# Recent Microgrid Technologies for Integrating Different Energy Sources: A Review

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*Abstract*— This paper discusses about the various microgrid technologies for integrating different non-conventional and conventional energy sources. Initially different architectures of microgrids are presented and then their control strategies are discussed. Afterwards the protection schemes are analyzed in different fault conditions and finally some recent applications of microgrid technologies are explained. Meanwhile a comparison of AC and DC microgrids is also made as a comparative study.

***Key words:*** Non-Conventional Energy Sources, Microgrid, Distributed Generation, Energy Management System (EMS) and Greenhouse Gas

## I. INTRODUCTION

### A. *Non-Conventional and Conventional Energy Sources*

Due to rising energy requirements and greenhouse gas emissions, countries all over the world are implementing goals for greenhouse gas emission minimization, improved energy efficiency, and encourage clean energy generation over the conventional energy sources like thermal, nuclear etc. This has led to the rise in use of non-conventional energy sources, which supply efficient and/or renewable energy, and are distributed throughout the main power system e.g. solar, wind, hydro, geothermal ocean wave and ocean thermal etc. Currently distributed generation units have not been connected in grid form and have only been used as a backup rather than main energy energy source. Furthermore, the unpredictable nature of renewable energy generation makes it difficult to balance energy in the main power grid. However, with many countries targeting to improve renewable energy use, the role of distributed generation is changing from backup to main energy supply. The summation of these distributed energy resources into “microgrids” can thereby play an important role in achieving these goals and balancing energy in the grid. [1]

### B. *Microgrids*

A microgrid is an connection of distributed energy sources, such as micro-hydro turbines, wind turbines, fuel cells and photo-voltaic added with energy saving devices, such as batteries, flywheels and power capacitors on small voltage distribution systems. Each supply system has circuit breakers and a power flow controller. The simple microgrid architecture is shown in Fig. 1. The microgrid gives a lot of significant benefits and gives a new pattern for distribution power systems. The main benefit of a Microgrid is its capability, during a grid disturbance, to detach and isolate itself from the grid smoothly with small or no interruption to the loads in the Microgrid. In peak load duration it stops grid failure by minimizing the load on the grid. Important environmental advantages made possible by the application of low or zero emission generators. The cogeneration (use of both electricity and heat) allowed by the close proximity of the generator to the consumer, thereby raising the energy efficiency. Microgrid can act to reduce the electricity costs to consumers by producing some or all of its electricity requirements, increasing the quality of power which is supplied to sensitive loads. [2]

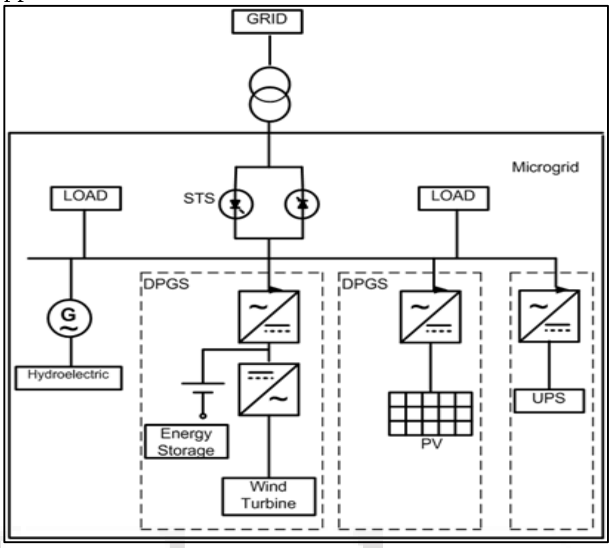



Fig. 1: Basic Microgrid Architecture

### C. *Need of Microgrids*

The options and advantages of integrating distributed energy resources into a microgrid are there for consumers and electricity utilities, transmitters, and distributors to supply different loads e.g. household, official, industrial, commercial, and institutes. For these consumers, onsite microgrid implementation can provide better reliability, improved power quality, lesser electricity bills by 20-25%. It also improves overall stability since expanding and adding onsite clean energy resources permits consumers to directly meet their electricity needs through a locally controlled grid that decreases the risk of power loss because they don’t have to depend on the main grid. Microgrids can also help local utilities by permitting system maintainace without affecting consumers, providing dispatchable power supply for use during maximum power loads, and reducing stress on the power transfer system. This can be taken as improved efficiency by minimizing distribution power loss because growing the amount of on-site power production reduces transmission and distribution power losses up to 7% of electricity produced. Thus, microgrids may profit the current infrastructure; provide distribution side energy management, mostly reduced costs, and better reliability for the consumer via a new path of producing and managing electric power. [1]

## II. ARCHITECTURES OF MICROGRIDS

### A. *AC Microgrids*

A general AC microgrid system interconnected with medium voltage system at the point of common coupling is shown in Fig. 2. The major system might be an AC or DC grid system. The distributed generation units and energy storage system are joined at few points within the distribution networks. A portion of the network having the distributed generation units and loads can make a small isolated AC power system i.e. an ‘AC microgrid’. During normal conditions, the two networks are connected at point of common coupling while the load circuits are given supply from the local renewable generation sources and if necessary from the utility supply. If the load demand power is low than the power produced by distributed generation units, extra power can be given to the grid system. [3]

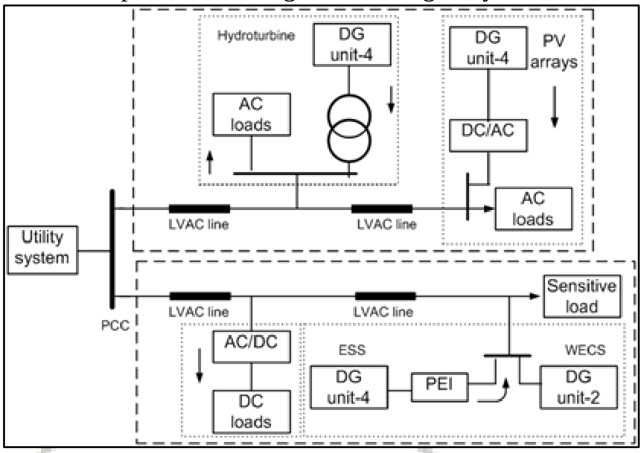



Fig. 2: AC microgrid architecture with the DG units and different types of loads.

