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Resource Adequacy Assessment from the Ground Up

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Abstract

In response to the expanding role of wind, solar, and storage, increasing demand flexibility, and a changing climate, new analytical methods and metrics to assess resource adequacy are needed. A focus has been on identifying ways to reduce risks of failure. Less attention has been directed to how new analytical approaches can inform the design of planning processes, regulatory standards, and markets. Using mixed methods and a community-engaged approach, data on community preferences and uneven distributions of impacts are used in a demonstration of a coupled socio-technical systems model that has been validated in diverse settings. The research is informed by the physical and institutional infrastructures in the Railbelt power grid of Alaska. The findings illustrate how new analytical tools can inform institutional design and facilitate more affordable, sustainable, and equitable outcomes.

Keywords: resource adequacy, equity, socio-technical modeling, uncertainty, energy transition

1. Introduction

Although most power outages are caused by disruptions in the distribution system, the recent large-scale outages in the Western and Southeastern regions of the U.S. and declared energy emergencies in the Northeast were linked to inadequate power supply and have been characterized as failures in resource adequacy planning (DiGangi, 2023; Hering & Stanfield, 2020; North American Electric Reliability Corporation, 2022). These outages demonstrate the significant and disparate economic and social impacts of failures in resource adequacy assessment and planning (Carvallo et al., 2021) and a fundamental knowledge gap in how to make decisions about generation and transmission infrastructure deployment in a changing climate and as the grid decarbonizes.

Grid reliability is composed of several interrelated dimensions including voltage and frequency stability, operational flexibility, and adequacy of resources and reserves, as well as the ability to withstand or recover from equipment failures, extreme weather, or human-caused disruptions. In the context of grid reliability, the term ‘resources’ refers to technologies or actors – supply, transmission, storage, and demand – that can maintain the supply-demand balance for electricity. The ability of an electric power system to meet demands for electricity using its supply-side and demand-side resources is known as resource adequacy (RA) (NERC, 2011). The conventional approach to RA assessment is a highly utility-centric process developed for an era in which the primary resources were large-scale thermal power plants. This approach is no longer viable with contemporary technology, more variable and extreme weather, and governance arrangements that have more polycentric characteristics (Electric Power Research Institute, 2021; ESIG, 2021; Robertson et al., 2023).

Overall, there is a critical need for new data, methods, and metrics that can characterize the evolving economic, sustainability, and fairness implications of reliability risk decisions in ways that are transparent and accountable. Industry actors are increasingly recognizing this need and developing new RA metrics (ESIG, 2021). Less attention has been directed to how new analytical approaches can inform the design of planning processes, regulatory standards, and markets. Such efforts will necessarily take place within the complicated institutional and jurisdictional structures in the U.S. power grid. These polycentric governance arrangements have multiple centers of decision-making authority with overlapping roles and levels of autonomy (Carlisle & Gruby, 2019).

This paper demonstrates how exploratory analysis and a novel modeling approach can be integrated into RA assessment to provide more transparency; illuminate linkages between reliability, affordability, and sustainability; and better inform policy decisions that influence resource procurement and investment. The research utilizes a coupled socio-technical systems model that has been validated in diverse settings (Carreras et al., 2004; Ian Dobson et al., 2007; Reynolds-Barredo et al., 2020) and is informed by the physical and institutional infrastructures in the Railbelt power grid of Alaska, a system where power reliability, affordability, and sustainability are at the forefront of policy agendas. The research presented here provides an illustrative example of how an

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existing inequity in reliability outcomes could be assessed in a multi-attribute optimization and the tradeoffs associated with efforts to rectify the inequity. The findings draw attention to the need for RA frameworks that integrate 1) heterogeneous preferences and differentiated spatial impacts; 2) optimization of transmission and grid resources using multi-attribute models with time evolution; and 3) metrics that examine event-specific shortfalls and preferences under uncertainty in order to inform institutional design and decision-making processes embedded in diverse regulatory contexts. Section II describes the use of RA assessments and the need for innovation. Section III describes the methods and model used to simulate resource and transmission assessment with a test system. Section IV provides evidence of heterogeneous community preferences and spatially differentiated impacts, describes an exploratory approach in support of multi-stakeholder governance designs, and provides test model results. Section V provides our discussion and conclusions.

