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Recovery from Large-Scale System Events Using Oasis Microgrids

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SUMMARY

Traditional reliability analysis predicts power system performance under contingencies that remove a few selected lines, generators, or substation buses. These analyses identify grid improvements that result in high-availability system performance for the vast majority of what could be considered high-probability, low impact scenarios. Recent hard experience has demonstrated that some lower-probability scenarios can remove large elements of the power system from service for days or weeks.

Small-footprint microgrids are proving capable of supplying critical power to point and campus loads during loss of the local distribution system. Microgrids have the further attraction of facilitating the addition of new distributed renewables and energy storage. Despite these strengths and improving economics, local regulations and their own newness are holding back broad adoption of smaller microgrids for the moment.

Today, work is taking place to increase the robustness of local or regional electric power systems through a concept we call the oasis microgrid. Using a set of pre-planning activities, the utility identifies a subset of transmission, generation, and load resources that can be started and operated indefinitely even if large segments of their regional bulk electric system are unavailable. This paper describes a natural disaster scenario that would leave the U. S. Pacific Northwest with a ruined bulk electric system and the studies being undertaken to prepare to operate a generation, transmission, and distribution subsystem for local critical power and to aid in recovery.

KEYWORDS

Cascadia Subduction earthquake, microgrid, oasis, black sky events, black start planning, disaster preparedness.

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INTRODUCTION

In July, 2015, an article in the popular The New Yorker magazine [1] described a 9.0 magnitude earthquake that has the potential to strike the U. S. Pacific Northwest in coming years. Geologists have been researching a particular fault line there for several years and have determined that a high-magnitude quake strikes there about every 245 years. Alarmingly, the most recent quake on that fault line took place in 1700, meaning that a recurrence could take place at any time and is increasing likely in the coming decades. The fault line in question is just off shore of Washington and Oregon states. A 9.0 magnitude earthquake there would produce a tsunami comparable to the one that impacted Japan in 2011. Geologic factors west of the Cascade mountains increase the potential damage to energy and transportation infrastructure in the Willamette Valley and Puget Sound areas for such a high-energy quake.

Emergency preparedness authorities in the region have not taken the research results lightly. In June 2016, many local and regional entities participated in the Cascadia Rising exercise, named for the Cascadia Subduction Fault that is due to produce the quake. Cascadia Rising [2] envisioned a 90th percentile event that would, among other things, render inoperable much of the bulk electric power system west of the Cascade Mountains in Washington and Oregon. The quake would leave millions without electric power, natural gas, and communication services. It would severely impact emergency services and transportation facilities and leave over 1 million people without shelter.

In the face of this sort of event, a utility on the edge of the major destruction zone is examining what it would take to operate its local electric power system without energy from the regional bulk transmission system. The steps necessary to determine the ability of this utility to provide an electrical oasis in what would otherwise be an energy desert is the subject of this paper.

THE OASIS MICROGRID OPERATING CONCEPT

The key challenge in defining an oasis microgrid is to identify a stable, operable mix of generation, transmission, and distribution resources sufficient to energize a meaningful set of critical loads. After it is energized, the oasis microgrid also serves as a synching source to facilitate operation of distributed energy resources (DER), such as solar PV, energy storage, and emergency response generation. Similar concepts and approaches have been used effectively in other locales, as described in [3]. The figures and text below describe the desired sequence of operations in response to the catastrophic event scenario. Severe event nomenclature used below is that proposed by the NERC Severe Impact Resilience Task Force [4], and represented in Figure 1.

