How detailed value of lost load data impact power system reliability decisions - a trade-off between efficiency and equity

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Overview

The value of lost load (VOLL) is an essential parameter for transmission system reliability management. It represents the cost of unserved energy of electricity interruptions. Various empirical studies have estimated this parameter for different countries and more recently, for different interruption characteristics -- such as interruption duration, time of interruption and interrupted consumer. However, most applications only use one constant VOLL. Our theoretical analysis shows that using more-detailed VOLL data allows to make better-informed transmission reliability decisions. To illustrate this, we estimate the efficiency gains of including consumer and time characteristics in short-term transmission reliability management using VOLL data from Norway, Great Britain and the United States. Depending on the VOLL data and the method of demand curtailment, our five-node network indicates efficiency gains up to 43%. However, increased efficiency leads to decreased equity. Striking the balance between these opposing objectives is crucial for social acceptance.

Methods

The cost of electricity interruptions is determined by the value of lost load (VOLL). VOLL is a parameter representing the cost of unserved electricity and is generally expressed in €/kWh or €/MWh. It is an essential parameter to determine the optimal reliability level of a power system. VOLL is used in many applications such as load curtailment contracts, network investment decisions, cost-benefit analyses, quality incentive schemes of transmission and distribution networks, energy legislation, and reliability standards. Most of these applications simplify the VOLL to a single, constant value. Precise knowledge of VOLL is paramount to make correct reliability decisions. Various empirical studies have estimated VOLL for different countries and for different interruption characteristics, such as interruption duration, time of interruption, interrupted consumer, location and advance notification. Table 1 summarizes studies that estimate VOLL as a function of different interruption characteristics. These detailed VOLL data allow to make better-informed reliability decisions. By providing more information about the benefits of reliability management, they ensure a better balance between the costs and benefits.

Table 1 Studies that estimate VOLL as a function of different interruption characteristics.

Country	Consumer type	Time	Duration	Advance notification	Location	Source
Australia	x		x			(CRA International, 2008)
Austria	x	x	x			(Reichl et al., 2013)
Cyprus	x	x				(Zachariadis and Poullikkas, 2012)
Germany	x				x	(Growitsch et al., 2013)
Great Britain	x	x				(London Economics, 2013)
Ireland	x	x			x	(Leahy and Tol, 2011)
Netherlands	x	x			x	(de Nooij et al., 2007)
New Zealand	x	x	x		x	(Electricity Authority, 2013)
Norway	x	x	x	x		(EnergiNorge, 2012)
Portugal	x	x				(Castro et al., 2016)
Spain	x				x	(Linares and Rey, 2013)
Sweden		x	x			(Carlsson and Martinsson, 2008)
United States	x	x	x	x	x	(Sullivan et al., 2009)

This paper is the first to assess the impact of using different degrees of VOLL detail in reliability management. We develop a theoretical model that shows the efficiency gains -- defined as the (relative) cost decrease -- of using a VOLL that differs over time and between consumers. Realizing the full efficiency potential of consumer-differentiated VOLL depends on the technological curtailment possibilities. The theoretical model is illustrated using a numerical example that focuses on expected total system cost (ETC) of TSOs' operational planning and real-time operation using different levels of VOLL detail. The expressions for real-time operation (left) and operational planning (right) are:

$$\min_{a_c^{RT}, P_{curt}^{RT}} C_{RT}(v) = \min_{a_c^{RT}, P_{curt}^{RT}} \left[C_{corr}(a_c^{rt}) + P_{curt}^{rt}(c) \cdot v\right]$$
$$\text{s.t. operational limits}$$

$$\min_{a_p, a_c^s, P_{curt}^s} C_{OP}(v) = \min \left[C_{prev}(a_p) + \sum_{s \in S} \pi_s \left(C_{corr}(a_c^s) + P_{curt}^s(c) \cdot v\right)\right]$$
$$\text{s.t. operational limits } \forall s \in S$$

With $v \in \{V, V(t), V(n,t), V(c,t)\}$ the different levels of VOLL detail. Our numerical illustration is simulated using a model developed within the GARPUR project (www.garpur-project.eu). The test system is discussed in (Heylen et al., 2016).

In addition we study the impact of VOLL differentiation on specific consumer groups, with a focus on equity and social acceptance. We propose a Gini-based inequality indicator (G) that summarize inequality of a system as a single value. If this indicator equals 0, this means that all consumer groups in all regions have the same reliability level. If it is closer to 1, this means that all interruptions are concentrated in one or a few consumer groups or nodes.

Results

Table 2 summarizes our main results. Including more detailed VOLL data leads to higher efficiency (lower ETC) but increases inequality (G higher). potential cost savings differ between Norway, Great Britain and the United States. They strongly depend on the absolute value of lost load.

Table 2 **Summary table presenting the trade-off between efficiency and equity**

	Norway				GB				US			
	V	v_t	v_n	v_c	V	v_t	v_n	v_c	V	v_t	v_n	v_c
ΔETC	0	-10.68	-20.27	-43.28	0	-0.01	-3.03	-9.37	0	-0.95	-11.14	-29.52
G	0.66	0.58	0.81	0.75	0.7	0.7	0.82	0.74	0.68	0.64	0.85	0.73

Conclusions

Many empirical studies have estimated how VOLL depends on interruption characteristics -- especially consumer type and time of interruption. However, few applications actually use detailed VOLL data to improve power system reliability. A theoretical analysis and a numerical illustration of short-term reliability management both show that incorporating detailed VOLL data leads to considerable efficiency gains. Our numerical illustration leads to potential gains between 3% and 20% when spatial curtailment is used, and between 9% and 43% when perfect curtailment is used.

Our analysis showed that this efficiency gain has a downside. Equity of reliability, represented as a Gini coefficient, decreases when more cost effective spatial and perfect curtailment are used. Striking the balance between these opposing objectives is the role of a regulator, based on society's preferences. When only temporal aspects of VOLL are incorporated, efficiency gains are lower, but without a significant effect on equity. Therefore, the benefits are clear for countries with much temporal variability of VOLL, like Norway in our numerical illustration.

Lastly, the increase of intermittent generation will require significant expansions in transmission infrastructure. However, the high costs of transmission investments and the difficulties to build new lines in both rural and urban areas could hinder this development. This will push power system operation closer to its limits. In such a stressed power system, the use of detailed VOLL data will yield even higher benefits.

References

Heylen, Evelyn, et al. "Framework for evaluating and comparing performance of power system reliability criteria." IEEE Transactions on Power Systems 31.6 (2016): 5153-5162.