## B. DC Microgrids

DC systems have been used in industrial distribution systems for electric power, telecommunication supplies and point-to-point communications over large distances or through sea cables and for connecting AC grids with various frequencies. Present customer equipments and tomorrow's renewable generation units are interfaced by power electronics devices. Common devices like PCs, fluorescent tube lights, adjustable speed drives, home appliances, businesses, commercial appliances and equipments requires the DC power for their use. Although, all these devices need conversion of the AC power into DC power for use, and the most of these conversion processes employ poorly efficient rectifiers. Furthermore, the energy from DC based distributed generation units should be transformed into AC to join with the existing AC electric grid, which is later on transformed to DC for customer applications. These DC–AC–DC power transformation stages give adequate power losses. The low voltage DC distribution network is a new idea which is one option to use the present power distribution problems and consider the future power system. It has the characteristics that meet the new needs of the electrical distribution networks. Fig. 5 demonstrates the typical DC microgrid systems connected with the main systems at the point of common coupling which can be medium voltage AC network from the conventional power projects or an HVDC transmission line interconnecting an offshore wind power plant. [3]

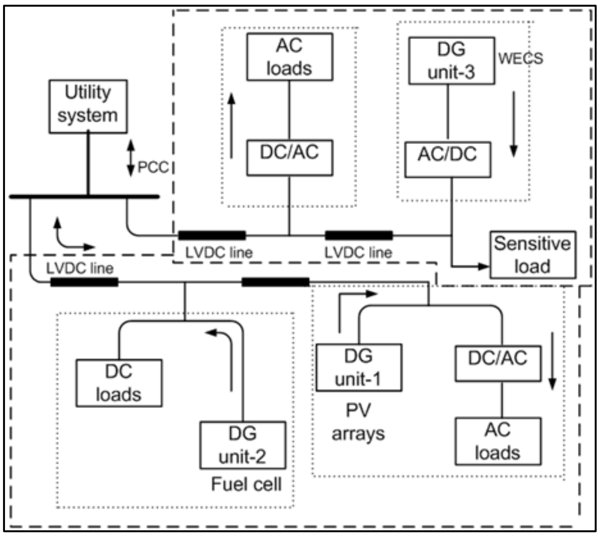



Fig. 3: Concept of a DC microgrid system with the distributed generation units and mixed types of loads.

In this method the loads can be interconnected across the positive polarity and the ground or between the two polarities.

## C. Hybrid Microgrids

Hybrid AC–DC microgrid is discussed as the future distribution network to use the advantages of both AC and DC networks. In this hybrid microgrid, AC and DC loads, non-conventional-based distributed generators, controllable distributed generation and energy storage systems are interconnected via separate AC and DC connections. Most low-voltage resources (e.g. fuel cells and batteries) generate DC energy which has to be converted to AC in order to be connected to the conventional AC grid, by DC to DC converters and additional DC to AC inverter. Meanwhile, many electricity consumers are using DC energy such as converter-based home gazettes (e.g. TV, computer, stove and air conditioner), light-emitting diode lights and electric vehicles. These loads should be connected to AC power systems through additional AC/DC rectifiers and DC/DC converters. [4]

Fig. 4 shows the general architecture of the hybrid microgrid. Hybrid AC–DC microgrid is introduced to minimize works of multiple power conversions in an individual AC or DC grid and to help the connection of several AC and DC sources and loads as a multiple energy career system. Energy management, control and operation of a hybrid microgrid are more difficult than those of an individual AC or DC microgrids.

## D. Networked Microgrids

A transformative structure for the optimal working and self-healing of autonomous networked microgrids. We consider the situation as multiple microgrids are physically interconnected through a common bus-bar. For the objective of data exchange and coordinated control, the microgrids are also interconnected via a cyber network. In the general operation mode, each microgrid operates independently.