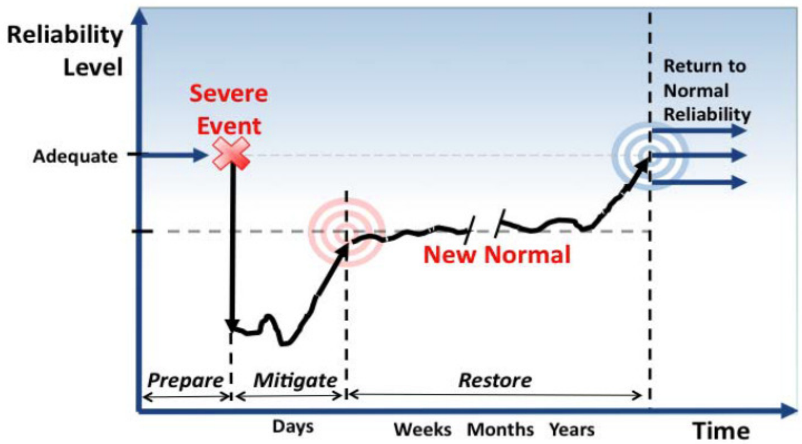

Figure 1: NERC Severe Impact Resilience Task Force Event Response Time-Frames [3]

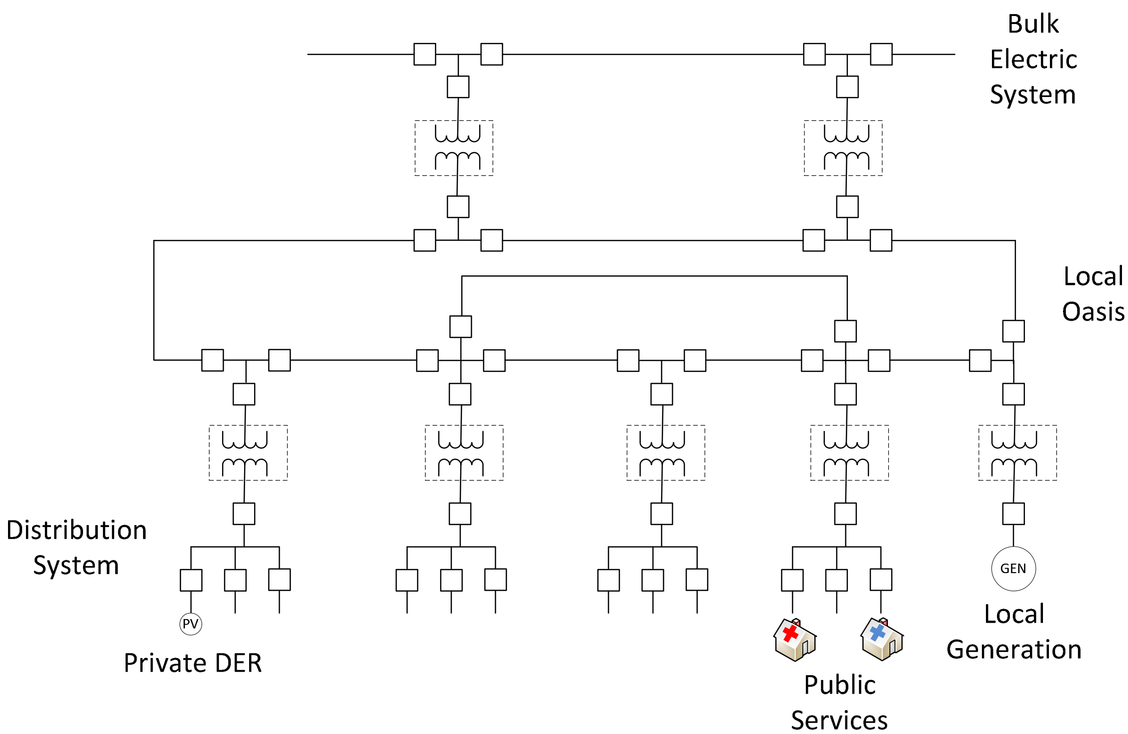

Figure 2: Simplified Pre-Event Electric System

Before the catastrophic event, the local electric system (Figure 2) serves distribution load using power imported from the bulk electric system and supplemented by local generation. Critical emergency and public safety loads are served by the distribution system. Privately owned DER are also connected to the distribution system, but are not controlled by the utility beyond establishment of appropriate interconnection and metering rules.

