MICROGRID CONFIGURATION FOR MAJOR NETWORK EVENTS

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ABSTRACT

This paper addresses the control techniques required for a microgrid in order to maintain the supply of electricity to a local community in the case of a major network event which results in a loss of grid connection. The electrical generating resources are residential PV and wind systems installed in detached houses and a battery storage system installed at a community centre. This study is based on a typical urban residential area in Japan and a generic distribution network. This study investigates the feasibility of using a microgrid configuration in the case of a major network event, where the energy supply from the interconnected grid may be interrupted.

INTRODUCTION

According to a study carried out for DTI and Ofgem, installed micro-generation capacity in the UK could grow to as much as 8GW by 2015 [1, 2]. Small Scale Embedded Generation (SSEG) is seen as an important part of the additional Distributed Generation (DG) that is required to meet these targets. This will require a new and highly decentralised approach to energy planning and policy and the decentralised control problem is perhaps the most challenging. The growth of SSEGs on the low-voltage distribution network is accompanied by network constraints like steady-state voltage limits, voltage unbalance limits, thermal limits or reverse power flow limits [3-5]. However, DG can be used to sustain the location distribution system during unavailability of the transmission feeds and brings opportunities to improve security of supply to customers in a major event such as a flood.

From the grid's perspective, the central advantage of a microgrid is that it can be regarded as a controlled entity within the power system that can be operated as a single aggregated load. In other words, it can establish binding contractual agreements with the bulk power provider covering its pattern of usage that are at least as strict as those covering existing customers, and potentially it could provide additional services [6]. Customers benefit from a microgrid because it is designed and operated to meet their local needs for heat and power as well as provide uninterruptible power, enhance local reliability, reduce feeder losses, and support local voltages. Therefore, many studies regarding microgrids are focusing on reliable operation under normal operating conditions. In this study, a concept of an isolated microgrid during emergency conditions is proposed and its feasibility is examined. The proposed microgrid comprises of residential distributed generator systems (wind turbines or PV) installed in the houses surrounding the load centre, and the battery installed in the load centre, such as a school. The control of the SSEG, the load and energy storage could facilitate islanded operation of a microgrid or multiple microgrids when connection to the main grid is lost. This study includes the following issues regarding the proposed microgrid:

- Balance of electricity supply and demand, considering the fluctuating electricity supply of SSEG systems.
- Required capacity of battery to compensate for shortage of power supply of PV systems.
- Autonomous control of each PV system and battery.

MODEL DEVELOPMENT

Typical urban residential area in Japan

As for the first issue, the statistical composition of the local demand was investigated and was based on grid statistics provided by the "Ministry of Internal Affairs and Communications" in Japan, which is the database regarding the residential and commercial sector summarized for each 500m x 500m grid. Then, considering the total number of sectionalizing breakers and the total length of distribution lines in Japan, various regional demand models according to the area concerned were developed [6].

Figure 1 show an example of urban residential area in Japan, which is composed of various demand types, such as. hospital, school, convenience store, detached houses and apartment houses. Table I shows the total floor space and maximum electricity demand of each demand type. In this study, residential PV systems are installed in all 310 detached houses, which make up the sole electricity supply resource in this area in the event of a network emergency. PV systems are not installed in other demand types, i.e. apartment houses, hospital, school and store. Taking the

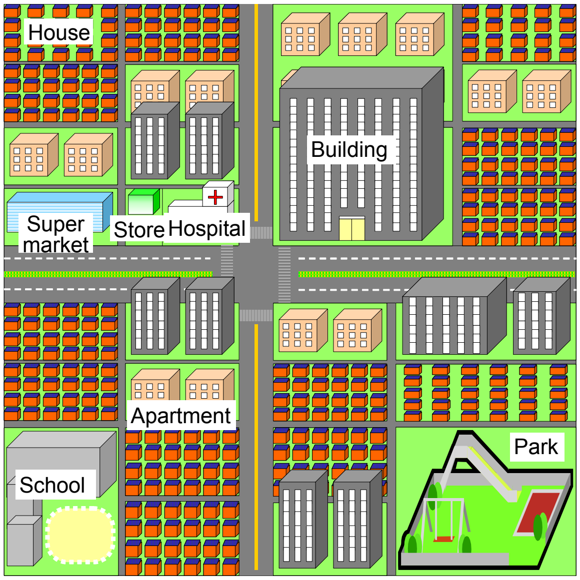

Figure 1 An example of urban residential area

TABLE I
ASSUMPTION OF EACH DEMAND TYPE

Demand type	Total number	Floor space [m²]	Maximum Electricity demand [kW]
Hospital	1	1860	117.9
School	1	7948	230.1
Convenience store	1	152	15.4
Detached house	310	136	(1.9)[#]
Apartment house	230	51	(0.6)[#]