2. Literature Review

Resource adequacy is a critical dimension of grid reliability focused on ensuring enough resources are being built and procured to meet demand. New technologies and a changing climate present RA challenges for utilities and regional transmission grid operators (collectively referred to in this paper as grid planners), as well as for local, state, and federal regulators and policymakers. The shift to more variable and time-limited resources, including wind, solar, hydroelectric, storage, and demand management, means reliability risks are no longer limited to the peak hour of load. A wider range of resource characteristics must be considered in RA assessment along with attention to changes in aggregate load shapes. In addition, the anticipated increase in climate variability and more frequent extreme weather events mean new analytical approaches will be needed to consider nonstationarity, correlated failures, and low-frequency, high-impact events. Across the world, these challenges are driving the reevaluation of RA assessment methods with important related adjustments needed in the development of reliability standards, resource planning approaches, and market designs.

Utilities have long used RA assessments to make investment decisions and coordinate reliability across balancing authorities (National Association of Regulatory Utility Commissioners, 2021). These assessments identify whether existing resources are sufficient for forecasted demand, and they originated to balance the cost of additional generation capacity with the likelihood of capacity shortfalls. The traditional approach to RA is based on: estimating future single peak electricity demand over long periods (for example on an annual or seasonal basis), comparing this load estimate to available resources, calculating the percentage by which installed capacity exceeds peak demand (i.e., a planning reserve margin), and assessing the likelihood of failing to meet peak demand. In the United States, the planning reserve margin is a common metric used to cover uncertainty, and the loss of load expectation (LOLE) is a common metric used as a threshold of acceptable reliability risk.

Today, RA assessment is a central component of regulatory processes used to evaluate resource procurement and enforce reliability standards within a complex patchwork of overlapping authority and significant regional variations. In the 1980s, many state legislatures and regulatory commissions embedded RA assessments in required integrated resource planning (IRPs). This was a step towards open public participation and consideration of non-economic issues such as environmental degradation (Hirsch, 1999). When industry restructuring was introduced in the late 1990s, RA assessment became important in regional transmission organization (RTO) market design and continued to be part of the state IRPs that persist, with continued or modified use in as many as 40 states (Robertson et al., 2023).

In 2005, the Energy Policy Act authorized the Federal Energy Regulatory Commission (FERC) to oversee and approve mandatory and enforceable reliability standards. To enact these provisions, the industry organization that had been developing voluntary reliability guidelines became an electric reliability organization (ERO) and is now comprised of the North American Electric Reliability Corporation (NERC) and six regional entities (Nevius, 2020). This brought greater attention to RA assessment and the “one day in ten years” outage target is used to translate the LOLE into an enforceable standard (NERC, 2011).

Embedded in these highly technical planning and reliability regulations are collective decisions about acceptable risks that are critical to community outcomes like affordability, air quality, health, and economic development. Yet, RA assessments, IRP, and reliability regulation are still largely undertaken using approaches designed for hierarchical institutional relationships involving the electric utility, the government regulator, well-understood technologies, and an engineering risk paradigm shaped by the uniform treatment of heterogeneous customer reliability preferences and the modeling of reliability as exogenous and static (Ovaere et al., 2019; Stenclik et al., 2021). Traditional metrics, such as LOLE, focus on a single dimension of shortfalls and lack spatial resolution. As a result, policy decisions are often made with limited information about how to balance competing objectives for resource costs, fairness, and reliability risks across spatial and social settings. Moreover, decisions about resource adequacy often fail to consider how they can complement and support clean energy and environmental policies. Adjusting traditional RA assessment practices to balance competing objectives, identify complementarities, and represent uncertain events will require reconfiguration of existing institutional arrangements and processes for resource planning and reliability regulation.

3. Methods and Model

This paper uses an interdisciplinary approach that develops a framework to improve the reliability of the electricity grid by integrating social, engineering, and institutional dimensions to assess the adequacy of power-grid resources (Fig. 1).

