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Sustaining Critical Social Services During Extended Regional Power Blackouts

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Despite continuing efforts to make the electric power system robust, some risk remains of widespread and extended power outages due to extreme weather or acts of terrorism. One way to alleviate the most serious effects of a prolonged blackout is to find local means to secure the continued provision of critical social services upon which the health and safety of society depend. This article outlines and estimates the incremental cost of a strategy that uses small distributed generation, distribution automation, and smart meters to keep a set of critical social services operational during a prolonged power outage that lasts for days or weeks and extends over hundreds of kilometers.

KEY WORDS: Critical social services; distributed generation; prolonged blackouts; smart grids

1. INTRODUCTION

Engineers have worked hard to make the electric power transmission and distribution system as reliable as possible. However, there are limits to how secure it is possible to make a system that consists of thousands of critical parts that are spread across the landscape.(1) Widespread and extended power outages can result from human error, intense geomagnetic storms,(2) extreme weather such as the 1998 ice storm in Ontario,(3) or terrorist attack.(4) The 1998 Ontario ice storm and the 2003 blackout in the Northeast left millions without power, and in the case of the former, for weeks.

Electricity supports many critical social services. When the power goes out, these services are interrupted or severely curtailed. Most of us have experience with blackouts after storms that last for just a few hours, and are relatively localized. Such blackouts are *not* the focus of this article. Here we ask: What could be done to make critical social services less vulnerable to low-probability, high-consequence events that cause a blackout lasting for several days or weeks and across hundreds of kilometers?

We examine four questions:

(1) How might "smart grid" additions be made to distribution systems that already contain some distribution automation and distributed generation (DG) to reduce social vulnerability in the event of large, long-duration blackouts?
(2) What would be the incremental cost of such additions?
(3) What would the probability of a large, long-duration blackout have to be to make deployment of such a system cost effective?
(4) What policy options might be employed to ensure that such a system serves as a sensible social "insurance policy?"

2. THE MODEL SYSTEM

Although power systems are interconnected at continental scale, there is great variability in their specific technology and operation at local scales. This makes it impossible to perform a detailed yet general

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technical design and cost assessment. Accordingly, we have constructed a simple hypothetical model and used it to obtain a first-order estimate of costs.

The model system makes use of DG to serve loads that supply critical social services. Because it would be too expensive to place a DG unit in proximity to all such loads, distribution automation and smart meters are used to create an electrically isolated "island" within which limited amounts of power can be moved to critical loads over existing distribution circuits, while keeping nonessential loads disconnected. There is already a considerable amount of small-scale DG installed in some power systems,[5] and there is growing interest in microgrids that serve a number of loads while also maintaining a connection to the distribution system.[6] However, because the necessary DG may not be available in any actual system, in the analysis that follows, we also consider alternatives that add DG to the system.

We model an urban/suburban region of approximately 5 km^2 with 5,000 households. Although the specific services considered to be critical during a large-scale blackout would vary seasonally and with local circumstances, here we illustrate the model using grocery stores, gas stations, cellular telephone base stations, police stations, and schools. Such a region could be expected to have 5–10 gas stations,[7] 2–3 grocery stores,[8] 5–10 cell towers,[9] 1–2 police stations/zones,[10] 2–3 schools,[11] and 1,200–1,500 streetlights.[12,13] Not all of these facilities would need to be powered to meet basic needs.

For simplicity in this analysis, we assume that the region being impacted is not subject to extremes of heat or cold. If a region did require heat or cooling to protect basic public survival, then arrangements would need to be made to address these needs, probably with centrally located heated or cooled predesignated shelter facilities such as shopping centers that have their own standby generation to power furnace blowers, air conditioning, or heat pumps.

A typical distribution feeder moves power from a distribution substation out to customers' loads. Each distribution system includes circuit breakers and reclosers to provide automatic protection in the event of faults (from falling trees or poles, lightning strikes, etc.). The distribution voltage is then stepped down for secondary circuits that supply power to most customers' meters. In our model, we assume that a number of small DG units with capacities of 10–100 s of kW either exist or are added on the customer side of some "smart meters" on one or several of the distribution feeders in the region and that power can be supplied to critical loads by "islanding" and reconfiguring the distribution system if the loads and DG units are not on the same feeders. We assume that the local utility has installed distribution automation and that the smart meters include a remote connect/disconnect feature, which is a common attribute of most smart meter deployments.[14] A number of utilities, such as Duquesne Light Company, have had distribution automation in place for decades,[15] and most smart grid projects now being implemented with support from the Department of Energy (DOE) stimulus grants include enhancements to existing distribution automation.[16]