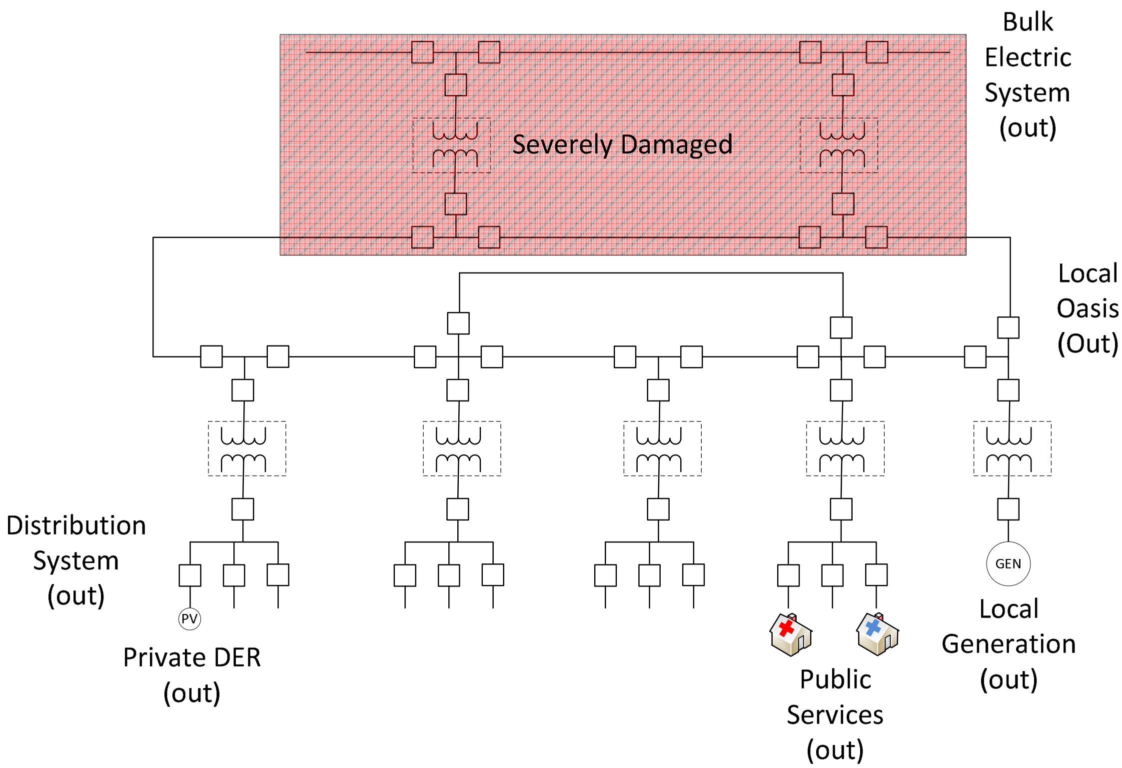

Figure 3: Immediate Post-Event Conditions: Complete Blackout

Immediately after the catastrophic event (Figure 3), the planning scenario suggests that the bulk-electric system would be severely damaged and that repair may take weeks or months. The extent of damage to the local sub-transmission and distribution system will take time to fully assess, but most scenarios predict that—for the subject utility service area—a meaningful portion of the local system will be operable within a short period of time (Figure 4). Critical medical and public safety loads would be re-energized first, followed by important communications, water and waste water, and public shelter facilities, to the degree permitted by the available local generation.

In the Mitigation period following the severe event, utility staff can make a fuller assessment of generation, distribution, and sub-transmission system damage. Staff restores those elements of the system that can be quickly repaired. Severely damaged sections are cataloged for later attention (Figure 5). Restoring additional distribution system elements makes energy available to second-tier support services like stores and gas stations. Nearly as important, it provides synching voltage for the restoration of pre-existing and emergency DERs that produce additional energy.

Finally (Figure 6), in the New Normal phase, sufficient system repairs have been made and generation added that rotating service can be provided to non-critical loads. This phase lasts until bulk electric system service is restored some weeks or months after the original catastrophic event.

