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ADVANCED HYBRID UNIT OF COMMON COUPLING (HUCC) INTERFACE FOR MULTIPLE MICROGRIDS INTERCONNECTION

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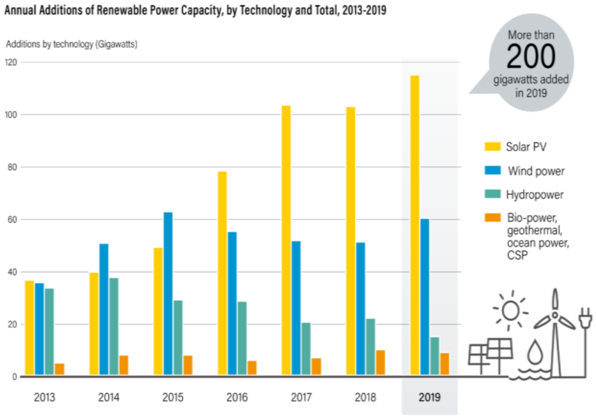
Abstract— Microgrid is the concept proposed to deal with the penetration of a certain amount of DERs. It effectively manages DERs and local loads as an integrated system and balances the power demand of the local area. However, when the scale of local DERs reaches a high level, microgrid control and power dispatch become very complex and difficult to realize, which could possibly decrease the reliability of the microgrid. The multiple microgrids system is a cluster of microgrids where every single microgrid manages its own DERs independently and cooperates with other microgrids actively to achieve an overall objective. The advanced HUCC not only provides a unified microgrid interface, but also improves the flexibility and coordination of multiple microgrids.In this paper, an advanced microgrid interface for multiple microgrids named hybrid unit of common coupling (HUCC) and its four-level control architecture are proposed. The HUCC employs the MMC and the ESS as its core components. It not only provides AC interface for the connection to the utility grid but also provides DC interface for the interconnection of multiple microgrids.

Keywords—HUCC, DER, ESS, Microgrid ,etc.

1. INTRODUCTION

In the present trend, Renewable energy sources are attractive choices for providing power in the places where an association to the utility network is either not possible or unduly costly. As electric distribution technology steps into next century, several trends have become noticeable which will modify the necessities of energy delivery. The ever increasing energy consumption, soaring value and exhaustible nature of fossil fuels, and also the worsening international environment have created enhanced interest in green power generation systems. Renewable sources have gained worldwide attention because of quick depletion of fossil fuels in conjunction with growing energy demand.

The energy that is collected from renewable resources is called renewable energy, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy provides energy in four areas like: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. Energy in general means capacity or ability to produce work. Energy is essential part of our life and it's impossible to survive without it. As time passed by and with technological advancement humans were able to use this energy in various forms. Considering the utilization of energy in daily life it was possible to categorize it as renewable and non-renewable sources. This thesis sheds light upon combine use of renewable sources i.e. solar & wind energy, hoping to discover and determine the extent to which energy generated using this technology is capable of satisfying the demand of energy. Using the combination of PV and wind renewable system has the advantage of using it in regions having higher wind speeds and less sunny days and the other way round.



Note: Solar PV capacity data are provided in direct current (DC). Data are not comparable against technology contributions to electricity generation.

Fig. 1.1 World energy consumption by renewable sources

Based on REN21's report (2016), renewable sources contributed 19.2% to humans' international energy consumption and 23.7% to their generation of electricity in 2014 and 2015, annually. This energy consumption is split as 8.9% returning from ancient biomass, 4.2% as energy (modern biomass, energy and solar heat), 3.9% hydroelectricity and 2.2% is electricity from wind, solar, geothermal, and biomass. Worldwide investments in renewable technologies amounted to quite US$286 billion in 2015, by countries like China and also U.S. in wind, hydro, solar and bio-fuels. Globally, there are 7.7 million jobs related to the renewable energy industries, with solar photovoltaics' being the most important renewable employer. As of 2015, quite half of all new electricity capability globally installed was renewable. The statistical data in recent years show that 33% of world population is non-electrified and most of such region lies in developing countries. [7-9]