In estimating the cost of the system, we include only the incremental cost of the equipment, controls, and operations required to support the *added* capabilities that we model. During an extended power outage, not all services need to be fully functional at all times. We assume that the limited supply can be cycled among the services based on need and a dynamic load schedule. We assume that prior arrangements have been made so that diesel fuel supply is unaffected by the outage. We also assume that natural gas supply is uninterrupted. If major gas pipelines do not have the ability to run electric-powered compressor stations using natural gas, this assumption might become invalid.

There are a number of other critical social services beyond the several we include in our model. Most hospitals, airports, and radio and television broadcasting stations already have independent systems for emergency backup power.[17] Although a number of other larger critical loads, such as water and sewage treatment plants, or lighting and ventilation in traffic tunnels, often do not have backup, they too are probably best served with their own dedicated standby emergency generators, especially if they are remotely located. Some small, distributed loads, such as traffic signals, are better handled with solar photovoltaic (PV) trickle charged battery backup.[18] Elevators in high-rise buildings might best be served with hybrid backup systems that use some battery or small generator backup as well as some emergency power supplied via a distribution feeder. Indeed, in many regions, building codes now require limited backup for such purposes in new construction.

2.1 Operation in an Extended Blackout

In the event of an extended outage, events might unfold as follows:

(1) The local utility realizes that the outage will continue for an extended period.
(2) Smart meters on all relevant feeders are instructed to disconnect (without this feature it would be necessary to send crews to every load on every feeder to manually disconnect).
(3) One or a few feeders with distributed units are manually or automatically islanded.
(4) DG units on these feeders are connected sequentially to the islanded system to ensure that they are properly synchronized.
(5) Following a previously defined schedule, meters at a select few critical loads are instructed to reconnect, whereas service to all other loads remains disconnected.
(6) Through the course of the outage, based on dynamic needs for power among different critical services, different loads are cycled on and off.
(7) Once the extended blackout ends, all meters are once again instructed to disconnect before the islanded feeders are returned to their original configuration and reconnected to the grid, and normal repowering proceeds.

In an emergency some degradation of services should be expected, so it should be sufficient to keep just a large enough fraction of services operational to ensure the safety and well-being of those affected. We assume in what follows that in addition to creating the technical capability to serve a subset of critical loads, contractual and other arrangements have been worked out between civic authorities and commercial entities so that there is prior agreement about who will be served and how costs and revenues will be shared.

For instance, fuel pump service and cashiers at two of four gas stations could be kept functional at staggered times. Perishables from grocery stores in the area could be transported to one centrally located store shortly after the outage occurs; refrigeration and essential lighting at this central store could be kept operational throughout the outage. A subset of cell towers in the area could be powered so that essential wireless communication could be sustained, and cell phones could be charged with solar or hand crank chargers.[1] Assuming that partial lighting is possible, a subset of the region's streetlights could be kept operational at night.

With classes operating in several shifts, one school could temporarily serve as an elementary, middle, and high school during different times of the day. One centrally located police station could run at full capacity during the night and at a lower level of functionality during the day.

For smaller loads like gas stations and cell towers, we set the critical fraction of total load equal to the total power needed to keep each of these services functional. For the larger loads such as schools, grocery stores, and police stations, we use the Energy Information Administration's Commercial Building Energy Consumption Survey data, which breaks down energy consumption by specific functions such as lighting, office equipment, etc., to estimate just the critical fractions of total load.[21] We assume that in the case of these loads, prior arrangements have been made to only power the subset of circuits in the facility that is needed to maintain basic service because otherwise the load would exceed available supply.

Table I describes the level to which each service is maintained during the outage and the accompanying management strategies needed to ensure that limited resources are used most effectively in the scenario we model. Fig. 1 shows graphical representations of electricity load profiles associated with the scenario presented in Table I. The total demand at each moment, D(t), is computed as the sum of individual demand at each of the loads at that time:

$$D(t) = \sum P_i(t), \text{ where } P_i(t) = \text{the load at the } i^{th} \text{ service at time } t,\ i \in \{1, \ldots, 6\}.$$

Under this scenario, the total demand is held constant at 350 kW except for the first few hours of the outage when we assume that some backup power is already available (e.g., batteries at cell towers), providing enough time to transition to the network of distributed resources.