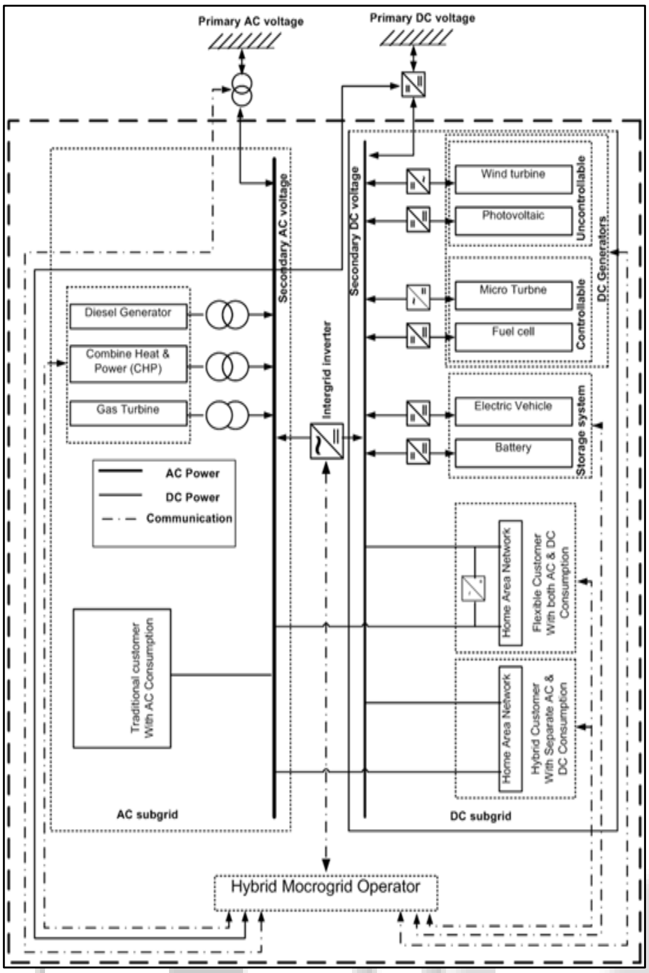



Fig. 4: General architecture of hybrid AC–DC microgrid

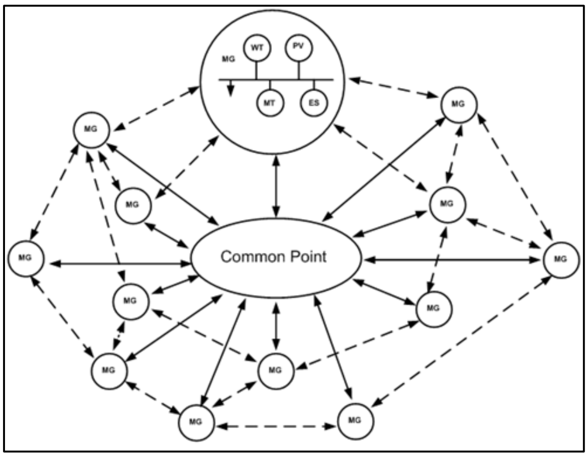



Fig. 5: Concept of networked MGs.

When an emergency happens, the emergency microgrid broadcasts its requested power support in the cyber link. An mean consensus algorithm is used to distribute the required power aid between all satisfactorily-operating micrograds. As an useful distributed mechanism, the mean consensus algorithm has been well studied and verified. The allotment finds the power support part of each microgrid, which will be applied by the local energy management system in each microgrid to do the optimal power dispatch. Finally, the accumulated power outputs from the satisfactorily-operating micrograds will approximately match the required power demand. Fig. 5 shows the autonomous networked micrograds where utilities are not available or down. The interconnected micrograds can help each other with local generation abilities to find the total reliability. [5] Finally Table1 below shows a comparison between AC and DC microgrid.

| **Operating Mode** | **AC microgrid** | **DC microgrid** |
|---|---|---|
| | Grid-connected mode | |
| Microgrid Central Controller | – Monitoring system diagnosis by adding information from the low voltage AC grid, distributed generation units and loads.<br>– Performing state estimation and security analysis, evaluate economic generation planning, active and reactive power management of the distributed generation units and demand side control functions. | – The main function of the microgrid central controller is to independently manage the energy flow and load-end voltage profile of the distributed generation units in responses to any noise and load changes.<br>– Participating in economic generation planning, Load scaning or management and Demand side control by controlling the storage devices. |
| Distributed generation controllers | – Ensuring synchronized operation with the main grid, maintaining the power tranfer at prior contact points.<br>– Ensuring that each distributed generation unit quickly picks up its generation to supply its part of the load in isolated mode and comes back to the gridconnected mode naturally with the help of the microgrid central controller.<br>– Performing active and reactive power management of the distributed generations in order to maintain stable voltage and frequency at the costomer ends.<br>– Managing load interruption/shedding strategies using demand side management with energy storage system help for maintaining power balance and voltage equations. | – Ensuring that each distributed generation unit quickly picks up its generation to supply its part of the load in isolated mode and returns back to the grid connected mode naturally with the support of of microgrid central controller.<br>– Independently control the power flow and consumer voltage profile of the distributed generation units in response to any noise and load variation. |
| | Islanding mode | |
| Microgrid | – Starting local black start to ensure reliability | – Ensuring the distributed generation units |

| | | |
|---|---|---|
| Central Controller | and continuous power supply.<br>– Changing the microgrid to grid-connected mode after the main grid supply is established without affecting the stability of grid. | quickly picks up its generation to supply its part of local load in isolated mode and naturally connect to grid with the with the help of the microgrid central controller. |
| Distributed generation controllers | – Controlling each distributed generation unit to rapidly pick up its generation to supply its corresponding local loads in the stand-alone mode and automatically resynchronize to grid with the help of the microgrid central controller. | – Ensuring that each distributed generation unit quickly picks up its generation to supply its part of the loads in isolated mode and comes back to the grid connected mode naturally with the help of the microgrid central controller. |

Table 1: Comparison between AC and DC microgrids

## III. CONTROL STRATEGIES OF MICROGRIDS

The use of the power converters to interface different parts in microgrids need correct control strategies. The controllers must be capable of:

- To exchange power from/to the grid network,
- To manage the real and reactive energy flows and manage the distributed generation units interconnected to it and
- To operate within its rated specifications i.e. the system frequency and voltage must be managed within their set limits. Contrary to the droop control methods, the master–slave microgrid control method is reported better. In this concept, the master–slave configuration ignores circulating currents between the power converters of the distributed generation units and change in frequency and voltage of the microgrid system. But this method minimizes the reliability of the system by setting an extra burden on the criticality of the master source and the interconnections among slave inverters and the power distribution unit. It also reduces the stability of the system. Otherwise it is an conveniently used method to avoid circulating currents and steps can be used to ignore the above-mentioned limitations. [3]

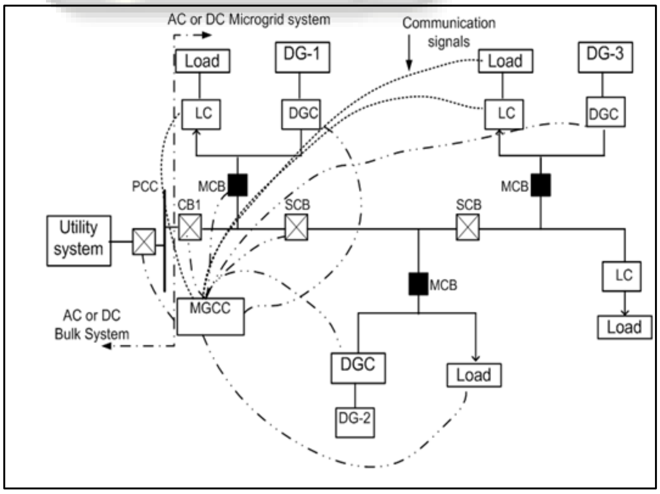



Fig. 6: Centralized control of microgrid system with microgrid central controller, DGCs and LCs.