The existing power system i.e. the one running on diesel or coal, is facing many energy crises as well as causing environmental pollution. Additionally, the transmission networks in remote areas suffer from huge transmission line losses and techniques such as centralized power flow and low voltage distribution causes inefficient use of the energy. Because of all these existing problems there is a recent trend of looking towards alternative sources of energy. Thus renewable sources are becoming more popular and the concept of microgrid came into existence so as to provide clean, reliable, efficient and flexible source of energy to the end user. Supplying power to small electrical loads at remote locations or isolated grids Hybrid PV/Wind power generation systems have become a prevalent option as it offers highly reliable solution for continuous power supply. Most previous studies of these systems concentrated on local feasibility analysis. But the practical application of these systems needs to consider parameters such as stability, control and reliability.[8]

2. MOTIVATION OF RESEARCH

There are ongoing researches focused on Microgrids and a lot of investigation has been conducted by many research groups to determine the feasibility and benefits of Microgrids. Even though the fundamental principles of Microgrids are well known, implementation of the system is not always well mastered.

GENERAL INFORMATION REGARDING MICROGRID

As electric distribution technology steps into the next century, many trends are becoming noticeable that will change the requirements of energy delivery. These modifications are being driven from both the demand side where higher energy availability and efficiency are desired and from the supply side where the integration of distributed generation and peak shaving technologies must be accommodated.[10]

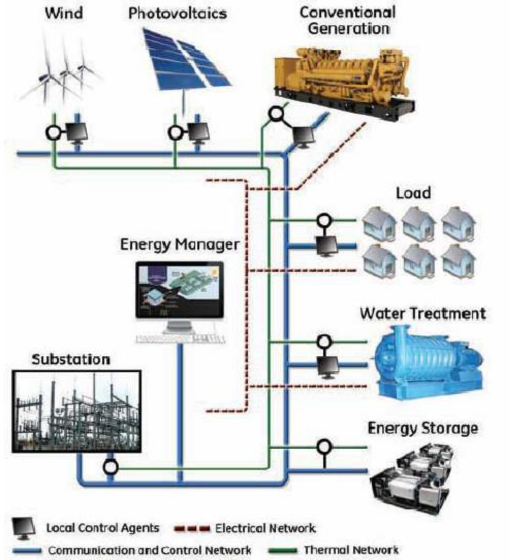


Fig 2.1 Microgrid power system [10]

Power systems currently undergo considerable change in operating requirements mainly as a result of deregulation and due to an increasing amount of distributed energy resources (DER). In many cases DERs include different technologies that allow generation in small scale (micro sources) and some of them take advantage of renewable energy resources (RES) such as solar, wind or hydro energy. Having micro sources close to the load has the advantage of reducing transmission losses as well as preventing network congestions. Moreover, the possibility of having a power supply interruption of end-customers connected to a low voltage (LV) distribution grid (in Europe 230 V and in the USA 110 V) is diminished since adjacent micro sources, controllable loads and energy storage systems can operate in the islanded mode in case of severe system disturbances. This is identified nowadays as a microgrid. Figure 2.1 depicts a typical microgrid. The distinctive microgrid has the similar size as a low voltage distribution feeder and will rare exceed a capacity of 1 MVA and a geographic span of 1 km. Generally more than 90% of low voltage domestic customers are supplied by underground cable when the rest is supplied by overhead lines. [11]

The microgrid often supplies both electricity and heat to the customers by means of combined heat and power plants (CHP), gas turbines, fuel cells, photovoltaic (PV) systems, wind turbines, etc. The energy storage systems usually include batteries and flywheels. The storing device in the microgrid is equivalent to the rotating reserve of large generators in the conventional grid which ensures the balance between energy generation and consumption especially during rapid changes in load or generation. From the customer point of view, microgrids deliver both thermal and electricity requirements and in addition improve local reliability, reduce emissions, improve power excellence by supportive voltage and reducing voltage dips and potentially lower costs of energy supply. From the utility viewpoint, application of distributed energy sources can potentially reduce the demand for distribution and transmission facilities. Clearly, distributed generation located close to loads will reduce flows in transmission and distribution circuits with two important effects: loss reduction and ability to potentially substitute for network assets. In addition, the presence of generation close to demand could increase service quality seen by end customers. Microgrids can offer network support during the time of stress by relieving congestions and aiding restoration after faults. The development of microgrids can contribute to the reduction of emissions and the mitigation of climate changes. This is due to the availability and developing technologies for distributed generation units are based on renewable sources and micro sources that are characterized by very low emissions.[12-3]

