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Design and Operation of Provisional Microgrids

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SUMMARY

The rapid evolvement of critical civil infrastructure towards more controllable and intelligent systems, under the context of smart cities, has necessitated a comprehensive synergy among various disciplines for addressing ongoing technical and economic challenges and laying the required groundwork for future advancements. This paper investigates the Provisional Microgrid as an enabling technology for the widespread, low-cost, and viable interactions of end-use customers and provides for a bottom-up approach in creating smarter cities, i.e., starting by transforming customers rather than systems. The provisional microgrid comprises similar characteristics as a microgrid but is not capable of operating in the islanded mode on its own. This paper discusses how provisional microgrids can be elevated to the status of microgrids, and accordingly increase the supply reliability of local customers in case of utility grid supply interruptions. The rationale, relevance, and features of the provisional microgrid along with its operation modes are further discussed.

KEYWORDS

Provisional microgrids, distributed energy resource, islanding.

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1. INTRODUCTION

A microgrid is a small-scale power system consisting of a set of locally installed distributed energy resources (DERs) that supply local loads in a reliable and economic manner. The microgrid is capable of operation in two modes: grid-connected and islanded. The microgrid master controller optimally regulates the microgrid operation mode to achieve the desired operational objectives [1]-[4]. The deployments of microgrids are increasing and projected to increase even more in the future due to significant advantages that this technology provides for end-use customers, such as improving local system resilience and reliability, higher power quality and efficiency, and increasing economic benefits [5]-[8]. Notwithstanding their numerous benefits, development of microgrids faces several challenges: (1) microgrids require substantial investments, considering the costly DER installations, distribution network upgrade, communication network upgrade, master controller deployment, etc., thus not all end-use consumers are capable of this investment; (2) the islanding feature requires that the installed generation capacity be larger than the local critical load, which requires the deployment of a high percentage of dispatchable DGs such as micro-turbines or gas-fired turbines. This reduces the deployment of the nondispatchable DGs, primarily renewable energy resources (solar PV, wind turbines, etc.) as they cannot be controlled; and (3) the installed DERs will potentially be underutilized since microgrids frequently import low-price power from the utility grid, which take advantage from the economies-of-scale in generation such as gas, coal, and nuclear units [9], [10]. These issues could significantly impact the deployment of the microgrids as they may increase the return on investment and significantly impact the anticipated economic and environmental merits. This paper introduces the concept of the provisional microgrid, which complements the ongoing efforts in microgrid deployments, while addressing the aforementioned challenges and further increasing the customers' control of energy usage and engagement in grid practices.

2. PROVISIONAL MICROGRIDS

The concept of a provisional microgrid is introduced to support the use of renewable generation in the distribution network; it holds similar characteristics of microgrids as it contains interconnected loads and DERs and a master controller that controls and regulates the operation of the provisional microgrid. However, it is not capable of operation in the islanded mode by itself and must be electrically coupled to at least one existing microgrid [10], [11]. Figure 1 depicts the provisional microgrid operation modes (islanded and grid-connected). The provisional microgrid would rely on locally generated power by the renewable energy resources and on the power transfer from the coupled microgrid [11]. The provisional microgrid represents an enabling technology for the widespread low-cost and viable connection of end-use customers and provides for a bottom-up approach in creating smarter cities. The advantages of the provisional microgrid can be demonstrated in increasing liveability in communities (by ensuring a cost-effective operation), workability (by collaborating with existing microgrids and enabling a viable response in emergency operations), and sustainability (by advancing the deployment of emission-free renewable energy resources). The purpose of introducing the provisional microgrid is to accelerate fundamental understanding and stimulate new ideas on dynamic systems that enhance customers' interconnection and interdependency while providing services and innovative applications to enable more connected, workable, liveable, and sustainable communities.