Electricity demand of houses does not occur during urban disaster

available rooftop area of a detached house of average size into account, it was assumed that the capacity of PV system installed in each detached house was 4.2 kWp. Therefore the total capacity of PV systems installed in all 310 detached houses is 1300 kWp in the area shown in Figure 1 and Table I.

Microgrid configuration

In this research a microgrid is defined as a controllable section of low voltage (LV) network containing a mixture of distributed generators, storage and load. Based on these requirements a dynamic PSCAD/EMTDC model of a generic distribution network with a typical urban residential area was developed [1]. Different levels of detail and different levels of aggregation were defined in order to allow for a flexible analysis [7]. One 11kV/0.433kV distribution substation is modelled in detail. A microgrid (Figure 2) comprises of four LV network segments. Three of them are represented as lumped load (equivalent to 24 customers) and lumped generation while one of them is represented in detail (Segment 4). Segment 4 comprises of four detailed models of a wind turbine and a load equivalent to 6 customers. Each microgrid supplies 96 customers in total. Minimum and maximum load demands, produced by the Electricity Association, were used [1].

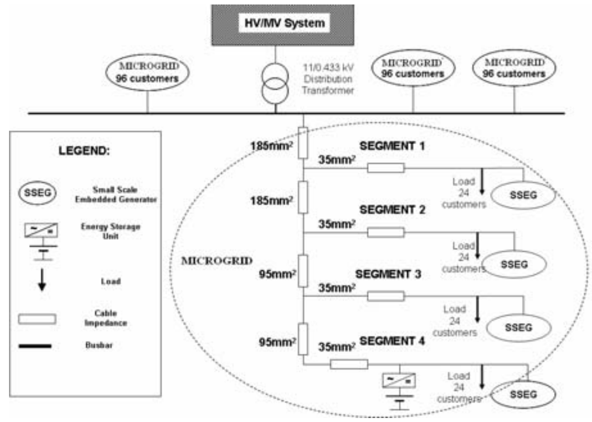

Figure 2 Microgrid configuration

BALANCE OF ELECTRICITY SUPPLY AND DEMAND IN MICROGRID FOR NETWORK EMERGENCY

Calculation of Voltage Profile and Battery State-of-charge

By using the model of isolated microgrid in the event of a network emergency shown in Figure 3 and TABLE II, the voltage profile and battery SOC were calculated. For simplicity, the model is composed of 9 PV systems (#13 - #21), 1 battery (#1) and 1 load bus (#6). The electricity demand of 10 kW occurs at #6 only. As mentioned above, the electricity demand does not occur in the buses with PV system (#13 - #21) in the event of a network emergency. The microgrid is assumed to be isolated at 6:00, where the battery SOC is 97% and all PV systems are turned on at 6:00. The electricity output of PV system is assumed based on the data of solar radiation observed for a few days with the sampling interval of 1 minute [6].

Figure 7 shows an example of a particular calculation result. In this case, because the weather condition is very good with enough solar radiation, the electricity output of PV system at #19 reaches 2.9 kW. In the early morning, however, the total electricity supply of 9 PV systems is smaller than 10 kW. Therefore, the battery discharges, and the terminal voltage of the battery gradually decreases. The solar radiation increases and becomes sufficient at approximately 9:30, the battery is then fully charged and the voltage at some PV systems reaches 1.05 pu. Then, PV systems at #15, #18 and #21 are turned off. PV systems at #14, #17 and #20 are also turned off a few minutes later, resulting in only 3 PV systems being operated.