3. MICROGRID

"In Microgrid it is assumed that a cluster of loads and micro-sources is working as a unity controllable system which supplies power as well as heat to its local area." - This idea yields a new prototype for operating distributing generations. Micro-sources having low cost and voltage, high reliability are laid out at customer site. These micro-sources are power electronic devices and controllers that insure continuity of supply to the customer and reciprocate with the utilities. Microgrid (MG) has some defined characteristics as follows:

- Decentralized
- Remotely dispatched
- Less than 50-100 MW
- Connected with distribution system

Microgrids are possibly implemented in two ways; it can be similar to small electrical generator to provide backup power or a complex system integrated with the Grid consisting of generation, storage and power management systems. These systems consist of a bunch of technologies on the supply side as well as on demand side and located at or near the location of loads. Thus MG technology has wide application for local controlling electricity usage.[7]

TYPES OF MICROGRID

In general, microgrid are classified into three types:

Residential Microgrid:

These type of microgrid is utilized in communities, residential houses and campus. The only problem associated with this type is that it can cause impulse to the grid voltage and frequency when switching from grid connected to islanding mode. Therefore, stability and reliability of the system is a matter of concern in residential microgrid.

Remote Microgrid:

As the name suggest it can be applied in rural areas or islands where it is difficult for utilities to maintain the adequate energy supply. This type of microgrid prevents transmission and distribution line losses and CO2 emissions of the utilities. Only problem with this type is that the system should be self-sustainable enough.

Mobile Microgrid:

This type is applied in military based camps or naval systems. Thus flexibility of the system the main reason for using this MG as it can be easily moved from place to place as and when needed. [8]

REASONS FOR USING MICROGRID

There are number of advantages for the conventional arrangement of modern large power system. Large generating stations are efficiently operated as they are interconnected by high voltage transmission network which operate efficiently to transfer bulk power at large distances with limited losses. In many cases the distribution network is designed for unidirectional flow and can shelter only customer loads. However, in recent years a lot of research is been done to improve the MG technology and the reasons encouraging them are:

1. Reduction in gaseous emissions

2. Energy efficient

3. Deregulation or competition policy

4. Diversification of energy sources

5. Climate change problems

6. National power requirement

Investigation on the feasibility and benefits of MG is carried out by several research groups around the world as problems like dealing with unbalanced loads and harmonics associated with it needs to be rectified. However, this report does not concentrate on addressing such problems, rather it focuses on Modelling the MG's to investigate the transient and steady state response. As electric distribution technology improves over period of time, noticeable changes are seen that will alter the energy requirements. The required modifications are carried on demand side where high availability and efficiency is needed as well as in the supply side where the distribution network and other critical technologies merge to maintain continuity of supply. Considerable changes are seen in power systems operations mainly because of deregulation and due to distributed energy resources (DER). DER has advantage that it allows micro source generations to participate and also utilize renewable energy sources (RES) like wind, solar or hydro technologies. Moreover, keeping them close to the load helps in reducing transmission line losses and avoid network congestions. Also power can be supplied without any interruption to the users and in case of any severe system collapse these micro-sources can be operated in islanding mode. Using combination of gas turbines, fuel cells photovoltaic systems, wind turbines etc. microgrid supply electricity to the customers. [9-10]