3. COST ANALYSIS

Implementing the capability outlined above entails costs in two categories: (1) additional distribution system components, battery installations for existing metering equipment to ensure that they can turn on when instructed during the blackout, and control system upgrades associated with

[1] Hand crank chargers are preferable to solar chargers because they can be used during the night. A wide variety of hand crank cell phone chargers, flashlights, radios, and similar products are available.[19] In addition, solar chargers are now available at affordable prices.[20] Most wire-line telephones are powered from central stations, although increasingly handsets require external power.

Table I. Schedule of Critical Social Services Provided in the Example System

Service	Points of Service	Power Consumed	Management Strategy
Police stations	1	60 kW to support lighting, office equipment, and communications[21,22]	One station is powered; it runs at full capacity (60 kW) at night and at half capacity (30 kW) during the day.
Grocery stores	1	200 kW for essential lighting and refrigeration during the day, and 160 kW at night for reduced lighting and essential refrigeration[21,23]	Under previously agreed upon arrangements, during the first few hours of the outage, perishable foods in stores around the neighborhood are transported to one central store. This store is powered through the course of the entire outage.
Gas stations	4	5 kW per station for a few dispensers and basic lighting; 10 kW at a time for 2 stations powered at once[24]	Two of four previously designated stations are powered at any given time on an announced rotating schedule (∼10 kW).
Schools	1	70 kW for lighting, computers, and other office equipment[21,25,26]	One school is powered with three groups of students (elementary level, middle-school level, and high-school level) convening at staggered schedules. For instance, the high-school students meet from 7 AM to 10 AM, middle school students from 10 AM to 1 PM, and elementary school students from 1 PM to 4 PM.
Cell towers	10	5 kW per site for a fully loaded 3G site[27]	Most cell towers require no additional backup power in the first few hours of the outage as they have battery backup power. But after the first few hours, 10 towers are kept operational during the day, and 5 at night.
Streetlights	Variable number	250 W per streetlight[28]	A variable number of lights is kept functional during the course of the outage so that total demand does not exceed 350 kW at any time.

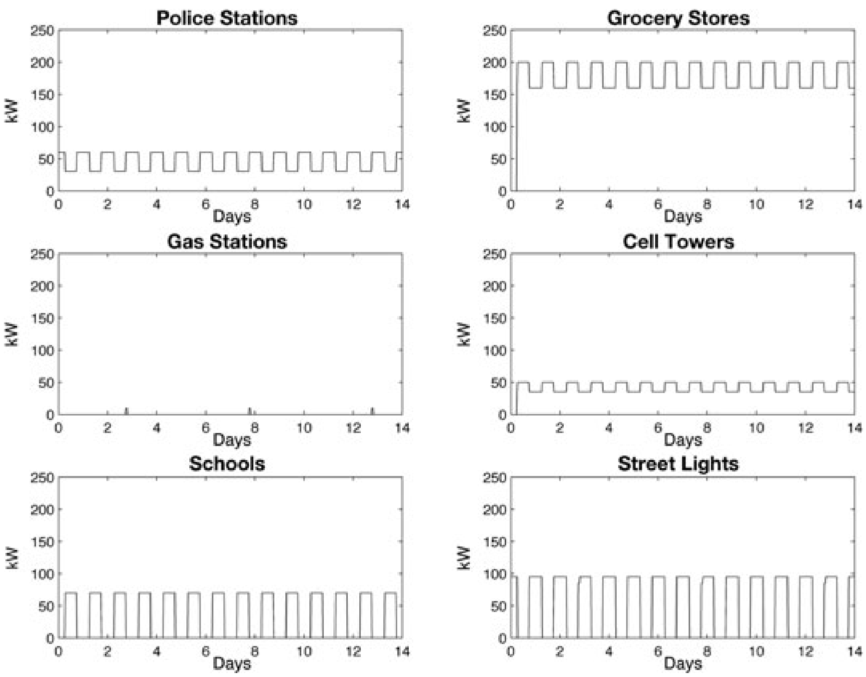

Fig. 1. Load profiles for the critical social services being served in the sample region reflect the dynamic power allocation strategies presented in Table I. The x-axis refers to the number of days after the outage occurs, and the y-axis refers to the electricity demand in kW. Peaks and valleys are a function of daytime (0700 to 1800 hours) versus nighttime.

operating the proposed system, and (2) DG resources if sufficient resources are not already in place to serve the selected group of socially critical services during a large, long-duration blackout. As already noted, we are only considering those costs that result from *additions* to distribution systems that already have a degree of automation and smart meters with auto-disconnect capability. The assumed level of distribution automation includes the ability to reconfigure feeders and the ability to island one or a set of feeders either manually or automatically as needed.