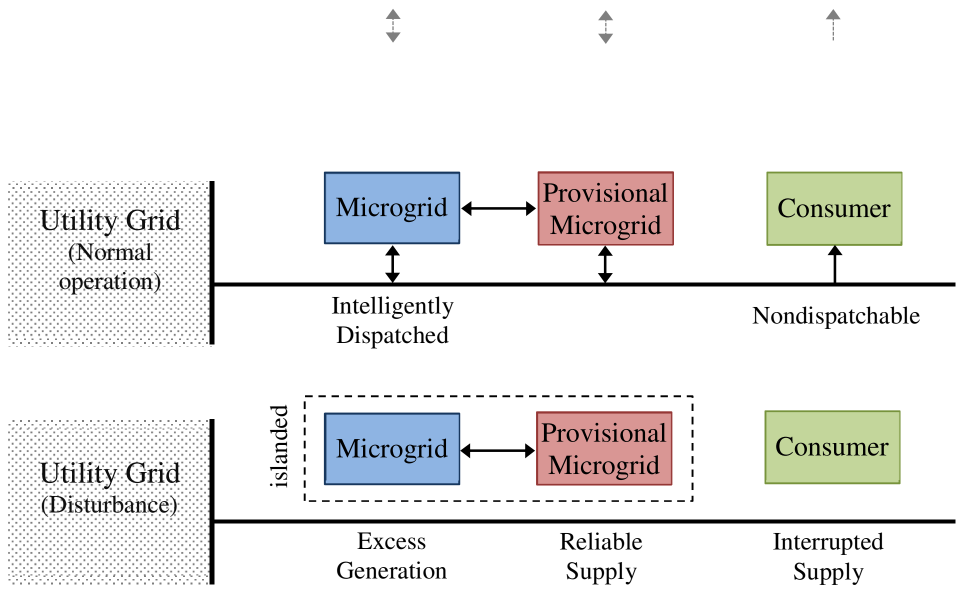

Figure 1. Illustration of the operation modes of a provisional microgrid. In case of a grid disturbance, the provisional microgrid can get connected to an electrically-coupled microgrid and supply local loads, while other consumers will encounter an interruption in power supply (i.e., a power outage).

Suppose that a provisional microgrid seeks to supply the forecasted load PD_t^{P} at time t. Within the scheduling horizon, the provisional microgrid master controller must ensure the following:

$$P_t^{\mathrm{C}} + P_t^{\mathrm{M}} + P_t^{\mathrm{P}} + LS_t = PD_t^{\mathrm{P}} \qquad \forall t, \tag{1}$$

where P_t^{C} is power exchanged by the coupled microgrid, P_t^{M} is power exchanged with the utility grid, P_t^{P} is generated power in the provisional microgrid, and LS_t is the load curtailment. The provisional microgrid is normally connected to the utility grid. However, in case of upstream disturbances, the provisional microgrid would switch to the islanded mode and rely on the generated power by locally installed DERs and the power exchanged with the coupled microgrid to satisfy local loads. Within this context, the provisional microgrid operation can be broken down as follows which is also summarized in Table 1:

(a) In the grid-connected operation, the provisional microgrid coordinates the available local generation and the power exchange with the utility grid and the coupled microgrid to maintain supply-demand balance.

(b) In the islanded mode (i.e., upstream network disturbance), the provisional microgrid would be disconnected from the utility grid distribution network and import its further energy requirements from the coupled microgrid to supply the local loads. Based on the available generation at the coupled microgrid side, it is possible that the provisional microgrid loads would be partially curtailed.

Table 1 Provisional Microgrid Operational Modes

Operation Mode	Provisional Microgrid	Coupled Microgrid	Utility Grid
Grid-connected	$P_t^{\mathrm{P}} \in [0, \overline{P}^{\mathrm{P}}]$ $LS_t = 0$	$P_t^{\mathrm{C}} \in [-\overline{P}^{\mathrm{C}}, \overline{P}^{\mathrm{C}}]$ (two-way flow)	$P_t^{\mathrm{M}} \in [-\overline{P}^{\mathrm{M}}, \overline{P}^{\mathrm{M}}]$ (two-way flow)
Islanded	$P_t^{\mathrm{P}} \in [0, \overline{P}^{\mathrm{P}}]$ $LS_t \in [0, PD_t^{\mathrm{P}}]$	$P_t^{\mathrm{C}} \in [0, \overline{P}^{\mathrm{C}}]$ (Import)	$P_t^{\mathrm{M}} = 0$ (No transfer)