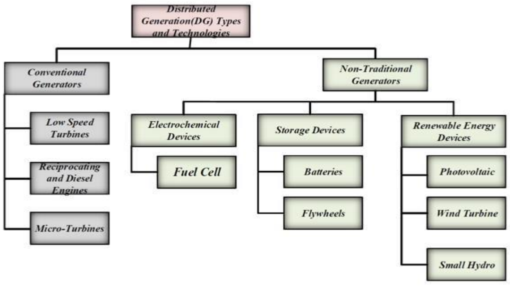


Figure 3.1 Classification of DG and technology used

Background

Hybrid AC-DC technology consists of mostly the renewable sources. These sources are available in abundant and can be utilized to maximum extent possible. These technologies previously consisted of only Batteries, wind turbines and diesel to supply the load, but was not sufficient to manage the load as the system was not stable in different conditions. Thus to overcome this problem, controller is used along with addition of PV module. Output of the PV arrays depends on the irradiation of the sun and it varies depending on the location. Thus, in this paper irradiance for Northridge and Texas is consider to see the effects on the power flow of system. It's necessary to carry out the transient analysis in such conditions were number of number of Distributed

Energy Resources (DER's) are present. Transient analysis will help in verifying the stability of this system during the occurrence of fault on different locations.[10-11]

IMPLEMENTATION OF MICROGRID

A typical fossil fuel based industrial microgrid was built in Indiana at Whitling refinery having installation capacity of 64 MW. But till 2015, up to 3.1 GW of new capacity is installed worldwide. It can be seen from the figure below that United states is the currently leading with exactly 626 MW of operating capacity which is expected to increase to 2352 MW by 2018.

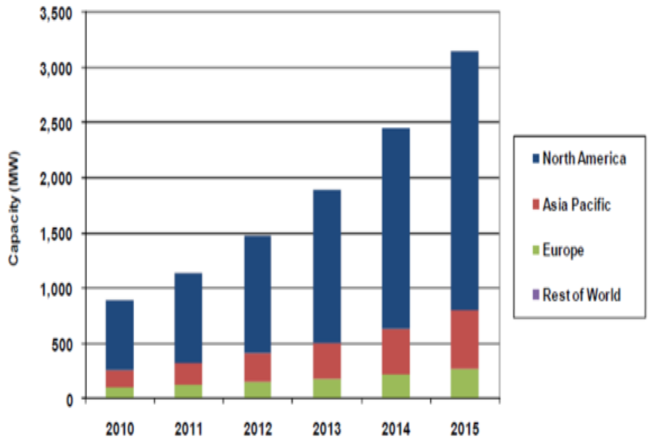


Figure 3.2 Microgrid capacity in the world

In year 2009 in United States, around 322 MW of college campus was lit up by microgrids and by 2015 $2.76 billion of investment was made to develop around 940 MW through microgrids.

CLASSIFICATION OF MICROGRID BASED ON POWER TYPE

Overview:

Microgrids are classified as AC systems, DC systems or Hybrid systems based on the power drawn from it. Any of these typical microgrid is identical to a small power system consisting interconnected components like DG units, loads and storage devices. Although controlling large number of DG's is challenging considering the safety and efficiency of the system, modern technology plays a crucial role in overcoming these problems using power electronic devices which interfere with DG's to create an architecture called as microgrid.

As discussed earlier the components of microgrid are connected to power distribution network using point of common coupling and thereby it appears as a single unit to the entity. The classification based on power type is shown below:

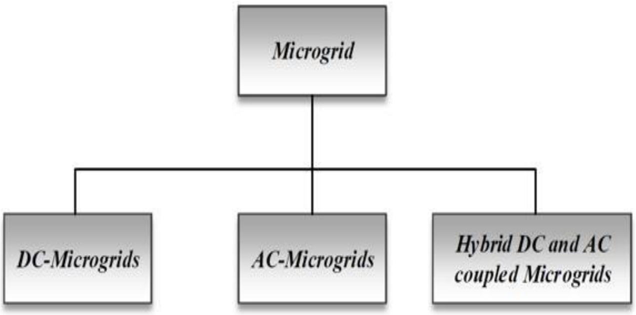


Figure 3.3 Classification based power type: AC or DC microgrid

4. ARCHITECTURE DESIGN OF THE HUCC

As the unified microgrid interface, the HUCC is utilized to replace the point of common coupling. The detailed configuration of the HUCC is shown in Fig.4.1

Primary system

As is shown in Fig.4.1, the primary system of the HUCC consists of four major components, which are the HUCC bus, the AC interface, the DC interface, and the ESS.