Additional distribution system components (Cost Category 1 from above) included in the model are low-power fault-handling equipment and necessary controls to operate that equipment. If one or a few feeders are to be disconnected from the main grid and operated as low-power islands during a blackout, existing fault-handling equipment will likely need to be augmented.[29] Two main components of fault-handling systems are reclosers and sectionalizers.[30] Automatic circuit reclosers are self-contained devices that can sense and interrupt faults, and repower the line by reclosing automatically. If a fault is permanent, a recloser stays open after a preset number of operations specified in a built-in counter.[30] Sectionalizers are circuit-opening devices used together with protective devices, such as reclosers and breakers, to automatically isolate faulted sections of electrical distribution systems.[30]

Also included in Cost Category 1 are battery installations for existing metering equipment, consisting primarily of smart meters and the control software needed to operate the meters. A "smart meter" is any of a set of different types of meters that can be used for two-way communication between the customer and the utility and sometimes even a third-party system.[31] Here we use the term "smart meter" to refer to an individually addressable meter that allows its associated load on a feeder to be connected or disconnected in response to signals from a central control system.

Estimates of the individual components of Cost Category 1 are summarized in the left-hand portion of Table II. Base values were chosen from component cost ranges quoted by a leading distribution automation equipment manufacturer.[32] Sectionalizer and recloser costs include solid dielectric vacuum interrupting components with electronic controls, pole mount frames, cables, internal voltage sensors on the source side, one radio and antenna per control, control programming software, four linemen, two trucks, and one technician for installation, programming, and testing.[32] The capital and installation cost associated with the additional control software includes two data concentrators for redundancy.[32] Here, control system costs refer just to the incremental cost of adding controls for smart-grid-style operation of the newly added low-power fault-handling equipment and the smart meters in the model. It is likely that if smart meters are present in a region, they already have some battery backup in place.[33] Even if this is not the case, labor costs for battery installation, as opposed to actual battery costs, are likely to comprise the largest fraction of total costs. For this reason, the capital and installation cost for smart meter backup are based on estimates for costs per person-hour for battery installation, and on the assumption that installing a smart meter battery takes one person-hour.

The right-hand portion of Table II reports total costs associated with the installation. Component numbers are based on the recommendation of engineers responsible for operating a major distribution system.[29] Fig. 2 presents a simplified diagram of both the normally operating transmission and distribution system (left) and the islanded distribution system serving critical social services (right).

In computing the cost of adding or securing access to DG units (Cost Category 2) we consider three scenarios: (1) the region has no available DG capacity; (2) the region has some capacity that can be applied to power critical social services, but the available amount is less than 350 kW; and (3) the region has 350 kW of capacity available that can be applied to power critical social services in the event of an extended blackout.

Scenario 1: We consider two DG sources, namely, a set of 35 10 kW combined heat and power (CHP) natural gas units of the type now being sold for home use in Germany by a consortium of Lichtblick and Volkswagen[34] (capital cost = \$740/kW; annual maintenance cost estimated to be \$160/unit,[29] after adjusting for inflation[35]), and a single 350 kW natural gas fired CHP unit whose cost is estimated by curve fitting to published EPA data[36] and adjusting for inflation[35] (capital cost = \$1970/kW; annual maintenance cost estimated to be \$160/unit as with the 10 kW engines). Because Scenario 1 assumes that the DG units are dedicated for use during a blackout, O&M costs

Table II. Estimates of *Incremental* Costs of Distribution System Components Required to Implement the Proposed System

Component	Capital & Installation per Unit	Annual O&M per Unit	Number in Model	Total Capital and Installation	Total Annual O&M
Low-power sectionalizers and associated control software	$30,000	$200	6	$180,000	$1,200
Low-power reclosers and associated control software	$30,000	$200	6	$180,000	$1,200
Additional software and controls at the substation for smart-grid-style operation of meters and low-power fault-handing equipment	$100,000	$5,000	1	$100,000	$5,000
Smart meter batteries	$40	$20[a]	17[b]	$680	$340
Total				**$460,680**	**$7,740**

[a]Assuming half a person-hour per year for maintaining one battery installation and $40/person-hour for maintenance costs.
[b]There are 17 individual loads being served in the model (1 school, 1 grocery store, 10 cell towers, 4 gas stations, and 1 police station) that require individually addressable meters. As clusters of streetlights are likely controlled from a single point, metering costs are not considered for street lighting.