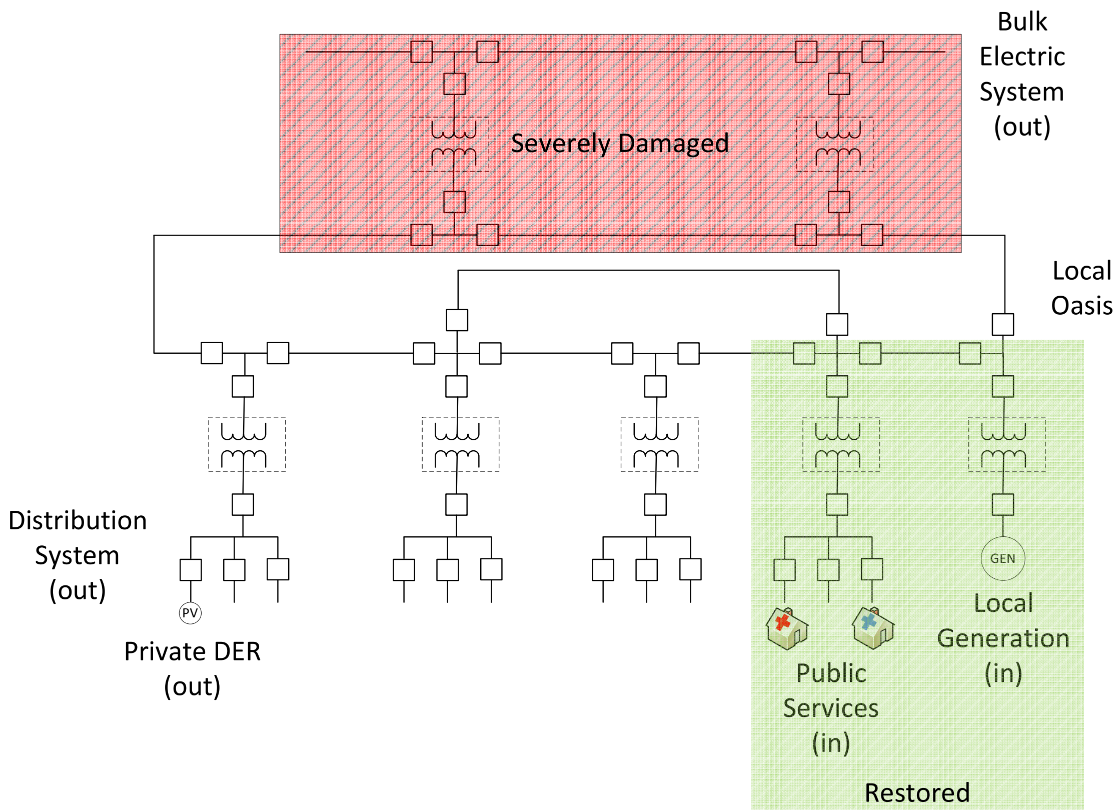

Figure 4: Initial Restoration Energizes Critical Services

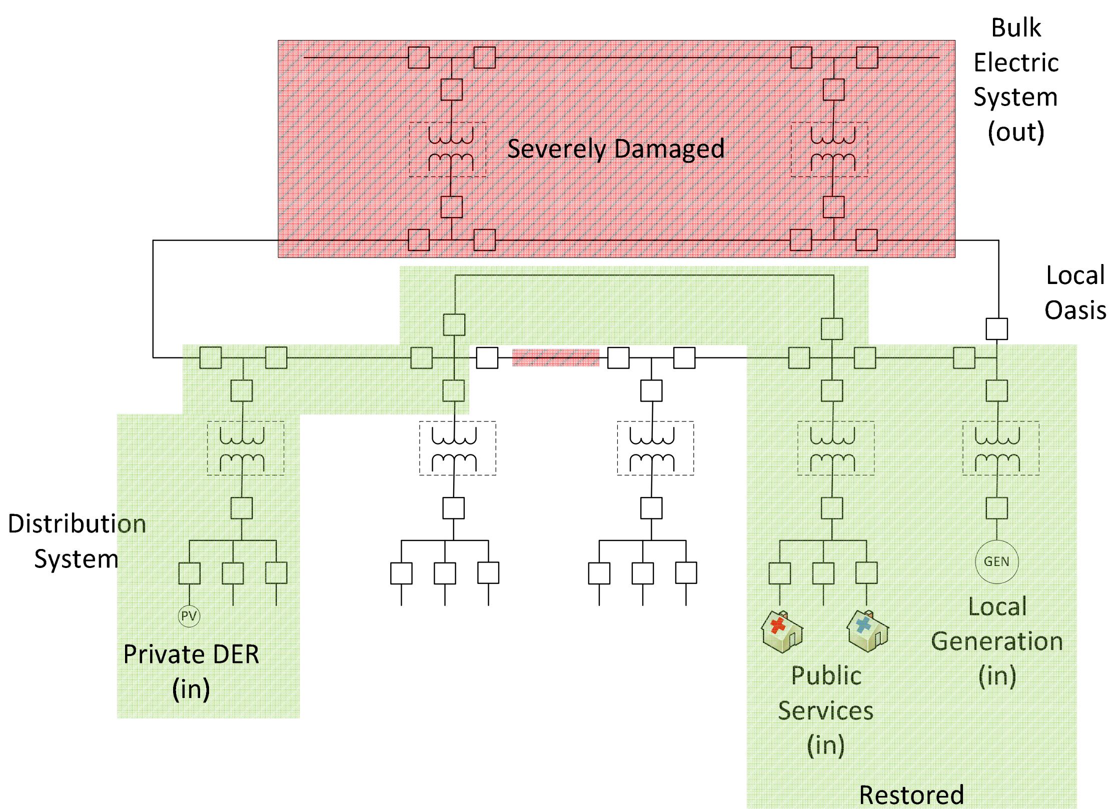

Figure 5: Mitigation Phase Restores Additional Utility and DER Facilities

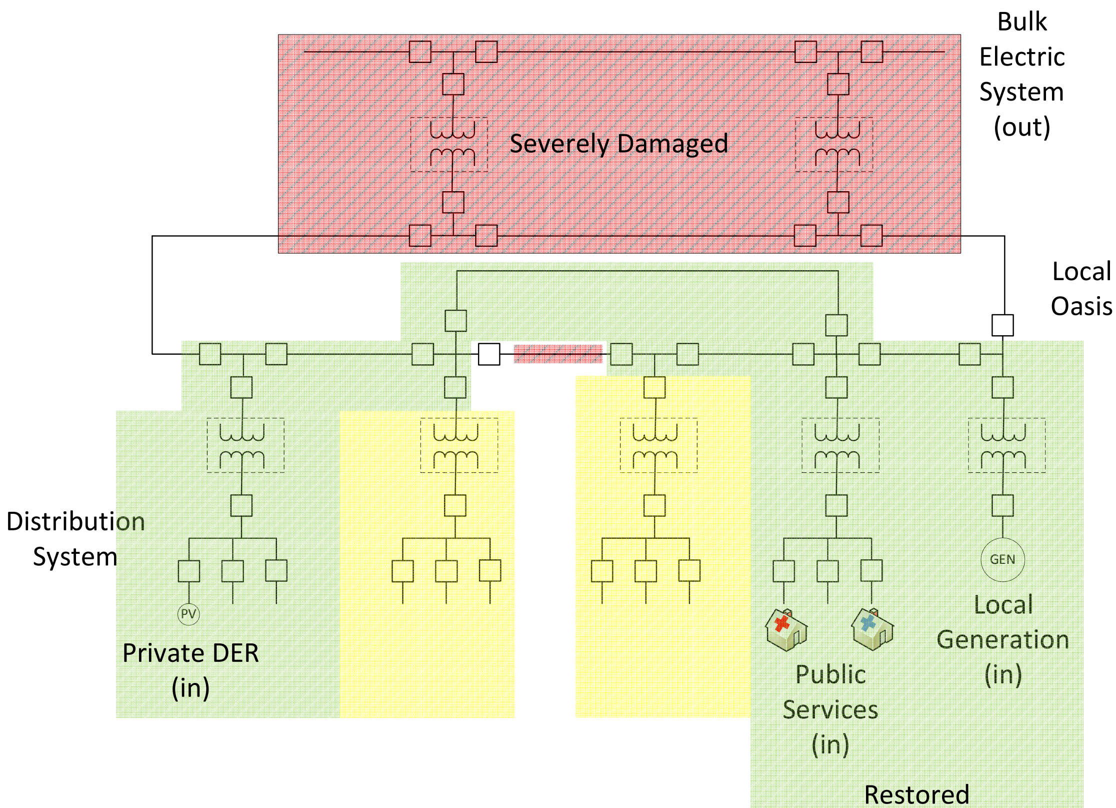

Figure 6: "New Normal" System with Rotating Service Areas Shown in Yellow

PLANNING FOR AN OASIS SYSTEM

The oasis microgrid concept rests on several founding assumptions:

- The event that damaged the bulk electric system will leave some local sub-transmission, distribution, and generation assets undamaged or quickly repairable.
- Real and reactive power resources are available in the local system in sufficient quantity, placement, and rating to energize and support critical loads and segments of the local electric system.
- Black start resources—those generation assets that do not require energy from outside the plant to start up—exist to permit initial re-energization.
- Utility staff needed to do the work of restoring and operating the system remains available after the event.

To prepare for such an event and recovery requires substantial advance planning and study. The outline below only addresses electric system operational issues. The requirements around staff preparation and ongoing support in the face of this sort of event are not trivial and are beyond the scope of this paper.

ASSUMED POST-EVENT SYSTEM INVENTORY