(i) HUCC bus: The HUCC bus is the bridge that links the HUCC to the microgrid. Meanwhile, the AC interface, the DC interface, and the ESS are parallels connected to the HUCC bus.

(ii) AC interface: The AC interface consists of an AC bus and an AC breaker. It is designed to provide connection only between microgrids and the host utility grid. The main purpose of such a design is to stabilize the voltage and frequency of the microgrid with the support of the utility grid. Meanwhile, compared with the microgrid which is connected to the utility grid via back-to-back converters, such a design utilizes the original AC lines and reduces the cost of system transformation.

(iii) DC interface: The DC interface consists of a DC bus, an MMC, a fault current limiter (FCL), and a DC breaker. It provides connection only for the interconnection of multiple microgrids.
The purpose of this design is to increase the control dimension of the multiple microgrids so as to realize controllable power sharing and more reliable operation. Since the DC current does not have the natural zero-crossing point, it is hard to eliminate fault in DC lines, especially under high-voltage conditions. Therefore, the FCL is utilized to limit the fault current in the DC line to avoid MMC damage. Meanwhile, the FCL creates a natural boundary for the multiple microgrids without influencing its normal operation, so that different protection schemes could be studied and carried out.

(iv) ESS: The ESS consists of different types of energy storage devices, such as battery, supercapacitor, superconducting magnetic energy storage (SMES), and so on. The SMES is connected to the DC bus, while other energy storage devices are connected to the HUCC bus. The ESS could not only stabilize the voltage and frequency of the microgrid, but also suppress the power fluctuation of the tie line.

Secondary system

To realize the normal operation of the HUCC, different HUCC components are controlled coordinately. Correspondingly, every component is equipped with a control module. The secondary system of the HUCC basically contains a switch controller, an ESS controller, an MMC controller, a central coordinator, and a relay protection device, as is shown in Fig. 4.1.

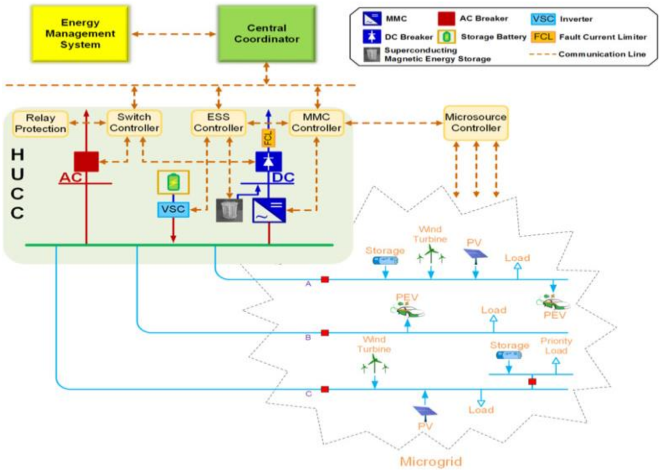


Fig. 4.1 Hybrid unit of common coupling

(i) Switch controller: The switch controller controls both the AC breaker and the DC breaker according to the actual operation condition. Its action decides the operation modes of the HUCC.

(ii) ESS controller: The ESS controller controls the operation of all energy storage devices. It actively cooperates with the MMC controller so as to balance the power of the microgrid and suppress the power fluctuation of the tie line. Under certain operation conditions, the ESS controller works to stabilize the voltage and frequency of the microgrid.

(iii) MMC controller: The MMC controller is the key component of the secondary system. The interactions and desired power dispatch among multiple microgrids could be achieved only via the MMC controller. It controls the operation of the interconnected multiple microgrids.

(iv) Central coordinator: The central coordinator is an agent of the HUCC which links the energy management system (EMS) and all the HUCC controllers. It gathers information about the HUCC from the HUCC controllers and transmits it to the EMS; meanwhile, the instructions from the EMS are issued to the HUCC controllers through the central coordinator.