Fig. 6 shows a structure of the microgrid system with the centralized control using microgrid central controller, distributed generation units and loads. The distributed generation units and energy storage systems are fitted with the distributed generation controllers that run smooth and flexible operation to meet consumer and grid needs. The distributed generation controllers may run with or without any interruption of the microgrid central controller. The goal of the distributed generation controllers is to care of the local control functions (levels 0 and 1) which mainly rely on power electronic interfaces fitted at each distributed generation unit and storage system.

### A. *Hierarchical Control Method*

The control and management of microgrids are multiple objective tasks with the control of power electronic devices, control of power flow, power quality, and control of different energy sources, etc. So a general hierarchical control method has been introduced for achieving total control for microgrids including primary, secondary, and tertiary control levels, as demonstrated in Fig. 7.

1) Primary control does the management of local power, voltage, and current. It is made in local controllers, following the set points used by upper level controllers.
2) Secondary control does the power quality control, such as voltage/frequency maintainance, voltage unbalance, and harmonic compensation. Grid synchronization in ac microgrid is also covered in secondary control.
3) The aims of tertiary control include power flow control and energy management.

The power flow control ensures the exact power management among distributed generation units, and the power transfer between microgrid and main grid. The energy management targets to add more intelligence to the system using economics. With the rising of the control level, the bandwidth is actually reducing in order to separate the dynamics of different levels. Normally, each upper control level requires being roughly an order of magnitude slower than the down streaming level. [6]

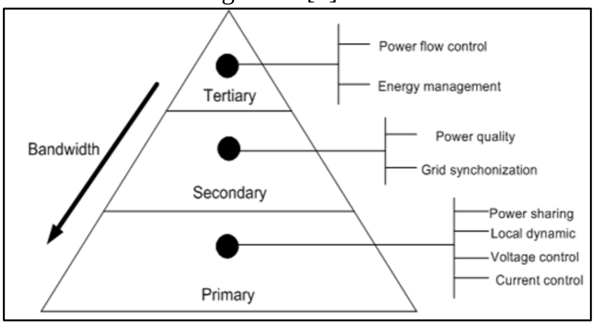



Fig. 7: General hierarchical control

Previously, the microgrid controllers make sure the system security, optimal operation, emission minimization and easy transfer from one operating mode to the other without neglecting system limits and regulatory needs. These goals can be achieved via three kinds of controllers, namely:

- A distributed generation unit controller connected to each unit and energy storage system.

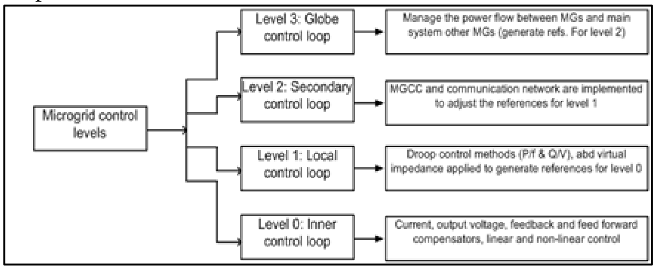
 

– A microgrid central controller and
– A Load controller.

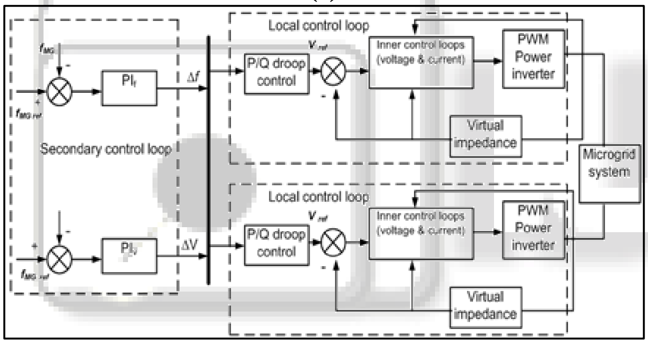
Every distributed generation unit can generate its output frequency and voltage matched in proportion to the amount of active and reactive power taken so as to find a proper load demand management. Based on these needs, the control in microgrid systems is done at four levels as follows:

*1) Level 0 (inner control loop):*

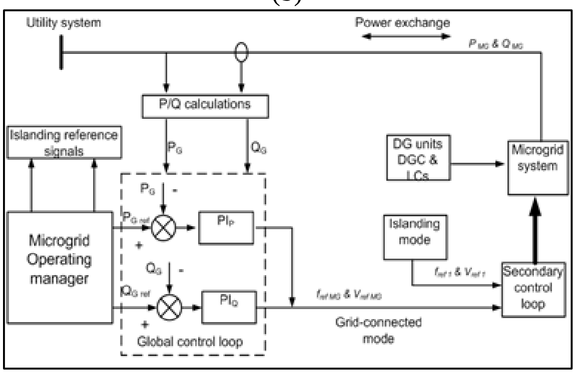
This is a power controller loop that finds the operating state of the distributed generation units and storage systems and it is famous as low level voltage and current controllers. Fig. 8(b) shows the setup of this control level in which the control issues such as the driving signal of each module are added. It also includes the feedback and feed-forward compensators along with the linear and non-linear control loops.




(a)




(b)




(c)

Fig. 8: Detail structures of microgrid system control levels: (a) hierarchical control levels in microgrid systems; (b) configuration of the secondary, local and inner control loops in microgrid systems; and (c) configurations of the global and secondary control structures.