To prepare for operation of an oasis microgrid, the first step is an inventory of the local system resources that could survive the scenario event. Considerations such as structural survivability and fuel availability post-event are critical. Locations of first- and second-tier critical loads, along with their real and reactive power requirements and the distribution circuits through which they can be served are needed. Generation and Bulk Energy Storage System (BESS) sources, including details such as capability curves and black start options, should be documented. Primary and alternate sub-transmission paths must be identified. VAR resources such as capacitor and reactor banks should be included in the inventory.

OASIS SYSTEM PERFORMANCE ANALYSIS

Once the post-event system inventory is complete, a thorough system performance analysis should be undertaken for the post-event system. This analysis should consider the following:

- Frequency stability as a result of the match between load real power requirements and generation real power capability.
- Voltage level and stability as a result of load-flow voltage drops and a match of reactive power sources and sinks.
- Angular stability and critical fault clearing times. Fault clearing times are often longer on sub-transmission and distribution systems and these times may be extended due to reduced available fault currents. As a result, angular stability of the oasis system due to faults may not be acceptable without relay settings adjustments to reduce tripping delays.

BLACK START ASSETS AND PROCEDURES

In the best case, the catastrophic event may leave some elements of the system operating. The more likely scenario is that the entire system will be dark following the event because of protective relaying operation for faults produced by the earthquake. Disorganized and unbalanced islands will likely produce tripping of the otherwise undamaged generators due to over/under frequency, over/under voltage, or mechanical/fuel problems. After the oasis is operating, it is likely to be somewhat brittle so we anticipate additional blackouts and restarts during the Mitigation and New Normal periods.

For all these reasons, the generation assets that can be black-started and the system configurations and procedures required to do so should be well documented. Those operating documents should be readily accessible. Because backup staff may be performing the work under high stress, the procedures must be crystal clear and complete for safety of the assets, staff, and the public. Preparedness drills might intentionally place backup staff in start-up positions to test the clarity of procedures under the quiet but watchful eyes of more experienced operators.

PROTECTIVE RELAYING STUDIES

As mentioned above, protective relaying operation may be challenged in the oasis configuration. Some normal sources of positive- and zero-sequence fault current will be unavailable and current-based protection elements and fuses may lose desired sensitivity and coordination. Faster protective relay operation may be required to preserve system stability. Automatic reclosing will probably not be desirable in the oasis configuration because operating stability might be reduced if a fault is re-introduced to the system through a reclose operation. Any or all these reasons may recommend alternate relay settings for the oasis system during operation.