(v) Relay protection: The relay protection device detects and eliminates faults in the HUCC and the multiple microgrids in order to ensure the safety of the system. It often acts in cooperation with the HUCC controllers.

SIMULATION AND RESULT DISCUSSION

Matlab Simulation of Proposed HUCC system during Grid Connected Mode

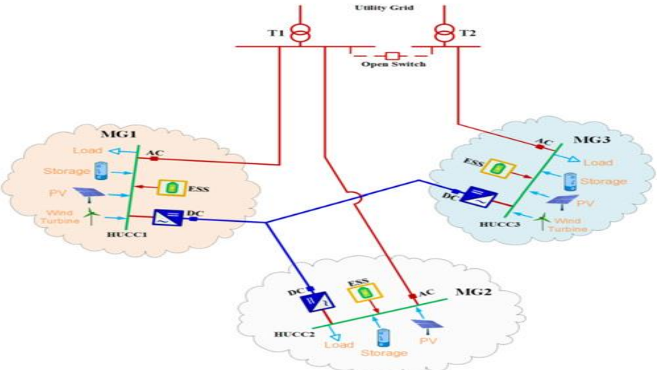


Fig 5.1-Simulation model structure for Grid Connected Mode

The simulation model of three interconnected HUCC-based microgrids is built in Matlab Simulink and its structure is illustrated in Fig.5.1. As is shown, the microgrids contain wind turbines, PVs, energy storage devices, and local loads. MG1 and MG2 are connected to the same feeder of the utility grid via the AC interfaces of their HUCCs, while MG3 is connected to a different feeder of the utility grid via the AC interface of its HUCC. At the same time, the three microgrids are interconnected via the DC interfaces of their HUCCs

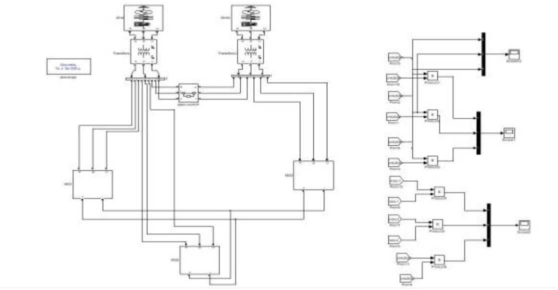


Fig 5.2-Simulation model for Grid Connected Mode of Proposed HUCC system

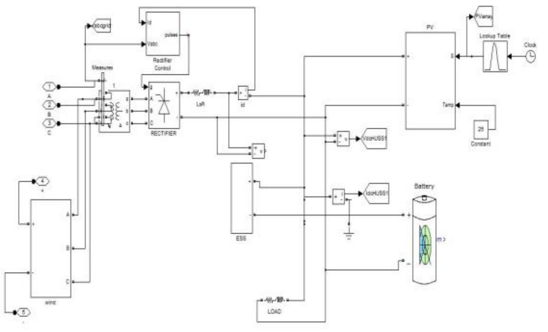


Fig 5.3- Matlab Subsystem of Microgrid Systems

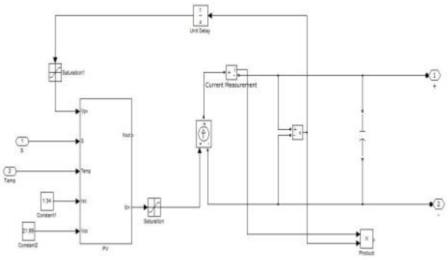


Fig 5.4- Matlab Simulation of Solar PV system

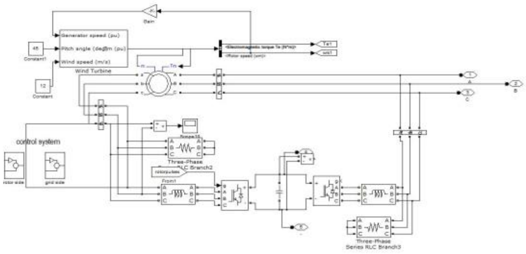
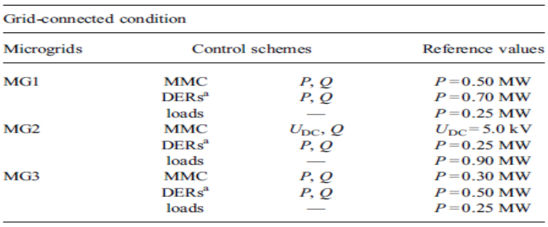