## IV. PROTECTION SCHEMES FOR MICROGRIDS

### *A. Microgrid Protection Systems*

One of the main risks in microgrid operations is the protection system to properly operate in both modes of operations. Protection relays must make to work in a grid-connected mode as well as in an isolated mode. From the literatures, the fault currents in the grid-connected and isolated microgrid systems are importantly different. In that case, the security of the microgrid systems cannot be attained with same methods that have been used in the general distribution systems. In the grid- connected mode, the protection relays to separate the microgrid from the main grid earliest possible to protect the distributed generation units and loads. In the isolated mode, the protection relays work to isolate the smaller section of the microgrid system during fault clearing condition. Similarly, the fault currents are limited by the limits of the power electronics converters to approximately 2–3 p.u. of their rated currents. A proper organize between the DG units, protective apparatus and loads is required to make sure a secure operation of microgrids. The protection apparatus setting should be regularly updated while considering the mode of work. The microgrid central controller communicates with all the electric relays and distributed generation controllers to record their positions as ON/OFF, their rated current and fault current contribution. Communication with the relays is needed to update the operating current, detect the direction of fault currents and so properly diminish the fault [3].

There are two main aspects that must be analyzed in order to get a microgrid protective strategy work satisfactorily. The first one is connected to the number of fitted distributed generation units within the microgrid system. Second one, the presence of sufficient level of short-circuit current in an isolated operating mode of the microgrid is important because this level may largely drop down after the disconnection from the main grid. Fig. 9 reveals the fault current given by each participant in a grid-connected microgrid system. When the microgrid is working as a self-holding power island, any fault currents shall have to be given by those distributed generation units which are still connected to it. Here their fault current donations are smaller values.

### *B. General Protection Technique in Microgrid Systems*

Basically, two main issues are important that must be carefully studied so as to get a generalized microgrid protection strategy. The first one is concerned with the number of installed distributed generation units within the microgrid system. Second, one the availability of an enough level of short-circuits current in an isolated operating mode of the microgrid is important as this level may largely reduce after the isolation from the main grid. Fig. 9 shows the fault current given by every component in a grid-connected microgrid system. When the microgrid is working as a self-contained power island, any fault currents will have to be provided by those DG units which are yet connected to it. Here the fault current contributions are comparatively smaller values. The problem created by the generator units that depending on the power converters is that these units are developed to control their output current to protect their power converters.

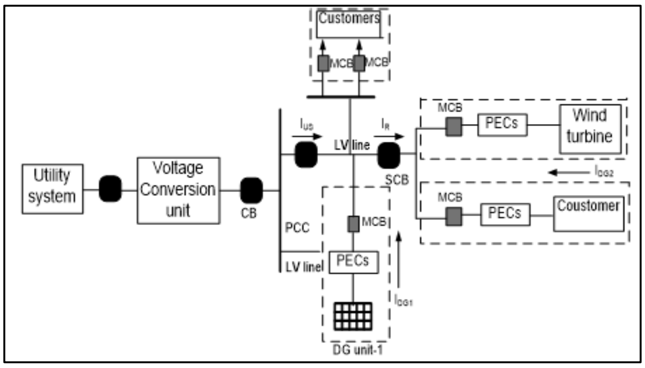



Fig. 9: Fault current contribution in microgrid system with DG units.

### *C. AC Microgrid System Protection Strategy*

Different techniques of saving the AC microgrids have been suggested with a wide variety of apparatus that are applied in the traditional AC distribution networks protection. These particular types of protection systems depend on the system circuits being protected and voltage level still there are no specific references for the overall protection. The devices which are mainly used for the AC distribution network protection are: (i) Over-current relays, (ii) Reclosers, (iii) Sectionalizers, (iv) Miniature circuit breakers and (v) Fuses. So far, the low voltage distribution protection strategies changes from utility to utility like (i) Fuse saving strategies, (ii) Fuse blowing strategies, (iii) Instantaneous reclose and (iv) Delayed reclose. One strategy which is used in the AC microgrids protection is to set each DG unit to have its own relay and operate in the decentralized method. This approach is more effective for the single L-G and L-L faults. But this technique is concerned with faults with low impedance. Other way is to apply a voltage protection strategy which is a centralized method. In this case, the phase voltages are converted into the d-q-0 axes and then compared with a standard voltage throughout the microgrid central controllers equipped with central protection unit. Whenever a variation in voltage happens above acceptable limits, the tripping device is activated to suitably isolate the faulted area by communicating the signal to the appropriate relay as shown in Fig. 10.

### *D. DC Microgrid System Protection Strategy*

In the DC microgrid system protection strategy, the boundaries of the safety standard SFS-6000 about electrical safety should be satisfied.

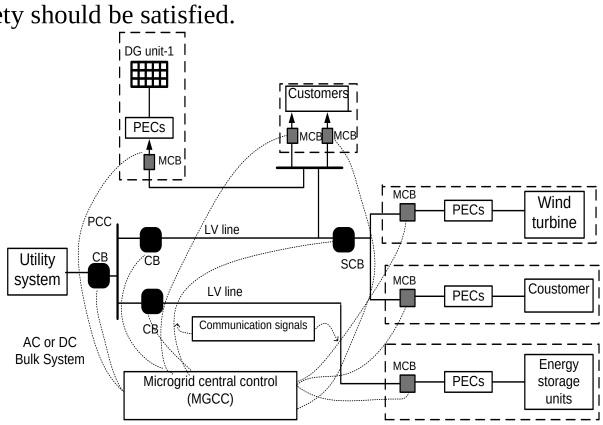



Fig 10: Centralized protection system in the AC microgrid system.

Presently, the major challenges in the DC microgrids protection scheme focuses to the consumer-end inverter, customer network faults including inverter transients and double-fault condition between AC and DC networks.