Arc flash hazards may be increased due to longer fault clearing times. For this reason, and because staff will be operating under difficult and unfamiliar circumstances, consider requiring all work to be performed with equipment de-energized to mitigate arc flash hazards.

SCADA AND CONTROL CAPABILITIES

We expect communication channels will be damaged by the earthquake through the same mechanisms that damage the electric power system. Preparatory studies should examine the exposure of communication channels to anticipated event scenarios. Are redundant or backup channels and operating centers available? What is the expected availability of wired or wireless voice and networking channels? How long will communication site backup power be available before fuel runs low?

DER INVENTORY/EMERGENCY GENERATION SUPPORT

Late in the Mitigation stage (Figure 5), we assume that the subtransmission and distribution systems have been restored to the point that privately owned DER can be restarted to contribute energy to the system. Pre-event inventory activities should identify the locations, types, and nameplate ratings of distributed energy generation and storage resources so that connections to them can be restored in an appropriate priority.

Additionally, early in the New Normal phase, emergency generation resources in the form of diesel reciprocating engine generator sets may be available if ground or heavy-lift air transportation into the disaster region can be established. Siting these emergency generators at utility substation yards having connection points pre-established for the purpose will speed the contribution these resources can make to system recovery.

SPARES AVAILABILITY AND ACCESSIBILITY

To expand the footprint and benefit of the initial oasis microgrid, it will be necessary to repair damaged electrical infrastructure. Planning should include careful consideration of which spares, repair supplies and tools, and procedures may be needed to perform that work. Storage of that material in several secure, accessible locations close to their envisioned points of use will be advantageous for restoration teams. Depending on the expected duration of repairs, stores might also include light medical supplies, non-perishable food items, water, and water purification resources to support the repair teams.

"NEW NORMAL" OPERATING PLANS

Finally, rough plans and procedures for the operation of the New Normal system can be developed. These plans are probably the least definable of the preparations since it will be difficult to predict the state of the system, availability of generation, and needs of loads in this time-frame. Still, there is value in having a pre-determined approach to defining how the system could be operated in this longer-term, reduced capability condition. Planning itself may also produce new insights that influence other aspects of the event response plans.

CONCLUSIONS

In addition to preparing the utility response to a high-impact, low-probability event, the planning and preparation activities have these additional immediate benefits to the utility and its customers:

- Preparing and documenting the system inventory offers improved awareness of the system assets and their condition.
- Oasis system performance studies improve understanding of the system operation in lower-impact, higher probability system events that leave greater portions of the system in service.
- Generation, communication and control backups and redundancies make these systems, the utility, and its staff performance more robust.
- Identification and installation of black start capabilities, along with documentation of their use, increases the availability of local generation in lower-impact events.
- The ability of the utility to provide synching voltage to privately-owned DER in a catastrophic event may encourage the investment in DER by utility customers, encouraging the penetration and effectiveness of renewables and energy storage.

Oasis microgrid planning helps speed utility response and recovery to disaster scenarios of several sorts. These activities improve local resiliency and encourage use of DER. As traditional microgrid economics and regulations become more favorable, oasis microgrid planning may offer one more reason for private owners to install them. Finally, these preparations serve to create a more flexible electric grid that can operate more reliably at nearly any available scale.

BIBLIOGRAPHY

[1] K. Schulz, "The Really Big One" The New Yorker, July 20, 2015

[2] The Washington and Oregon Whole Community Exercise Design Committee, "Cascadia Rising Exercise Scenario Document," January, 2015

[3] C. Abbey, et al., "Powering Through the Storm: Microgrids Operation for More Efficient Disaster Recovery," in IEEE Power and Energy Magazine, vol. 12, no. 3, pp 67-76, May-June 2014

[4] NERC Severe Impact Resilience Task Force, "Severe Impact Resilience: Considerations and Recommendations," May 9, 2012