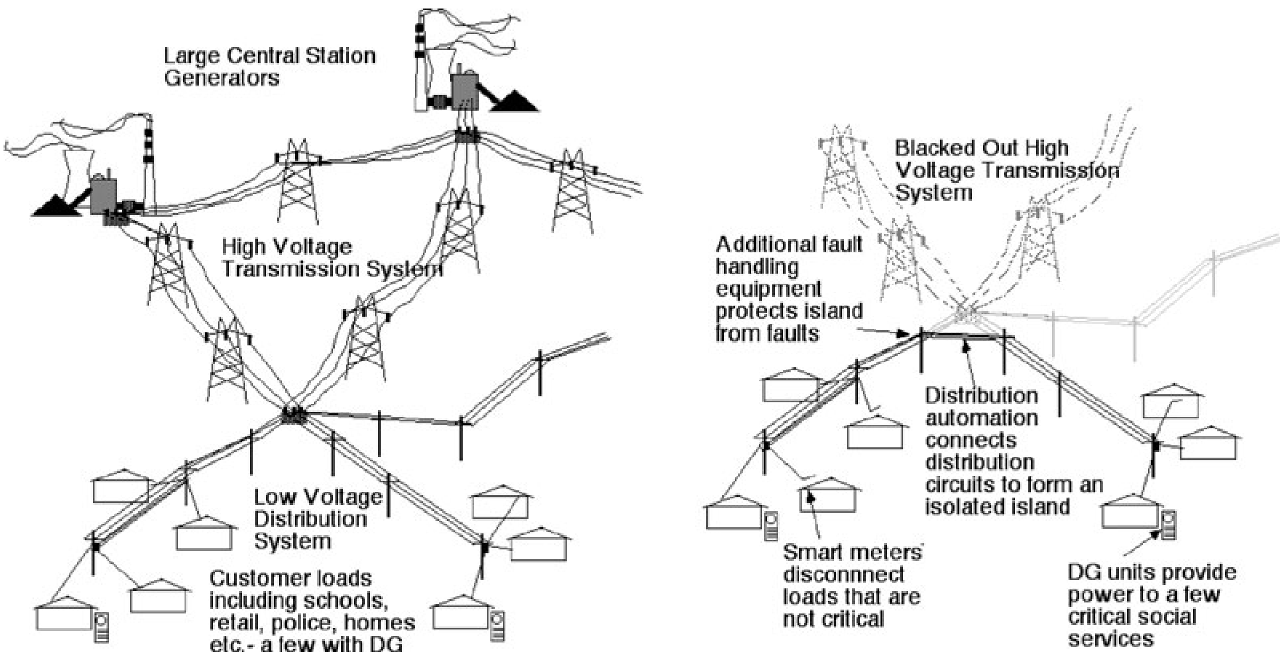

Fig. 2. Left–simplified illustration of the electric power transmission and distribution system under normal operation. Right–simplified illustration of the islanded distribution system during a large, long-duration blackout in which DG units serve local critical social services. Smart meters have disconnected loads that are not critical. Feeders have been reconfigured to form an isolated "island" using distribution automation and added low-power fault-handling equipment.

include only the cost of regular maintenance during the year. It is assumed that necessary fuel will be available for use through a previously negotiated fuel contract. Maintenance costs are dominated by personnel time and are based on two person-hours per visit, and two visits per year.

Scenario 2: Costs in this case include the incremental capital cost of installing enough additional DG to provide sufficient capacity to serve critical social services up to 350 kW as well as the cost of purchasing an option on capacity that is already available.