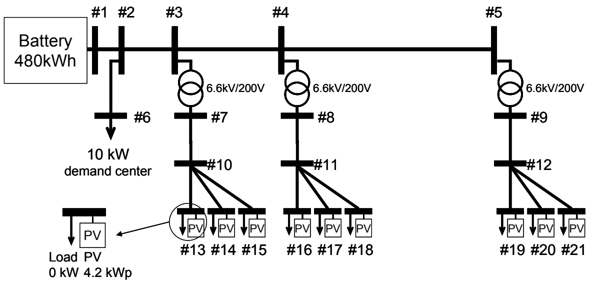

Figure 3 Model of isolated microgrid in urban disaster

TABLE II
ASSUMPTION OF DISTRIBUTION LINES

Distribution line			
bus – bus	voltage	length [m]	R + jX [Ω]
#1 - #2	6600	20	0.006 + j0.008
#2 - #3	6600	200	0.063 + j0.075
#3 - #4	6600	400	0.125 + j0.151
#4 - #5	6600	800	0.250 + j0.302
#2 - #6	6600	20	0.006 + j0.008
#7 - #10	200 V	40	0.013 + j0.015
#8 - #11	200 V	40	0.013 + j0.015
#9 - #12	200 V	40	0.013 + j0.015
#10 - #13	200 V	20	0.006 + j0.008
#10 - #14	200 V	30	0.009 + j 0.011
#10 - #15	200 V	45	0.014 + j0.017
#11 - #16	200 V	20	0.006 + j0.008
#11 - #17	200 V	30	0.009 + j 0.011
#11 - #18	200 V	45	0.014 + j0.017
#12 - #19	200 V	20	0.006 + j0.008
#12 - #20	200 V	30	0.009 + j 0.011
#12 - #21	200 V	45	0.014 + j0.017
Transformer			
bus – bus	voltage		R + jX [Ω]
#3 - #7	6600 / 200	-	0 + j2.5 %
#4 - #8	6600 / 200	-	0 + j2.5 %
#5 - #9	6600 / 200	-	0 + j2.5 %

Because the electricity supply of 3 PV systems is smaller than 10 kW, the battery discharges and the voltage begins to decrease. Then, some PV systems are turned on at around 11:30, although they are turned off again before 12:00. Finally, in the early evening, the battery SOC is maintained at a level of approximately 96%. If the battery only meets the electricity demand of 10 kW in local community center, the battery SOC decreases to about 76 % at 16:00.

The calculation of battery SOC was carried out for 365 days, taking various patterns of solar radiation into account. Figure 4 shows the battery SOC at 16:00. The battery SOC is kept higher than 90% for 85% of the days in a year. This means that the proposed operation of PV systems and battery works very well with regard to maintaining a healthy battery SOC even with various weather conditions.

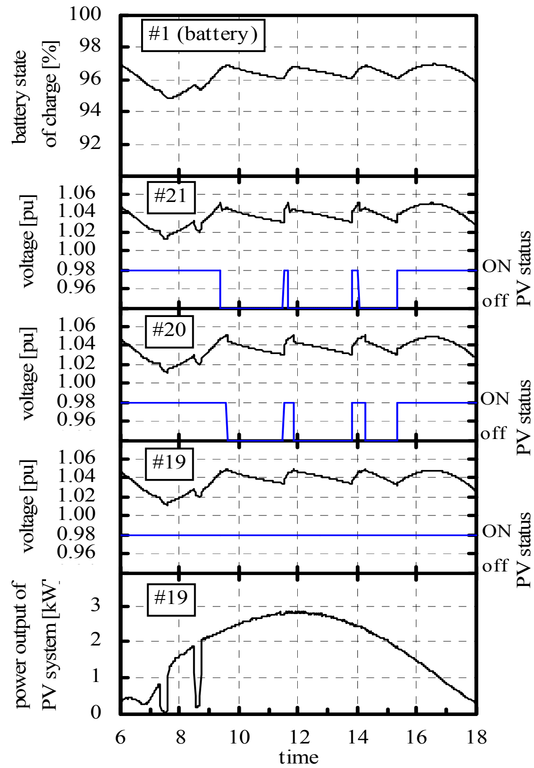

Figure 4 An example of change in voltage and battery state-of-charge.