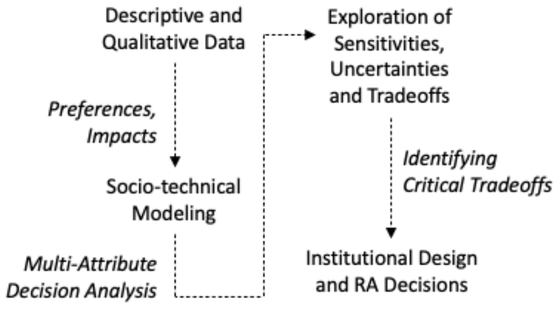

Figure 1. Research design

3.1. Descriptive and Qualitative Data

A qualitative research approach was used to engage with local collaborators on the Railbelt Reliability Council (RRC) to better understand the diversity of community preferences, identify salient uncertainties related to RA, and observe the emerging institutional design choices and rules structuring governance arrangements. The Railbelt interconnection links Fairbanks, Anchorage, and the Kenai Peninsula and the five utilities serving approximately 75% of the Alaskan population (Dunleavy & Tansy, 2023; Regulatory Commission of Alaska, 2021). In 2020, the Alaska Legislature passed SB 123 mandating the creation of a regional electric reliability organization (ERO) to develop and administer an IRP, enforceable reliability standards, and transmission interconnection and cost recovery procedures. The IRP must evaluate a full range of cost-effective means to serve all customers, including generation, transmission, storage, and conservation or efficiency and it is required to "meet customers' collective needs in a manner that provides the *greatest value*, consistent with the public interest…" (*Sec. 42.05.780(a)* [emphasis added] (Electric Reliability Organizations, 2020). The RRC was certificated as the ERO in September of 2022, and a 15-member stakeholder board was seated within a governance structure intended to balance interests (Railbelt Reliability Council, n.d.).

The field research included a workshop, a review of existing documents, participating in publicly open meetings, and semi-structured interviews. Researchers organized a workshop with RRC stakeholders in Anchorage, Alaska. The three-hour workshop included 19 in-person and 4 online participants. We observed 4 meetings totaling 10 hours. We examined documents related to the history, governance structure, previous planning efforts, legislative and regulatory frameworks, and meeting agendas. We conducted 15 interviews with current and former RRC board members, and other key stakeholders affiliated with the process. Purposive sampling was used to select key informants from all nine of the stakeholder classes on the RRC board. Interviews were conducted in person or online through a video communication platform. The interviews were typically 30 - 50 minutes and resulted in 156 pages of single-spaced transcripts. The interviews were semi-structured with questions about planning processes and decision-making. The qualitative data analysis included recording analytic reflections and coding informed by the research design and existing literature to identify recurring concepts while also interpreting and synthesizing new ideas. The secondary review included identifying important themes and further nuance in the data.

Descriptive data were collected to gain a comprehensive understanding of the distributions of impacts and regional heterogeneity in the Railbelt Grid service areas. The U.S. Energy Atlas mapping application was used to determine which census-designated places should be included. Then, the census tracts were divided into four service areas according to geographic area and utility provider. Next, the researchers collected statistics describing the distribution of impacts, including metrics on energy cost, air pollution, population loss, and economic development in the selected areas. All data were collected from official government sources. The qualitative and descriptive data were used to inform the exploration in the test model and decision analysis.

3.2. Socio-technical Modeling

To demonstrate how a socio-technical coupled modeling approach for RA assessment can incorporate heterogeneous preferences along with the integration of generation and transmission planning, this work uses the ORNL-PSerc-Alaska (OPA) model (Carreras et al., 2004; Ian Dobson et al., 2007). This is a multi-attribute optimization expansion model with time evolution and combinations of weighted objective functions. This view of a power transmission system considers the engineering and physical aspects of the power system, and also the engineering, economic, regulatory, and political responses to blackouts and increases in power demand. Comprehensive inclusion of all these dynamics in a single model would be extremely complicated if not intractable. However, it is useful to consider simplified models to gain some understanding of the complex dynamics in such a framework and the consequences for power system planning and operation. This is the basis for OPA. In this paper, OPA is used to explore possible techniques for adjusting spatially differentiated reliability risks or other burdens using a local objective function.

The OPA model demonstrates how slow opposing forces of load growth and network upgrades can self-organize the power system to a dynamic equilibrium. Blackouts are modeled by overloads and outages of lines determined using a Linear Programming (LP) dispatch of a DC load flow model. This model displays complex dynamical behavior (Carreras et al., 2004; Dobson et al., 2007; Newman et al., 2011) consistent with that found in NERC data (Hines et al., 2009). The various opposing forces in power transmission systems interact in a highly nonlinear manner and may cause a self-organization process to be ultimately responsible for the regulation of the system. OPA computes long-term reliability taking into account these complex systems dynamics and feedbacks; that is, OPA is run until it converges to a complex systems steady state with stationary statistics and long time correlations. Because of the time correlations intrinsic to such a system, these simulations are different from more common Monte Carlo methods for generating statistics. In the case of OPA, we run the simulation for longer times to generate better statistics, thereby sampling more of the allowed system states with the probabilities of sampling a given state being generated by the system itself. This allows us to easily investigate the impact of different levels of inhomogeneity on risk and dynamics as well as other network characteristics. OPA has been validated against real data (Carreras et al., 2013) making it ideal for this type of study. OPA results are used for the computational analysis.

Our analysis uses two different test grids. Both are made by linking 200-node subnetworks, referred to as zones or regions. Each zone is connected to each of its neighbors with on average three lines. The first test grid links four zones in a loop (Fig. 2) and the second links six zones in a linear pattern (Fig. 3).

