies and development related issues that each country or society is faced with.

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