Fuses and automatic relays are tough to apply with power converters. This is because of the fact that the power converters do not generate short-circuit currents as long time as fuses are needed to work. So a different protection approach is used with different fault detecting and grounding techniques. In that case, the protection apparatus in the DC microgrid systems has the current interrupting devices, protective relays, measuring apparatus and grounding systems. Furthermore, there are five protection types which are used namely: (i) Utility protection, (ii) Converter protection, (iii) Distributed generation unit protection, (iv) Feeder protection and (v) Busbar protection. Therefore, by considering all the possibilities as operating conditions of every element connected within the given microgrid system, technical choice for the microgrid working and control, microgrid operating mode and the microgrid fault ride-through needs a proper protection strategy for the microgrid systems can be made.

## V. FAULTS IN DC DISTRIBUTION SYSTEMS

### *A. Possible Faults*

Two types of faults are there in dc systems: 1) L-L and 2) L-G, which can be seen in Fig. 11. A L-L fault occurs when a way between the positive and negative line is made, short-circuiting both. A L-G fault happens when either the positive or negative pole is short-circuited to ground. The L-G faults are the most common types of faults in industrial distribution systems. [7]

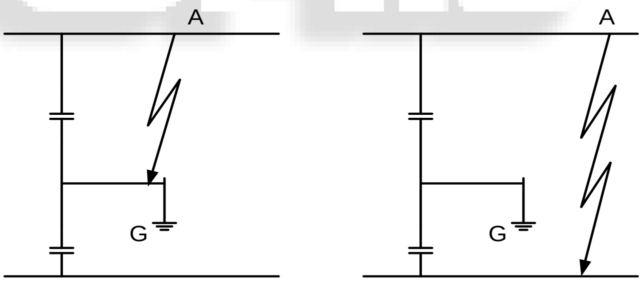



Fig. 11: Fault types in dc systems: (a) line-to-ground fault and (b) line-to-line fault.

Voltage Source Converters may have internal switch faults that can cause a L-G and L-L fault. This is a terminal fault for the system that cannot be cleared; in most scenarios, the devices have to be substituted. Therefore dc fuses would be an appropriate protection scheme for this type of fault. In ac systems, the ac-side circuit breakers will trip.

### *B. DC Fault Currents*

When a fault happens in a section, the line current will divide between load current and fault current as follows:

$$iLine = iLoad + iFault \text{ ---------------- } (1)$$

The amplitude of the fault current depends on the fault position and resistance of the fault current way. If the impedance of fault path is low (e.g., a L-G fault with solid ground), the current polarity at the receiving end can be made opposite, blocking the load from being held at all. The time constant of the dc fault current is very small as the line resistance of the dc system is small compared to ac power systems that have high reactance of the line. The bus voltage will reduce or fail, depending on the capacity of the power supply and energy-storage system in the bus, and the grounding impedance.

### *C. Reliability-Related Aspects*

Microgrids in a distribution system are usually taken as sections in terms of security. From the reliability point of view, the whole system is taken as sections or microgrids and not components. The number of components in a section or a microgrid affects the failure rate and average maintainace time annually for that microgrid. On the other hand, low number of components in a microgrid will result in a larger number of microgrids and less generation or storage systems per microgrid. This will also rise the average maintainace time annually for the microgrids. So the optimal microgrid foundation should be found by solving an optimization equation.

### *D. Supply -Security-Related Aspects*

In response to noises, a self-healing system redesign that breaks a power network into self-sufficient and supply-safe microgrids, which can stop the pass of noises and ignore cascading occurrences. Therefore a best microgrid structure is with maximum generation reliability and security. When the microgrids are made in a distribution system with highest generation-security, more consumers can be given supplied in case of self-governing mode of operation and the energy losses on power lines will be reduced. Conventionally only the real power components have been studied in system partitioning. But by studing the reactive power in helping the voltage profile, both real and reactive power balance can be achieved in making the microgrids. In such make, each microgrid may work in grid-connected or isolated mode, with smallest interactions from other elements of the system. With the presented work in this research, the build microgrids will not only be reliable but also they will have security of supply in case of isolation from the main substation. [8]

## VI. APPLICATIONS OF MICROGRIDS

### *A. Plug-in Hybrid Electric Vehicles*

The fast technological developments in automobile field and rise in crude oil rates along with rising environmental factors have resulted in fast use of electric vehicles with more energy resources. There are two types of electric vehicles: 1) only battery electric vehicles, which entirely work with batteries as electric power supply; and 2) Plug-in hybrid electric vehicles, which definitely run with a set of two power supplies, i.e., batteries and gasoline. The Plug-in hybrid electric vehicles are an extended version of current hybrid electric vehicles using a battery with larger automation and can be charged from a standard power outlet at home.

Plug-in hybrid electric vehicles use large electric power, so power consumption will have various possible remarkable maximum values. Thus charging these vehicles from home power outlets largely affects the distribution power system. The charging effects of Plug-in hybrid electric vehicles on the power distribution networks have been studied in the literatures and have been largely explored. These effects are generally classified into two types: 1) The effects on distribution system apparatus including transformers, cables, circuit breakers, and fuses; and 2) General impacts on distribution system characteristics having harmonics, load profile and power loss. [9]

### *B. Integration of Wind-Power and Wave-Power Generation Systems Using a DC Micro Grid*

Recently, renewable energy and distributed generation systems have attracted rising consideration and have been largely researched and developed. They moderately change the concepts and works of conventional power supply systems. The increase in various countries made it feasible that this kind of distributed generation systems can be applied to a grid-joined system with wind energy, solar energy, hydro power etc. The output of distributed generation systems usually takes two types: fluctuating DC and fluctuating AC. But the generation capacity of distributed generation systems comparing with conventional large synchronous generators is much lesser and so, the DC micro grid can be applied to convert the supplied time-changing variables of natural renewable energy and distributed generation systems into DC electricity that can then be converted back into AC variables supplied to other power system networks. Since the fluctuating nature of renewable energy and distributed generation systems, bi-directional DC/DC converters are usually required to supply the interconnected loads with good power quality.