These are artificial power networks with realistic parameters constructed by following the algorithms of (Wang et al., 2010, 2008). The figures should not be taken as a geographical representation and the length of the lines connecting the zones is really a normal length line. Three of the zones will be kept as standard 200-node networks, the zone shown in red is a zone that is disadvantaged and will be modified in different ways to study the impact of the changes on both that zone and the other zones. In the looped grid, Zone 4 (the red zone) is a disadvantaged zone with Zones 1 and 3 being the zones directly linked to Zone 4. In the linear grid, Zone 6 (the red zone) is the disadvantaged zone and is directly linked only to Zone 5.

Part of the utility of a model like OPA for performing RA analysis in a polycentric decision context is that it captures the frequency and magnitude of the largest blackout events and is relevant to thinking about extreme weather events. It also includes multi-attribute optimization and an ability to differentiate spatially. These capabilities may be of particular interest in decision-making contexts in which stakeholders have different preferences or disagree about how uncertainty should be represented.

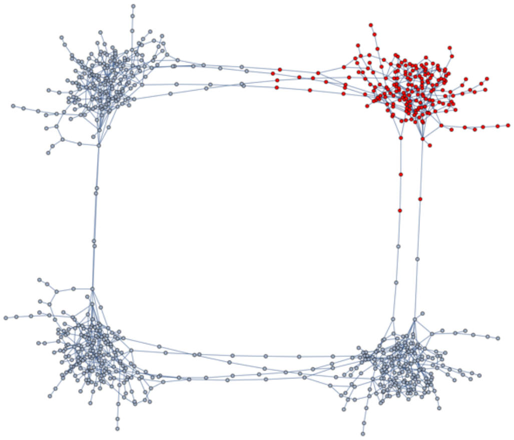

Figure 2. Loop test grid

Figure 3. Linear test grid

The model also provides a relatively stronger integration between generation and transmission expansion modeling, which can be important for systems that are stability-limited or are anticipating integration of high levels of inverter-based resources.

3.3. Sensitivities, Uncertainties, and Tradeoffs

Traditional RA assessment approaches are based on implicit agreement around analytical objectives and procedures grounded in achieving high reliability (i.e., no more than one outage in ten years) at the least cost. As more areas adopt governance arrangements that are more polycentric in nature, actors involved in RA assessments have fundamental differences about process in addition to results. Decision making is hard when stakeholders do not know how to represent important uncertainties or do not agree on how uncertainty should be represented, how outcomes should be measured, or the kinds of objectives that should be reflected in the decision. For example, stakeholders may disagree on the rate of demand growth or the availability, reliability, and cost of various power generation technologies. They may also disagree on the metrics that should be used to judge whether the RA assessment yields a satisfactory plan. Amid this kind of *deep uncertainty* (Haasnoot et al., 2013; Morris et al., 2018; Quinn et al., 2017) exploratory analysis can be helpful in communicating tradeoffs between metrics, objectives, or other decision factors. It can also help show how outcomes may be more or less sensitive to different decision factors or weights.

With heterogeneous preferences, uncertainty in key planning inputs, and the evolving power grid, RA assessment, IRPs, reliability standard formulation, and the design of decision-making processes need to move beyond the traditional decision criteria of minimizing cost to achieve a target LOLE. As more non-utility stakeholders have a role in RA assessment, planning, and decision processes, these additional criteria could include environmental concerns, climate, equity (in terms of outages or in terms of cost burden), sustainability, resilience, and affordability. Traditional RA analysis is also very scenario-driven. The system is planned to achieve the LOLE performance target under a defined scenario. With a larger number of factors that could contribute to resource inadequacy, especially with high penetration of weather-dependent renewable generation and changes in temporal demand patterns, a more temporal and spatially granular RA analysis approach is needed. Exploratory analysis with scenarios and sensitivity analyses informed by collective decision-making processes and established policies can highlight tradeoffs and improve RA decisions.

4. Demonstration: Economic Engineering to Improve Equity

This section provides an illustrative application of these approaches in a particular context.

4.1. Preferences and Distribution of Impacts

The qualitative analysis identifies heterogeneous preferences across spatial and social settings of the Railbelt grid, a number of uncertainties, and an uneven distribution of impacts. The Railbelt cooperatives vary in their efforts and mechanisms to understand community preferences. Some conduct member surveys and listening sessions, others have regular communication with specific engaged members, and others have had board elections that are driving new directions. Alongside these efforts, some customers express concern about a lack of communication and lack of transparency.