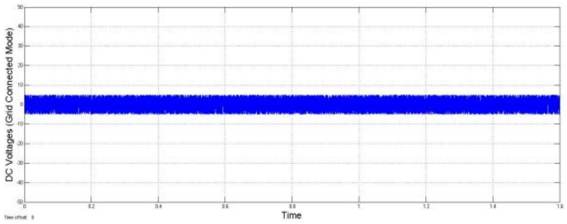
Fig 5.5- Matlab Simulation model of Wind Power Plant



Grid-connected condition			
Microgrids	Control schemes		Reference values
MG1	MMC	P, Q	$P = 0.50$ MW
	DERs[a]	P, Q	$P = 0.70$ MW
	loads	—	$P = 0.25$ MW
MG2	MMC	U_{DC}, Q	$U_{DC} = 5.0$ kV
	DERs[a]	P, Q	$P = 0.25$ MW
	loads	—	$P = 0.90$ MW
MG3	MMC	P, Q	$P = 0.30$ MW
	DERs[a]	P, Q	$P = 0.50$ MW
	loads	—	$P = 0.25$ MW

Table 5.1-Basic parameters of the simulation model under grid-connected condition

Case-I Simulation Results for Grid Connected Mode



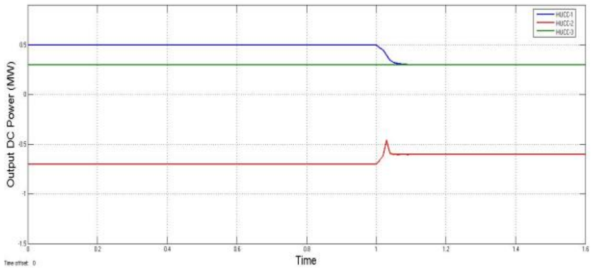


Fig 5.3- output DC power of the HUCCs during grid-connected condition

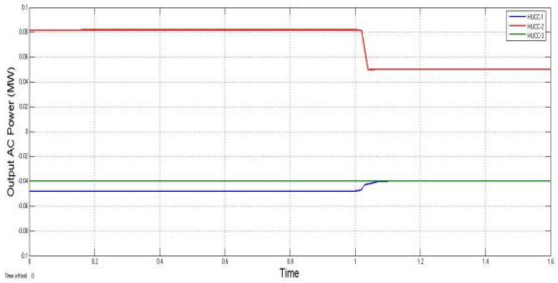


Fig 5.4- output AC power of the HUCCs during grid-connected condition

As is shown in simulation results fig 5.4, the HUCCs control the power exchange among the micrograms and the utility grid as scheduled. They also keep the system DC voltage constant. After the power drop of MMC1 at 1 s, the HUCC begins to adjust its control schemes and the system soon reaches a new steady state after a short transient process. In general, the system operation under grid-connected condition is steady and stable

Matlab Simulation of Proposed HUCC system during Grid Islanded Mode

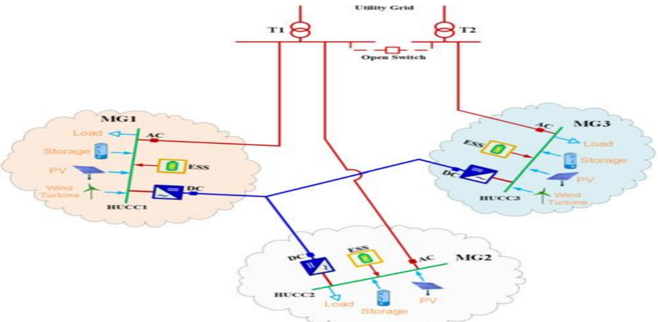


Fig. 5.5 Simulation model structure for Islanded Mode

Under islanded condition, the connection to the utility grid is disabled and the interconnection among the microgrids stays the same as grid connected condition. At 1 s, the reference value of active power of MMC1 increases to 0.7 MW and the reference values ofMG2 are adjusted correspondingly. The DC voltage and the output DC power of every HUCC during islanded condition are illustrated in Fig. 5.6