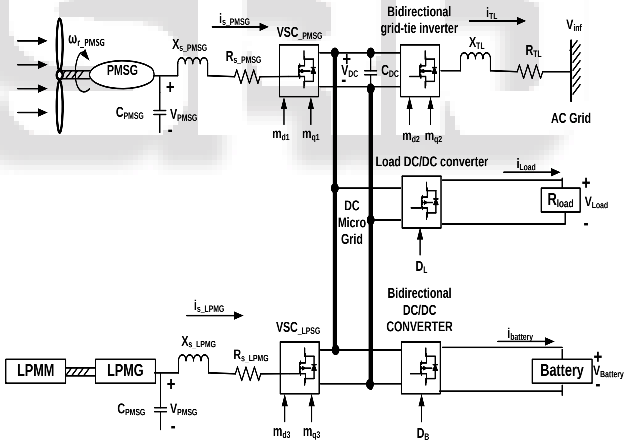



Fig. 12: Configuration of the studied integrated wind and wave power generation system connected to a power grid

In order to mimic a hybrid AC/DC micro grid system, photovoltaic and wind power generator models, doubly-fed induction generator model, and inverter model were made to simulate dynamic behavior of the studied system as shown in Fig. 12. A low-voltage bipolar-type DC micro grid was made using a gas engine as the power supply while a bi-directional DC/DC converter paralleling a super-capacitor was utilized as an energy- storage device system to balance the power need of the system in consideration. [10]

### *C. S3 Inverter for 1-Phase Microgrid Applications*

A single-phase VSI with a dc–dc converter followed by a synchronized push–pull configuration working at desired frequency is presented. The duty cycle of the dc–dc convertor is changed as a unidirectional sine waveform to generate same output voltage across the dc-link capacitor.

The unidirectional voltage is converted into an AC voltage by the synchronized push–pull design. This inverter uses three switches, in which one is operating at a higher frequency and the remaining are operating at a fundamental frequency. So it is named as S3 inverter. Moreover it is simple and economic analog elements are used for the production of switching pulses and the control of the power given to the grid network. The rising concerns on the reducing fossil fuels and greenhouse gas effects in conventional sources of energy have provoked the operators of power systems to search for an efficient and reliable methods to work with the rising power requirements.

Furthermore, the values of duty cycle and the voltage burdon on power switches of high voltage gain schemes, the higher input current ripples in a coupled-inductor-based power converter, and the switched-capacitor needs in an interleaved boost converter are a few important challenges. Otherwise the topology based on an high frequency transformer has many power phases and does not stop dc current injection into a grid. [11]

*D. Microgrid addition of a prosumer and Smart Grid application*

Here, a complete structure of an urban power network is taken as a way to help the summation of multiple distributed prosumers in the electrical power system and in power market. In this structure, the summing elements are the key moderators between prosumers and customers on one side and markets and the Distributed System Operator on the other side (see Fig. 13). The summing elements collect the information from the Distributed System Operator (and the future markets), they demand and signals for prosumers, which are situated in an urban area. They take the “flexibilities” and the supplements are supplied by prosumers and customers to form grid utilities, and they help theses utilities to the different power system stake holders through the different markets. At the prosumers’ sides and electrical apparatus, distributed generation can be managed and optimized by the E-box, the connector with the external world. Here home apparatuses are managed with conventional supply units by a central energy management system to make a microgrid (see Fig. 13).

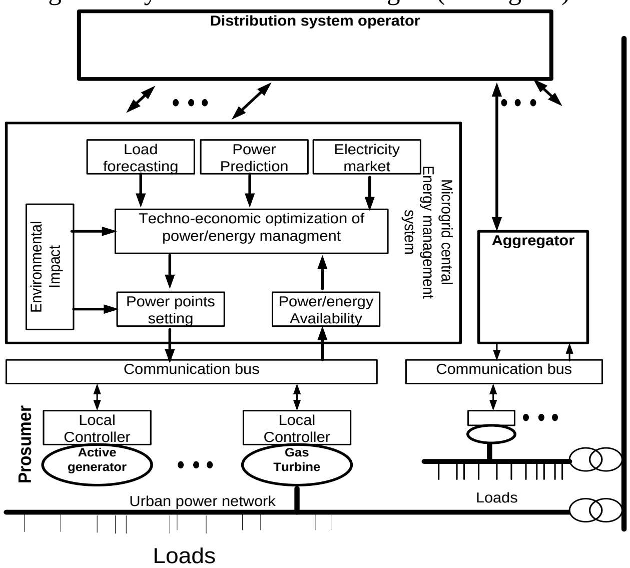



Fig. 13: Central energy management system

The global objective consists in matching the total power generation to the demand in an optimal way. This concept is relevant in the framework of smart grids through the combined use of an additional communication network within an intelligent EMS and controllers. This method is a step between current grid needs and future smart grids. To help the presentation of theoretical concepts, a single prosumer and a gas microturbine are taken in this microgrid (see Fig. 14). The E-box adds three roles: a load manager, an advanced meter, and a local EMS. The load manager enables consumers to naturally program their apparatus to turn on when prices are lower or to make habits, like continuous supply of high priority loads, time programmable applications, etc. Furthermore, it can minimize a portion of the house power demand when the grid is overloaded by disconnecting the controllable loads. A smart meter supplies the local EMS and the load manager. Furthermore, the utility can ping the meter. PV panels are linked with a energy storage system which has a set of batteries as a storage device and a bunch of ultra capacitors as a fast dynamic power flow regulator (Fig. 14). These are joined through a dc bus by choppers and are interconnected to the microgrid by three-phase inverters. The amazing face of this hybrid generator is that it can deliver a preset power level as conventional power generator (for example, a gas micro turbine). The local energy management system thus allows the use of PV energy as per the grid operator need and also when the sun is not available.