Customer/member preferences differ across user types. From a utility perspective, residential members are supportive of low-carbon resources but are primarily concerned with affordability, whereas, large industrial users are seeking both lower-carbon and more affordable resources. In contrast, military installations have a policy priority to advance low-carbon power and are developing self-supply options to ensure reliable and resilient power. The civil society organizations active in the Railbelt support different priorities for power planning ranging from affordability, diversity of resources, renewable generation, local ownership and control of resources, and opposition to large-scale hydroelectric development. In addition, several stakeholder groups raised concerns about how resource planning and investment will affect economic development opportunities, existing businesses, and retention of residents within communities. The interviewed stakeholders connect this preference to providing affordable and reliable service, as well as, decarbonization and expansion of independent power production. Not surprisingly, the RRC stakeholders are seeking a wide range of values from the grid and value more than one attribute. Cutting across all stakeholder perspectives is the recognition of a need to balance different preferences rather than only seek reliability at the lowest cost, but no clear understanding of what mechanism to use.

Another theme from the qualitative analysis is a broad understanding that the system is transmission-constrained with important differences across subregions in access to resources and sensitivity to weather. At least one stakeholder explained this as related to the challenge of financing transmission, stating that in the past when the utilities have done individual planning the conclusion has been, "…the answer was always really obvious…everyone builds their own generation assets" (Respondent 12). Others pointed to deficiencies in the process for wheeling power and lack of economic dispatch. The limitations of the existing grid are not only a constraint on regional exchanges but are seen as limiting the potential integration variable renewables. One utility stakeholder suggested that renewables have been integrated more easily in other regions because "…you have this infinite grid. We're literally on an extension cord [in Alaska] …" (Respondent, 22). Importantly, the grid is perceived as having high reliability, but as one stakeholder explained "We don't know what the outer limits of our system are" (Respondent 16). This has made each region dependent on local assets and has made it difficult to understand how new resources will affect reliability. Finally, despite a sense of urgency, many stakeholders expressed a willingness to rely on the process and optimism that the process will generate trust and credible results.

In addition to providing insights into heterogeneous preferences, the qualitative data identified a number of deep uncertainties associated with risk management and IRP approaches, including 1) how to understand the tradeoffs between investing in transmission versus local generation, 2) the forecasting uncertainties because "both your demand and your supply side are in upheaval," 3) the tradeoffs associated with a 99.99% reliability target, 4) the potential for new clean energy regulations and government investment, 5) the impact of potential military-adjacent community resiliency efforts, and 6) the pathways for industrial development or a robust green energy hub in Alaska.

The Railbelt Grid can be divided into four service areas: Greater Anchorage (Anchorage Municipality), Greater Fairbanks (Fairbanks North Star, Denali Boroughs, and Census Tract 4 of the Southeast Fairbanks Census Area), Kenai Peninsula (Kenai Peninsula Borough) and Mat-Su Valley (Matanuska-Susitna Borough) (Table 1). These regions face an uneven distribution of impacts, with disparities in energy costs, population growth rates, air pollution, and economic development. The Greater Anchorage area includes the largest population and the lowest energy burdens (7.49%) for low-income households. Comparatively, the Kenai Peninsula has the highest energy burden (12.29%) and the highest share of the American Indian/Native Alaskan population (10.93%) among the Railbelt regions. The Mat-Su Valley has a relatively high energy burden (11.25%), a high share of residential load (59.66%), and is often considered the State's fastest-growing region, having experienced the greatest annual population growth rate (1.84%). The Fairbanks area experienced population loss, has the highest share of industrial load (65.70%), and faces the highest levels of air pollution. Fairbanks is considered to be in nonattainment under the Clean Air Act for its PM2.5 levels and elevated levels of SO2 from coal and oil-fired energy generating units are significant contributors to the PM2.5 levels (U.S. Environmental Protection Agency, 2023).

In summary, the Railbelt Grid encompasses stakeholders with diverse preferences, many uncertainties, and an uneven distribution of impacts. Moreover, the limits to the physical architecture of the grid necessitate a focus on the location of assets, level of decentralization, transmission, and stability. RRC stakeholders are recognizing a diverse set of preferences and in fulfilling the charge to develop a regional IRP are considering how to balance multiple preferences in a region with different burdens and risks and in a context with many uncertainties. This case demonstrates the potential benefits of RA assessment approaches that include multi-attribute optimization, integration of generation and transmission, and tools to evaluate uncertainty.