Again costs are computed for both the case of enough 10 kW Lichtblick/Volkswagen units, or for a single larger unit (again scaling costs from EPA data). The size of the annual fee (R) that must be paid to DG owners to purchase an option to use a portion of their existing capacity will of course depend on local circumstances. For simplicity, we estimate an upper bound on R:

$$R = P^{*} A^{*} C^{*} S, \text{ where}$$

P = The annual probability of a large, long-duration outage occurring.
A = The quantity of available resources in kW for which owners are willing to sell a use-option.
C = The cost per kW of building the same amount of capacity from scratch (again, we consider both 10 kW units and a large single unit) plus the annualized cost of maintenance.
S = A scaling factor ≥ 1 that accounts for the fact that DG owners may require more compensation than the expected value of the new resource before selling an option. The choice of S should be made such that the rent paid to DG owners is sufficiently attractive to induce participation while not being so high that building dedicated DG resources of necessary size proves to be more economical. We compute total system costs for $S = 2$.

Maintenance costs involved in keeping necessary DG resources in working order are estimated in the same way that they are for Scenario 1.

Scenario 3: In this case, sufficient capacity is available, and the cost is simply the fee (as calculated in Scenario 2) for purchasing the option to acquire 350 kW in the event of a blackout.

The total cost per customer, assuming 5,000 meters, can now be computed as the sum of the annualized incremental cost per customer of the additional distribution automation and protection equipment plus the cost of needed DG and option fees. The results are shown in Fig. 3 for annual outage probabilities of 0.0001, 0.001, and 0.01 for the two types of generation considered. The costs range from \$0.74/meter per month to \$1.80/meter per month. A 20-year project lifetime is assumed in annualizing costs. The computation is performed with real interest rates of 3% and 6% to examine the implication of securing the needed system upgrades and DG with public (3%) or private (6%) financing.

Whether it is worth making these investments depends upon the probability that such outages will occur and the cost incurred in the event of such an outage. The latter is extremely difficult to estimate. Most available estimates, such as those computed by EPRI, Lawrence Berkeley National Lab, and others,[37] of the costs of outages are based on lost revenue and earnings from business activity. In an extended outage, these values are less relevant than the value to customers of the provision of critical social services. Although the value of a few services might be estimated from consumer surplus, others such as the value of keeping children in school, retaining access to basic food, or maintaining basic policing and emergency communication capabilities are more difficult to estimate.

For this reason, estimates of the economic losses for past much briefer outages are, at best, useful only to obtain an order-of-magnitude indication. In its 1990 report, the Office of Technology Assessment estimated disruption costs of \$1–\$5/kWh for disruptions of relatively modest duration.[4] The blackout that struck the Midwest, the Northeast, and parts of Canada in August 2003 is estimated to have affected more than 50 million people and resulted in costs of between \$4.5 billion and \$8.2 billion.[38] North American Reliability Council data indicate that the amount of electrical energy not delivered during that blackout was approximately 920,000 MWh.[39] The last two numbers suggest that the economic cost of the 2003 blackout came to approximately \$5–\$9 per foregone kilowatt-hour or between \$90 and \$160 per capita. The much longer disruption that resulted from the 1998 Ontario ice storm blacked out power to 1,673,000 customers in Quebec, and is reported to have resulted in economic losses of \$1.6 billion.[40] This comes to losses of just under \$1,000 per capita.

One could conduct a survey that asked people's willingness to pay to avoid the loss of critical social services in the event of an extended blackout. However, although some more sophisticated commercial customers have performed quantitative analyses of the costs of a power outage on business operations, without experiencing an extended outage there is little reason to believe that residential customers could provide an informed, quantitative answer to such a question, even if they generally understand some of the consequences of an extended blackout.[41]

Any such estimate will be limited by available income. Let us assume a median income of \$50,000