3. RATIONALE, RELEVANCE, AND FEATURES

The objective behind proposing the provisional microgrid is that by eliminating the islanding requirement the necessity of deploying a high percentage of dispatchable DERs is further eliminated, which facilitates the deployment of any generation mix. Consequently, a high percentage of renewable DGs (primarily small-scale wind and solar units) without concerning about islanding requirements could be installed. This deployment, however, is only applicable for loads that have low criticality and sensitivity characteristics, since the power exchanged with the coupled microgrid is based on the coupled microgrid's unused capacity, which could be low during an islanded operation. The generation of the renewable DGs in the provisional microgrid would be fully utilized regardless of the electricity rate at the utility grid, which alleviates the underutilization concern of the installed capacity. The provisional microgrid would benefit from the connection to the coupled microgrid to obtain the required flexibility for coordinating the renewable generation, if needed, and import additional power as needed to supply local loads during the islanded mode [10], [11]. Mutual benefits stem from this integration (i.e., connecting the provisional microgrid to the coupled microgrid) as the coupled microgrid would maximize its economic benefits by selling its excess generation to the provisional microgrid, which in turn benefits from this power exchange to supply the local loads and achieve the required reliability. Though the primary application of the microgrids is to manage and control the increasing penetration of the DERs and addressing the economic and reliability aspects for local consumers, the primary application of the provisional microgrids is to promote the use of the renewable energy resources in the distribution network and provide desired reliability levels for local consumers by leveraging the unused capacity in the already installed microgrids.

The idea behind the provisional microgrids is quite different from the networked microgrids. Networked microgrids, also identified as integrated microgrids or microgrid clusters, comprise two or more interconnected microgrids that exchange the power among themselves to reduce the total power losses, manage local loads, and enhance the reliability and economic objectives, and are able to be islanded individually; while the provisional microgrid, as the name implies, depends on at least one coupled microgrid for islanding capability. The proposed provisional microgrid solution has specific characteristics, including (1) it can operate when connected to the utility grid, but has the capability to synergistically operate with the coupled microgrid for reliability and resilience purposes; (2) it mainly consists of renewable DGs, and if desired, energy storage; (3) it makes smart decisions to connect/disconnect to/from the utility grid and the coupled microgrid to reach desired objectives; (4) it is capable of optimally operating smart appliances such as HVAC systems, which will be carried out by its master controller; and (5) it is interoperable externally and internally using standard protocols that meet control and communication potentials as desired by the utility, and/or the community where it is installed. Provisional microgrid technology is scalable to significantly higher levels of penetration in distribution grids as it is expected to have minimal interconnection issues with the utility grid.

4. OPERATION MODES

The islanding is implemented to promptly disconnect the provisional and the coupled microgrids from the faulty upstream network, and protect the local DGs and voltage sensitive loads from the disturbances. The dynamic connection to the utility grid and the coupled microgrid is ensured by adding (2) and (3) to the developed economic and reliable operation model. Let v be the utility grid connection binary variable (1 during normal grid operation and

0 during emergency operation), and w be the coupled microgrid connection binary variable (1 when coupled and 0 when fully islanded); hence:

$$P^{u}v_t \le P_t^{u} \le P^{-u}v_t \qquad \forall t \tag{2}$$

$$P^{m}w_t \le P_t^{m} \le P^{-m}w_t \qquad \forall t \tag{3}$$

Once integrated with the developed operation model, the dynamic connection/disconnection scheme will be determined under the optimization framework and based on the value of the binary connection variables. Possible combinations and the resultant operation modes (OM) are listed as follows:

OM1: $v = 1$, $w = 1$ → Normal operation (grid-connected and microgrid-coupled)
OM2: $v = 1$, $w = 0$ → Normal operation (grid-connected only)
OM3: $v = 0$, $w = 1$ → Emergency operation (microgrid-coupled)
OM4: $v = 0$, $w = 0$ → Emergency operation (fully islanded)

The connection between the provisional and the coupled microgrid is to be sustained during emergency incidents, i.e. OM3 is preferred over OM4. This connection is characterized by providing mutual benefits for both microgrids, i.e. the provisional and the coupled microgrid, where the reliability level in the provisional microgrid would be improved by importing its further need of power from the coupled microgrid, in particular during the islanded operation, while the coupled microgrid would increase its economic benefits by selling its excess generation to the connected provisional microgrid. The provisional microgrid, however, would further benefit from this connection by exploiting the dispatchable DERs in the coupled microgrid to regulate the frequency and control the voltage, if needed.