Table 1. Distribution of Impacts

Railbelt Service Area[1]	Avg. of American Indian/ Native Alaskan (% pop.)	Energy Burden for Low-Income HH[2]	Daily Density of PM2.5[3]	Annual Pop. Growth Rate 2010-2020	Res. Share of Total Sales (%)[4]	Ind. Share of Total Sales (%)[4]
Greater Anchorage	8.39%	7.49%	5.90	-0.02%	31.91%	3.06%
Greater Fairbanks	7.88%	9.21%	12.30	-0.25%	24.30%	65.70%
Kenai Peninsula	10.93%	12.29%		0.60%	38.21%	26.41%
Mat-Su Valley	4.25%	11.25%	4.70	1.84%	59.66%	0.00%
Grand Total	**7.77%**	**9.11%**	**6.95**	**0.37%**	**36.56%**	**17.34%**

1. Census Tract 2 and 4 of the Yukon-Koyukuk Census Area and Census Tract 1 of Southeast Fairbanks Census Area were excluded. These census tracts were determined to not have a significant enough share of the population served by a Railbelt utility.
2. Low-Income Households were determined as 60% or less of the area median income. Energy burden is defined as the percentage of gross household income spent on energy costs.
3. Measured in (μg/m3). The State of Alaska does not monitor air quality at the Kenai Peninsula Borough, Denali Borough and the Southeast Fairbanks Census Area as part of their State Implementation Plan to fulfill their requirements of the Clean Air Act. The EPA website mentions that placement of monitors is determined by the states in areas of higher pollutant concentration and/or higher population.
4. Data on Residential and Industrial electricity sales was available only by balancing authority. This data was assigned to each Railbelt service area according to the main utility service provider in each county.

Sources: Alaska Department of Labor and Workforce Development, 2023; National Environmental Public Health Tracking, 2023; U.S. Census Bureau, n.d.; U.S. Department of Energy, n.d.; U.S. Energy Information Administration, 2021

4.2. Equity Factor: Mechanism for Control

As illustrated in the case presented in Section 4.1, different physical regions (locations) have different relationships with the electric power system. Subregions of the grid often have differences in income, energy burden, air pollution, or different types of consumers (industrial vs. residential for example), or different community energy preferences (desire for more sustainable or decarbonized power). Here we explore how to better understand the inequity between zones due to any number of these regional differences and we look at ways of decreasing this inequity. We use OPA as a tool and build simple test networks to represent different situations. The basic approach is to examine a test grid that has inequity across zones. One approach to improve equity between the zones is to modify the objective function being minimized in the LP dispatch. For example, in a grid with differences in reliability across the zones, varying the penalty costs for unserved energy (e.g., in the model specifications the load shed) in the disadvantaged zones we can get better parity between the risk of the blackouts across the zones of the power grid. Next, we consider the objective function and the network used in the calculations.

As described in Section 3.2, the OPA model for a fixed network configuration represents transmission lines, loads, and generators with the usual DC load flow approximation using linearized real power flows with no losses and uniform voltage magnitudes. In the OPA code (Dobson et al., 2001), to do the power dispatch we minimize a cost function:

$$\text{Cost} = \sum \text{Cg}\,(i)\text{Pg}\,(i) + \sum \text{CLS}\,(i)\text{PLS}\,(i) \tag{1}$$

In equation (1), Cg(i) is the cost of power generation by the generator i, Pg(i) is the power generated, CLS(i) is the cost given for the load shed in node i, and PLS(i) is the load shed in node i. In most of the OPA calculations, we use Cg(i) =1 and CLS(i) = 100. However, in investigating the impact of decarbonization or inequity or other objectives, the power generation cost function and the load loss cost functions can be made arbitrarily complicated allowing for multi-attribute optimization. For example, the "cost" of health impacts from local fossil fuel plants could be added to the generation costs of plants depending on their location, cost of inequity of reliability risk can be added to the load shed costs again depending on their location. In these test-case calculations, we keep the generation cost the same for all generators but we vary the cost of the load shed CLS(i) depending on the zone in which the node is located. The normal cost of the load shed for the standard zones is kept at 100, but for the disadvantaged zone, we have considered various penalty costs for unserved energy including 30, 50, 100, 200, 300, 400, 500, 600, and 700.

4.3. Equity Factor: Results of Control

As described earlier, in this study, in order to have clearly identified zones, a linked network is used. As a starting point, we use an artificial power network with realistic parameters constructed by following the algorithms of (Wang et al., 2008). We take copies of this network and we link them using a few lines. The approach that we follow in selecting the nodes to link is to reduce the average of the shortest distances (here distance really means resistivity) between all nodes. This approach has been proven to be the most effective in reducing the risk of blackouts for these types of networks (Carreras et al., 2014b, 2016).

The mechanism by which the disadvantaged zone is made disadvantaged is by weakening the zones electric infrastructure, by modifying (reducing) the demand, the maximum generation power in the zone, and the max power flow on the lines in the zone as well as reducing the number of generation plants in the zone. All of these can be independently varied. This weaker infrastructure in Zone 4 could reflect any number of factors.