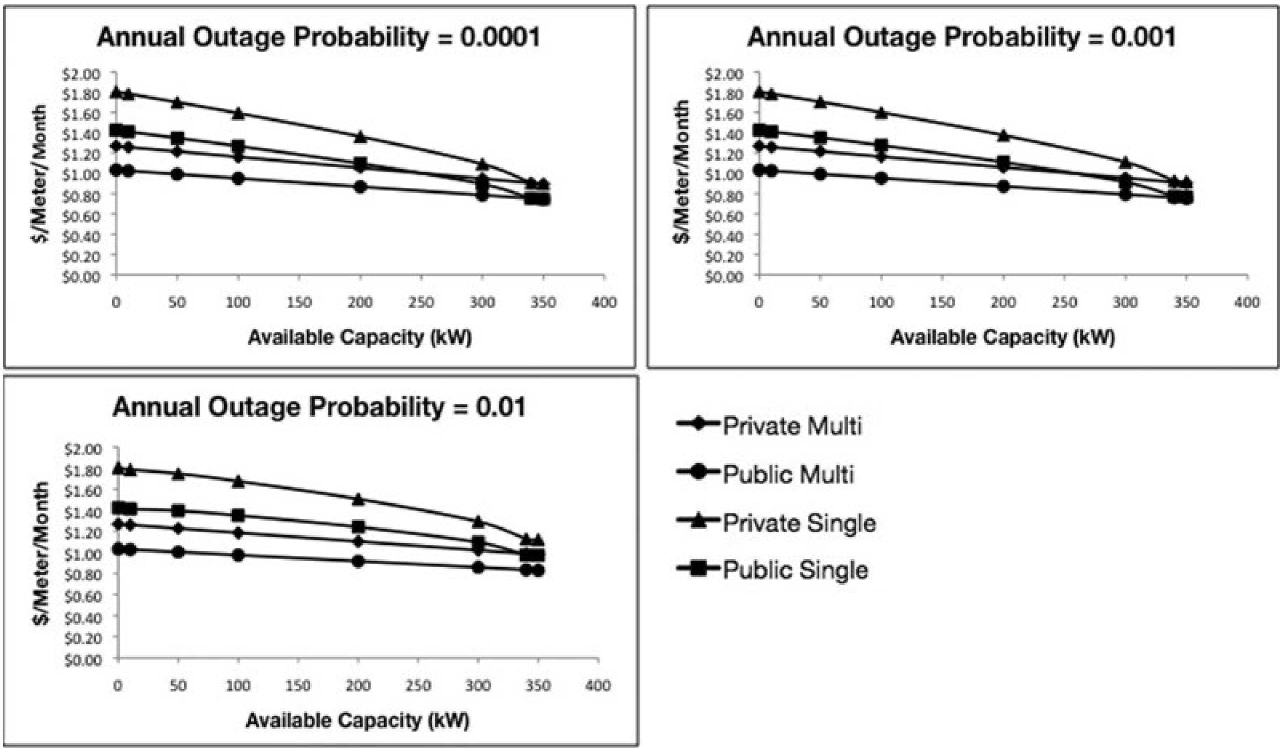

Fig. 3. Cost (in 2010 dollars) per meter per month as a function of available capacity in the region of installing sufficient capacity to ensure that 350 kW is available for emergencies for the two DG configurations (single unit, multiple unit) and two financing options (public, private) considered for each of three annual outage probabilities assumed (0.0001, 0.001, 0.01). Here, "Public Multi" refers to the public financing option for the multiple unit configuration, "Private Single" refers to the private financing option for the single unit configuration, and so on. Note that the costs do not vary significantly between the $p = 0.0001$ and $p = 0.001$ cases because annual outage probabilities only affect R (the annual fee paid to DG owners for use of their resources) in each case, with the capital cost of newly installed DG resources constituting the bulk of total cost

per household[42] for our model community. It is then reasonable to assume that an expenditure of between $500 and $2,000, that is, 1–4% of annual household income, to sustain critical services is a reasonable range to consider.

The costs for the system we have outlined range from $9 to $22 per year per household, for annual outage probabilities of 0.01, 0.001, and 0.0001 for the different scenarios and DG configurations assumed. Even the upper-bound estimate of $22 per year per household comprises less than 1% of median annual household income, making the proposed strategy seem worthwhile. The percentage of annual income that a household is willing to contribute to the cause of sustaining critical services during blackouts could be expected to rise after a surge in terrorist activity, or in the face of evidence that climate change was giving rise to more frequent major ice storms.

3.1. Costs Not in the Model

If a region wanted to make its critical social services truly robust in the face of extended blackouts there are several other investments it should make in addition to the distribution-system modifications that we have modeled. At a minimum, these include backup power for water and sewage treatment, some limited backup power for traffic signals on key traffic routes, and backup power at the local jail. As noted above, in very hot or cold regions, arrangements would also be needed to provide warmed or cooled shelter space.

A typical water treatment and distribution system includes the following processes: collection from a source, treatment at a water treatment plant, and distribution to end-users.[43] We can estimate just the amount of backup generation capacity needed in the model region to ensure that all 5,000 households have access to clean water during an extended blackout.