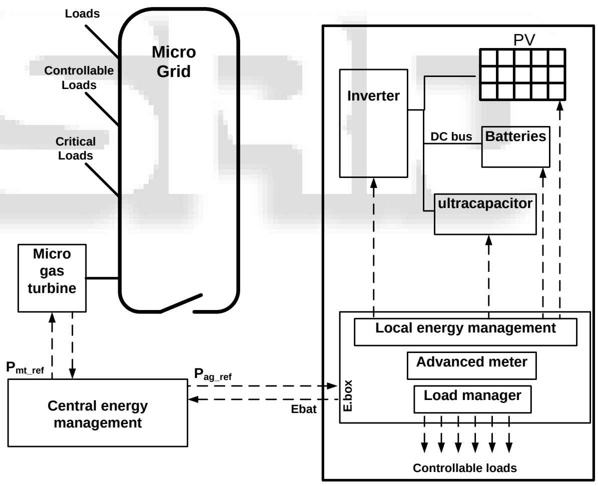



Fig. 14: Microgrid with prosumer and a gas microturbine.

Then the batteries are used to supply the needed power. To focus the difference with conventional PV panels, this concept is named as active generator system. Extra PV energy is saved in batteries for use when required and the real-time power flow control is done with ultracapacitors. The E-box connector has a remote control of the utility to the grid operators to permit rapid adjustments and to supply more flexibility to reroute power flow in a particular served margin. [12]

## VII. CONCLUSIONS

So far we discussesed the various microgrid technologies for integrating different non-conventional and conventional energy sources. Starting with different architectures of microgrids like: AC, DC, and Hybrid and Networked type. Then the hierarchal control strategies are discussed at different levels. Afterwards the protection schemes for AC and DC microgrids are analyzed in different fault conditions and lastly some recent applications of microgrid technologies are explained e.g. Plug-in hybrid electric vehicles Integration of Wind-Power and Wave-Power Generation Systems Using a DC Micro Grid and S3 Inverter for Single-Phase Microgrid Applications etc. In between a comparison of AC and DC microgrid is also made as a comparative study.

## REFERENCES

[1] Mariya Soshinskaya, Wina H. J. Graus, Josep M. Guerrero, and Juan C. Vasquez, "Microgrids: experiences, barriers and success factors, Renewable and Sustainable Energy Reviews, 2014 – Elsevier.

[2] Allal M. Bouzid, Josep M. Guerrero, Ahmed Cherit, Mohamed Bouhamida, Pierre Sicard, and Mustapha Benghanem, A survey on control of electric power distributed generation systems for microgrid applications, Renewable and Sustainable Energy Reviews 44 (2015) 751–766.

[3] Jackson John Justo, Francis Mwasilu, Ju Lee, and Jin-Woo Jung, AC-microgrids versus DC-microgrids with distributed energy resources: A review Renewable and Sustainable Energy Reviews 24 (2013) 387–405.

[4] Payam Teimourzadeh Baboli, Mahdi Shahparasti, Mohsen Parsa Moghaddam, Mahmoud Reza Haghifam, and Mustafa Mohamadian, Energy management and operation modelling of hybrid AC–DC microgrid, Published in IET Generation, Transmission & Distribution.

[5] Zhaoyu Wang, Student Member, IEEE, Bokan Chen, Jianhui Wang, Senior Member, IEEE,and Chen Chen, Member, IEEE, Networked Microgrids for Self-Healing Power Systems, IEEE TRANSACTIONS ON SMART GRID, VOL. 7, NO. 1, JANUARY 2016.

[6] Lexuan Meng, Member, IEEE, Adriana Luna, Enrique Rodríguez Díaz, Bo Sun, Student Member, IEEE, Tomislav Dragicevic, Member, IEEE, Mehdi Savaghebi, Senior Member, IEEE, Juan C. Vasquez, Senior Member, IEEE, Josep M. Guerrero, Fellow, IEEE, Moisès Graells, and Fabio Andrade, Member, IEEE, Flexible System Integration and Advanced Hierarchical Control Architectures in the Microgrid Research Laboratory of Aalborg University, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 52, NO. 2, MARCH/APRIL 2016.

[7] Jae-Do Park, Member, IEEE, and Jared Candelaria, Student Member, IEEE, Fault Detection and Isolation in Low-Voltage DC-Bus Microgrid System, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 28, NO. 2, APRIL 2013.

[8] Seyed Ali Arefifar, Member, IEEE, Yasser A.-R. I. Mohamed, Senior Member, IEEE, and Tarek H. M. EL-Fouly, Member, IEEE Optimum Microgrid Design for Enhancing Reliability and Supply-Security, IEEE TRANSACTIONS ON SMART GRID, VOL. 4, NO. 3, SEPTEMBER 2013.

[9] Hamed Nafisi, Seyed Mohammad Mousavi Agah, Member, IEEE, Hossien Askarian Abyaneh, Senior Member, IEEE, and Mehrdad Abedi, Two-Stage Optimization Method for Energy Loss Minimization in Microgrid Based on Smart Power Management Scheme of PHEVs, IEEE TRANSACTIONS ON SMART GRID, VOL. 7, NO. 3, MAY 2016.

[10] S,heng-yen Lu, Li Wang, Te-Ming Lo and Anton V. Prokhorov, Integration of Wind-Power and Wave-Power Generation Systems Using a DC MicroGrid, 0093-9994 (c) 2013 IEEE DOI 10.1109/TIA.2014.2367102, IEEE Transactions on Industry Applications.

[11] B. Dastagiri Reddy, M. P. Selvan, Member, IEEE, and S. Moorthi, Member, IEEE, Design, Operation, and Control of S3 Inverter for Single-Phase Microgrid Applications.

[12] Hristiyan Kanchev, Di Lu, Frederic Colas, Member, IEEE, Vladimir Lazarov, and Bruno Francois, Senior Member, IEEE, Energy Management and Operational Planning of a Microgrid With a PV-Based Active Generator for Smart Grid Applications, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 58, NO. 10, OCTOBER 2011.