To quantify the system, we will use the risk metric first developed in (Carreras et al., 2014a) and an "Equity" metric. The risk metric is defined through two steps. First, a risk for a given size failure is calculated as the product of the probability of an n event of size i times the cost of an event of that size (Risk(i) = Probability(i) x Cost(i)). The cost of an event of size i is given by a cost factor A times the power lost times the duration (Cost(i)=A x Power lost x Duration of blackout). The second step is to integrate this over all sizes to construct a single metric R for the Risk to an electric system shown in equation 2 (Carreras et al., 2014a).

This can be done for the entire system or for parts of the system such as the zones.

$$R \equiv \frac{1}{P}\int_0^P Risk\left(\frac{L}{P}\right)dL$$

With the equity metric simply being the ratio of the "Risk" in the disadvantaged zone to the average Risk in the other zones, for example for the 4 Zone case:

$$E = \frac{R(4)}{\frac{1}{3}\sum_{j=1}^{3} R(j)}$$

It is worth pointing out that 1 is perfect equity and larger than one is inequity (smaller than one would also be inequity but with the disadvantaged region being better than average so perhaps advantaged).

Fig. 4 shows the Risk R for the four zones as a function of the load shed cost in the loop test grid. The risk for the disadvantaged zone (Zone 4) decreases from a factor of 10 greater to near parity. This suggests that by increasing the cost of outages in high-risk zones the risk can be reduced in those regions without significantly increasing risks to the other regions. Fig. 5 shows the same thing using the equity measure. Directly showing the Equity factor reduces (meaning the equity improves) from ~ 20 to less than 2.

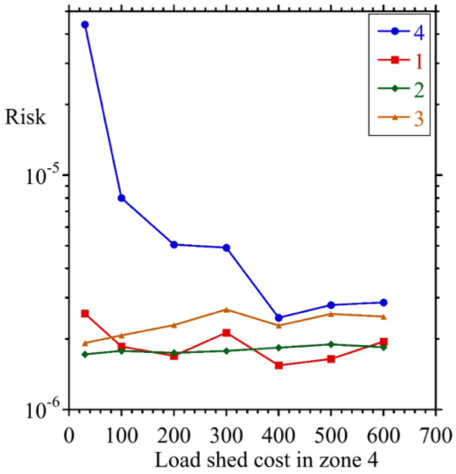

Figure 4. Risk in the loop test grid

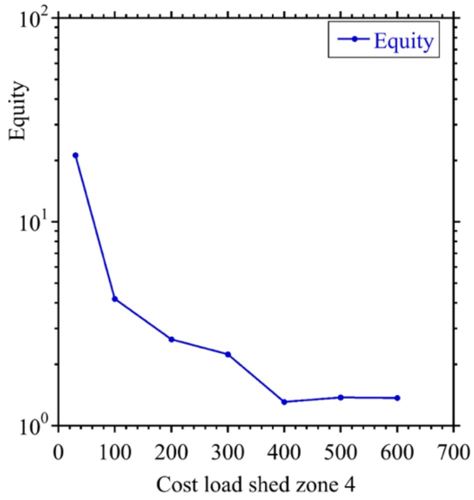

Figure 5. Equity factor

Repeating this for the linear test grid, Fig. 6 shows the risk for the different zones as a function of the load shed cost for Zone 6. Once again as the load shed cost in the disadvantaged zone is increased, the risk in the disadvantaged zone is reduced. However, this time the risk in the neighboring region goes up significantly at the same time. This is likely because in this configuration Zone 6 is only connected to Zone 5 adding significantly more stress to Zone 5 and an increase in the risk due to transmission limitation into Zone 6. This is in contrast to the loop grid in which all the zones have transmission connections on both sides. In that case, the added stress of mitigating the inequity in the disadvantaged zone is shared between both neighboring zones leading to little degradation in their risk. It is also important to note that for the loop grid, the overall risk to the entire system is slightly decreased with the increase in load-shed cost in the disadvantaged zone.

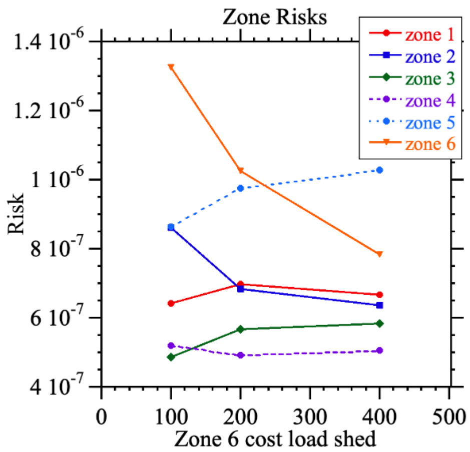

Figure 6. Risk in the linear test grid

Three important points from the modeling are: 1) it is possible to modify the risk to regions of a grid using regional cost functions for either the load-shed or generation costs, 2) cost functions that go beyond the simple cost of production per kWh can be very useful for multi-attribute optimization, and 3) transmission constraints can be modeled and can have a significant impact on our ability to improve equity.