Water consumption per household is around 350 gallons per day.[44] Depending on the topography of the land, the volume of water treated, and the distances involved in distribution, the energy intensity of the different processes varies.[43] Assuming an energy intensity of 1.5 kW/1000 gallons for the water use cycle[43] yields an estimate of about 37 MWh of energy, or 109 kW of power needed to provide clean water to 5,000 households over the course of a 2-week outage, assuming 24-hour per day operation. This estimate should serve as an upper bound because it is reasonable to assume that people will consume water frugally during an extended blackout if there are city or region-wide ordinances providing specific ways in which water use can be reduced during emergencies.[45]

Often, electric pumps are used to supply water to the upper stories of high-rise buildings, but the power consumed by such pumps would be small.[2] Further, the burden of ensuring that there is sufficient backup power within buildings should fall on building owners.

Similar to water treatment and distribution, different wastewater treatment and conveyance systems consume varying amounts of power. Assuming an energy intensity of 2.5 kW/1000 gallons for treating and appropriately recycling or discharging wastewater, and assuming that water consumed is roughly equal to the wastewater produced (i.e., 350 gallons of wastewater produced per household per day), the amount of backup power needed to handle wastewater from 5,000 households during an extended power outage would be about 180 kW.[43,44]

For both systems, fuel supply and delivery with trucks for diesel and functional pipelines for natural gas are key factors for operation. Often, cities or private entities sign priority contracts with fuel suppliers to ensure that necessary fuel is available in the event of an emergency.[46]

Traffic lights were excluded from the model system because we believe they are best handled in a distributed way. Scaling from the city of Pittsburgh we estimate 20–25 intersections with traffic lights in the model region.[47] Assuming signals are converted to LED, and assuming PV trickle charge batteries are installed at each signal for backup power, the cost of upgrading one traffic signal would be around $9,000,[48] making the total cost of upgrading all signals in the model region around $225,000.

Finally, sufficient backup power should be made available at a city or county jail in the region. Jails vary greatly both in capacity and in energy consumption, the latter varying as a function of the extent to which facilities have been modernized to include renewable energy sources and intelligent resource management. As an example, the Santa Rita Jail of Alameda County, CA, has a peak electricity demand of around 3 MW and a capacity of 4,500 inmates.[49] The facility has a 1.2 MW PV system in addition to a relatively large (1–2 MW) battery installed onsite. Some correctional facilities such as the Worcester County Jail in Massachusetts are implementing small-scale wind generation to meet the energy demands of the facility as well as to provide power to neighboring loads by selling electricity back to the grid.[50] However, without onsite storage, a wind facility alone would not solve reliably the backup problem under our scenario.

4. CONCLUSIONS AND POLICY ISSUES

The cost analysis above suggests that at least a few regions might find it reasonable to invest in a system of the type we have outlined to secure critical social services in the event of a large, long-duration outage that occurs in a temperate season of the year. Clearly, no electric utility will make these investments on its own. However, if a public utility commission (PUC) concluded that installing such capabilities constituted a prudent investment, then in regulated distribution companies nondepreciated capital costs and operation costs could be recovered through the rate base with the approval of the regulator. Alternatively, local, county, or state government might choose to fund the project with tax revenue, contracting with the local distribution utility and other parties to implement the changes.

In states such as Pennsylvania that incentivize DG with CHP, the enabling legislation could be modified to incentivize DG owners to install additional capacity that they would contract to share during emergencies. The Pennsylvania Alternative Energy Portfolio Standards Act allows net metering[2] for private owners of 3–5 MW generators on the condition that they serve the primary or secondary purpose of maintaining critical infrastructure. Owners of units that are smaller than 3 MW can participate in net metering irrespective of whether they share

[2] The Energy Policy Act of 2005 defines net metering as "service to an electric consumer under which electric energy generated by that electric consumer from an eligible onsite generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period." [51]

any of their electricity with critical infrastructures in times of need.[52] The law could be amended to allow participation in net metering only if owners of units smaller than 3 MW also agree to share power during emergencies. A DG owner for whom net metering is sufficiently beneficial[53] might agree to bear the entire cost of installing necessary distribution automation equipment.

If a region does choose to invest in a system of the type we have outlined, then it will face the task of negotiating a set of contractual and other agreements with private firms such as gas stations and food stores, as well as service providers such as police and school systems, to determine which will be powered in an emergency. These agreements should specify how cost and revenues are allocated.

If upgrades are not geographically widespread, then in the event of a major disruption, regions that have secured their social services could find themselves inundated by people from neighboring regions to use services during blackouts. This potential predicament argues for implementation at a state level, or perhaps even national level, with support from the Department of Homeland Security.

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