Distributed control of a microgrid

In order for a microgrid to be able to operate autonomously it has to be controlled such that it can respond to load variations. This must be achieved rapidly enough to ensure that voltage and frequency regulation requirements can be met. In order to meet these requirements the microgrid has a number of components which can be controlled: distributed generators, load and an energy storage unit. The study approach is based on a generic distribution network dynamically modelled in PSCAD™/EMTDC™ (Figure 2) in order to identify appropriate active control strategies for autonomous operation of microgrids. If a close match is achieved between local demand and local generation capacity, a microgrid could attempt to operate self-sufficiently, with no power exchange with the distribution network. This self-sufficient operational goal could be applied to maintain the balance between demand and generation in an islanded situation [8]. The simulation results are based on the following assumptions (Figure 5):

i. The model has the ability to vary the power consumed by the load between the minimum demand figure (0.16kVA) and maximum demand figure (1.3kVA) using a proportional-integral (PI) controller.
ii. The maximum generation curtailment for each unit was set to 50%. The real power control can be described as a PI control function which sets a mechanical torque

command for the generator in order to control the power output of the generator.

iii. A lead acid battery is used as energy storage unit.

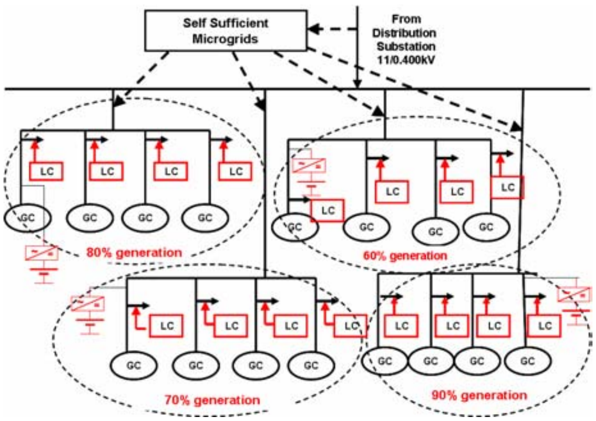

Figure 5 Cooperative controls techniques of microgrids

The case study considered a scenario in which it was supposed that the feeder lost its connection with the grid at t(time)=30s at which time the microgrids began operating in islanded mode. At the moment the connection is lost the microgrid was exporting approximately 170kW to the grid. Through cooperative active control techniques it can be seen from Figure 6 that this was rapidly reduced to zero by curtailing generation and adding load and charging storage devices.. The result of this is that there is no real or reactive power exchange between the microgrids and the rest of the grid and this therefore suggests that they could operate autonomously if this transition could be carried out rapidly enough.

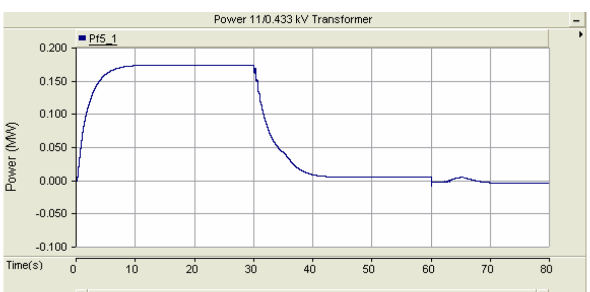

Figure 6 Active power flows at the distribution substation level

CONCLUSIONS

This study proposes a concept of isolated microgrids as a solution to the failing energy supply from the main grid in the situation of a major network event. This was modelled based on typical urban residential areas in Japan and a generic distribution network. Islanding could be used to improve the security of supply to customers in selected parts of the network. Network operators could make use of islanding as part of their wider strategies to improve the quality of service. Based on simulation results it was shown that LV networks can run autonomously and this could be seen as an important contribution to network operation. The proposed microgrid, which is composed of residential PV systems and battery, would be feasible in terms of the balance of electricity supply and demand, even with the nature of fluctuating solar radiation patterns. Then, assuming that some PV systems may be turned off to avoid excessive voltage rise in the daytime, an autonomous control scheme for the PV systems and battery SOC was proposed. PSCAD/EMTDC simulations based on a generic distribution network have shown that autonomous microgrids can be adequately controlled by employing combinations of generation active power control, load control and energy storage control. Technically it has been shown that LV networks can run autonomously but investment in a control system is required. If major network events become more common it may become attractive to invest in the control technology required to facilitate microgrid islanding.

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