4.4. Tradeoffs Between Objectives

The output from the OPA model in Section 4.3 illustrates one way in which we might understand and illustrate tradeoffs in a simple context. Adjusting value weights in the objective function yields different optimal RA approaches and different levels of risk in each area. For example, for the loop network, we see that the risk for Zone 4 decreases as we increase the penalty cost for unserved energy in Zone 4 (Fig. 7). There is not an increase in the risk for the other three zones in the same size as the risk decrease in Zone 4. The risk measure in Fig. 5 is a measure that includes both frequency and magnitude of power outages. Based on this one risk measure, it seems like a win-win situation for the four zones in the test system. However, when we decompose the risk measure and look at the frequency of outages for the four zones, the frequency of power outages for Zone 3 increases while that for Zone 4 decreases. The reason for Zone 3 having more frequent outages while keeping the same level of risk is that the sizes of outages are smaller. With the intention of reducing Zone 4 risk, Zone 3 experiences more frequent power outages. There is thus a tradeoff between the risk for Zone 4 and the frequency of outages for Zone 3. Different stakeholders may have different opinions about whether such a tradeoff is a good decision, but this kind of exploratory analysis can highlight the tradeoffs in clear ways to all stakeholders.

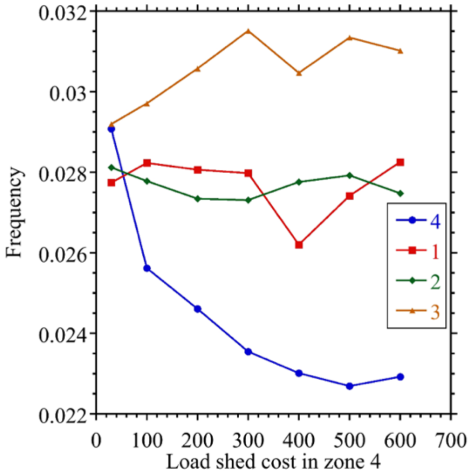

Figure 7. the loop test grid

Because of the temporal and spatial granularity of OPA, the modeling framework lends itself to the calculation of both conventional and emerging RA metrics. These include metrics like LOLE, but also other possible system-wide or location-specific metrics like expected unserved energy (EUE), customer or system average interruption frequency indices (CAIFI or SAIFI). OPA is also well-suited to evaluate the risk of extreme events (tail risk).

5. Discussion and Conclusions

RA assessment has been and will continue to be a key aspect of IRP processes, reliability standard formulation, and market design but the circumstances under which RA assessment is occurring are changing. This paper highlights two important dimensions of this changing planning environment, motivated by the development of the RRC, a new ERO for the State of Alaska. One is the need to develop metrics (and standards based on those metrics) that reflect the changing nature of technology in the power grid and the stresses to which the grid will be exposed. A second is a changing institutional environment for resource planning from a utility-centric and regulator-centric environment to a polycentric environment in which a much broader set of stakeholders are engaged in developing the requirements of the IRP process, the elements that will be standardized across balancing areas, and the institutional designs that will translate RA assessment and uncertainty analyses into regulatory decisions and market designs.

Using the RRC as a test case, we developed and illustrated an integrated sociotechnical approach to developing RA assessment. Our approach starts by using qualitative research to glean the perceptions of stakeholders around the kinds of criteria and metrics that should be included in RA planning processes, and which critical uncertainties should be included in RA assessments. These perceptions are used to formulate a multi-attribute objective function and parameterize uncertainty in OPA, a reliability risk assessment tool that is capable of integrating complex objectives and uncertainty. Using OPA with some simple examples, we illustrated how different stakeholder preferences can give rise to tradeoffs between multiple objectives including cost and equity.

The focus of the present paper is on describing our approach, which we are currently developing and implementing in collaboration with the RRC. Future work will involve using the output from OPA to illustrate multiple RA metrics that capture spatial variation in reliability impacts as well as extreme events. We will also further explore the parameterization weighting of objective functions with consideration of recent literature. As the RRC completes the development of its own RA planning criteria, we are also planning to use the tools developed here to capture tradeoffs that are relevant to the future power grid in Alaska.

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