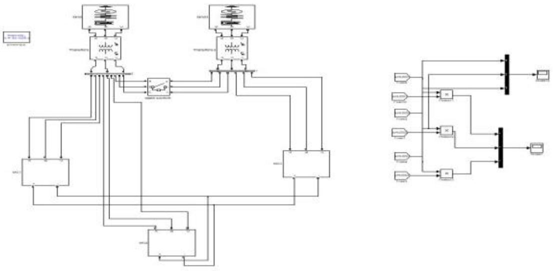


Fig. 5.6 Simulation model of HUCC system for Islanded Mode

Islanded condition

Microgrids	Control schemes		Reference values
MG1	MMC	P, Q	$P=0.40$ MW
	ESS	V, f	10.5 kV, 50 Hz
	microsources[a]	P, Q	$P=0.65$ MW
MG2	MMC	U_{DC}, Q	$U_{DC}=5.0$ kV
	ESS	V, f	10.0 kV, 50 Hz
	Microsources[a]	P, Q	$P=0.30$ MW
MG3	MMC	P, Q	$P=0.20$ MW
	ESS	V, f	10.0 kV, 50 Hz
	microsources[a]	P, Q	$P=0.45$ MW

Table 5.2 Basic parameters of the simulation model under islanded condition

Case-II Simulation Results for Islanded Mode

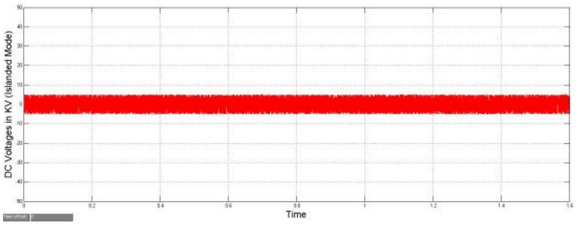


Fig. 5.7 DC voltages of the HUCCs during islanded Condition

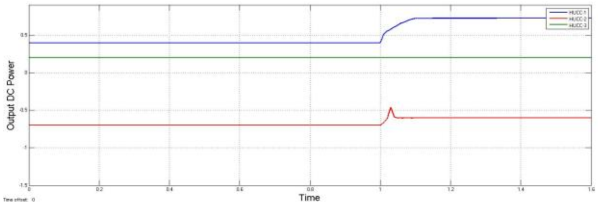


Fig. 5.8 output DC power of the HUCCs during islanded Condition

As is shown in simulation results of fig 5.8, the power is exchanged among the three microgrids under the control of the HUCCs during islanded condition. Meanwhile, the DC voltage keeps constant during the simulation.

After the power increase in MMC1 at 1 s, the HUCCs re-distribute the system power immediately and the system quickly reaches a new steady state after a short transient process. In general, the system operation under islanded condition is steady and stable.

5. CONCLUSION

The HUCC employs the MMC and the ESS as its core components. It not only provides AC interface for the connection to the utility grid but also provides DC interface for the interconnection of multiple microgrids. Via the AC interface, voltage and frequency of microgrids could be stabilized with the support of the utility grid; via the DC interface, asynchronous interconnection and higher control dimension among the multiple microgrids are obtained due to the favorable control features of the MMC. The four-level control architecture of the HUCC is based on the configuration of the HUCC. The four control levels are defined sequentially regarding functions and they work in good coordination. It can be expected that the controllability, flexibility, and the reliability of the multiple microgrids would increase with the implementation of the HUCC. Case studies under different operation conditions are carried out. The simulation results show that the desirable power dispatch is realized via the HUCCs and the multiple microgrids are well coordinated. In general, the HUCC proves effective and efficient

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