5. ILLUSTRATIVE STUDY

The robust day-ahead schedule of a test provisional microgrid [11] is determined based on a certain 3 MW transfer limit with the coupled microgrid and an arbitrary 3-hour islanding (hours 17:00, 18:00, and 19:00). The scheduling results are shown in Figures 2 and 3. Figure 2 illustrates the provisional microgrid power exchange between the utility grid and the coupled microgrid. The figure clearly demonstrates that the provisional microgrid will interact with the utility grid in the grid-connected mode and will rely on the generation from the coupled microgrid in the islanded mode. Figure 3 shows the provisional microgrid load curtailment during the islanded mode. If adequate generation is not available, as this is the case in hour 18:00, load will be partially curtailed. It is noteworthy that the corresponding prosumer (before being elevated to a provisional microgrid) would encounter a total load curtailment of 7.67 MWh instead of 0.08 MWh in this case. In terms of outage cost, assuming a small value of lost load (VOLL) of $10/kWh and negotiated price of $0.1/kWh, it represents a saving of $75,900. The coupled microgrid would further benefit from this transaction as it would be paid for the 7.59 MWh energy sold to the provisional microgrid at the negotiated price.

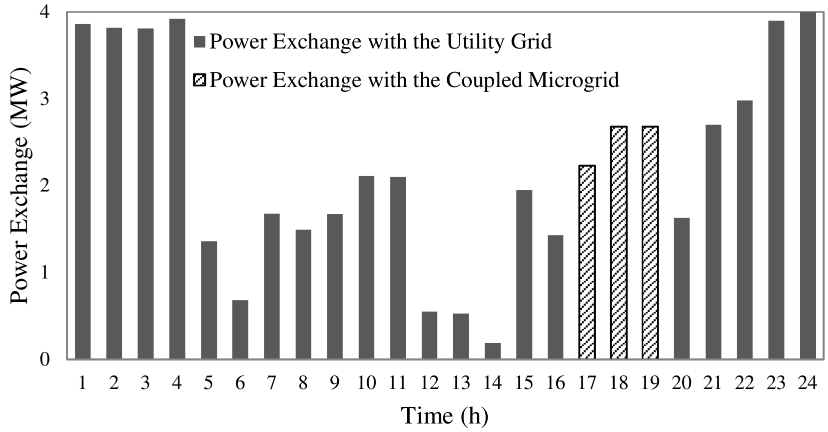

Figure 2. Provisional microgrid imported power from the utility grid and the coupled microgrid during the selected scheduling horizon.

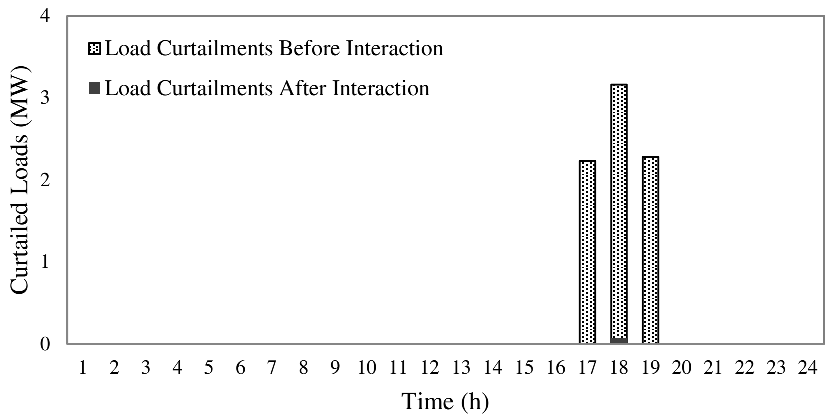

Figure 3. Provisional microgrid load curtailments during the islanded mode.

6. CONCLUSION

The provisional microgrid concept was investigated in this paper and an optimal scheduling problem was solved to test the performance of this newly-proposed technology. Provisional microgrids enhance the penetration of the renewable DGs in the distribution network by removing the islanded capability requirement and obtaining the required flexibility and reliability for local consumers by utilizing the unused capacity of the existing microgrids. Coupled microgrids, in turn, would economically benefit from this connection. The illustrative study indicated a considerable improvement in terms of reliability for the provisional microgrid and an increase in economic benefits for the coupled microgrid. The significance of this technology was further demonstrated for end-use customers while increasing the use of the installed capacity of the DERs within the coupled microgrid.

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