A Successful Implementation with the Smart Grid: Demand Response Resources

Contribution to the Panel: "Reliability and Smart Grid: Public Good or Commodity"

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***Abstract*—The effective harnessing of control, communication and computer technologies in the operation of the power system - the key notion behind the Smart Grid concept - can markedly impact the system reliability. The appropriate utilization of intelligent line switching, demand response resources (*DRR*s), *FACTS* devices and *PMU*s is key in the smart grid deployment to bring about improvements in the reliability of the power system. While the Smart Grid can support the provision of differentiated levels of reliability to different customers, the maintenance of system integrity requires that a certain minimum level of reliability be kept throughout the system. We view the provision to meet this reliability requirement as a public good. In this paper, we consider the long-term impacts of *DRR*s - a successful application of the smart grid - and evaluate their impacts on system reliability. We use a simulation engine to study these impacts under different scenarios. We demonstrate the tangible reliability benefits of *DRR* applications in terms of reduced number of loss of load events as a result of voluntary load curtailments.**

***Index Terms*—Electricity Markets, Demand Response resources, Reliability, Smart Grid.**

I. Introduction

POWER systems are experimenting deep and exciting changes. The key notion behind the Smart Grid concept [1] – the effective harnessing of control, communication and computer technologies in the operation of the power systems – is creating several possibilities and challenges all over the electricity industry. In the planning arena, the concept of resilient power systems in which the system can recover by itself from contingencies, contrary to a preventive viewpoint, emerges as one of such deep changes. In the distribution side, the use of decentralized control is going to allow faster response to contingencies or disturbances in the system [2]. Advanced smart metering and the possibility of more price sensitive demand will deeply impact the way to design and operate the markets [3], [4]. The appropriate use of intelligent line switching, demand response resources (*DRR*s), *FACTS* devices and *PMU*s can help power system operators to improve the reliability of the power system [4] - [7]. However, the use of more information technologies also creates new security concerns due to the possibility of cyber attacks [8].

In this paper, we focus on the reliability impacts Smart Grid can have. While the smart grid can support the provision of differentiated levels of reliability to different customers, the maintenance of system integrity requires that a certain minimum level of reliability be kept throughout the system. We view the provision to meet this reliability requirement as a public good. In particular, we present how Demand Response Resources can provide tangible reliability benefits for this public good side of system reliability.

This paper contains three additional sections. We devote section II to the public good/commodity discussion of reliability. We illustrate impacts of *DRR*s in system reliability in section III. We present concluding remarks and future directions for research in section IV.

II. Smart Grid and Reliability

Inherent network characteristics of power systems and technical considerations have created the conditions to conceptualize power system reliability as a public good in which everyone must consume the same level [9]. Such reliability level is in general quantified through reliability metrics such the widely used 1 interruption every 10 years criterion. In a given neighborhood, all the customers are connected to the same feeders and wires, making it impossible to provide differentiated levels of reliability. Hence, the reliability criterion is applied to the whole system, and all the users end up consuming the same quantity. The system must be planned and operated in such a way to achieve the specified reliability standard. For example, resource adequacy markets such as the Reliability Pricing Model of PJM or the Forward Capacity Market of New England ISO use the 1 interruption every 10 years as the system reliability criterion target.

The implementation of the Smart Grid opens the possibility of having multiple reliability levels [10]. In a market environment, the technical possibility of having differentiated reliability level will require, among other changes, the creation of differentiated electricity prices according to the reliability level.[1] Metering and data management are key infrastructure requirements to achieve differentiated price schemes [11]. Customers that would need a stricter reliability criterion – say 1 interruption every 20 years – should pay higher prices than customers under a reliability criterion that is comparatively less strict – say 1 interruption every 10 year criterion.

The possibility of having an additional dimension of commodity for the provision of reliability will entail changes in

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[1] The differentiated prices for different levels of reliability are similar, in nature, to the use of highways; we have public highways with an adequate level of functionality and private highways for people willing to pay for them.

power system planning and operations. Multi-level reliability assessments [10] emerge as a potential upgrade in this setting. Electricity markets in all their realizations, i.e., the energy markets, the capacity markets and the markets for ancillary services, should be redesigned to capture the new commodity dimension of reliability.

Notwithstanding the new commodity dimension of reliability, the importance of electricity in society and the centralized and structural characteristics of the system still require a minimum reliability level. Indeed, the provision of differentiated levels of reliability is sustained in such minimum reliability level. For example, a failure in the bulk transmission system impacts everyone connected to the grid. We continue to view the provision of such minimum reliability level of the system as a public good. Consequently, in the new Smart Grid environment both the public good and the commodity viewpoints of reliability must coexist.

III. Impacts of *DRR*s on Reliability

In the public good provision of reliability, we focus our attention on the use of *DRR*s to satisfy the minimum reliability level. *DRR*s are demand-side players with the capability of curtailing their loads when provided with the appropriate economic incentives. *DRR*s provide load curtailment services to the system operator and voluntarily modify their load consumption to provide these services [4], [12]. It is clear that *DRR*s are private goods having characteristics of excludable and rival goods. The use of *DRR*s is determined by the willingness of consumers for curtail loads; the benefits associated with the *DRR* in terms of payments are exclusively for the seller of *DRR*, hence excludable from other players. Similarly, once a *DRR* is sold, it cannot be sold by anyone else; hence it is a rival good [13]. However, as with other public goods, *DRR*s are used for the "provision" of the public-good side of reliability.[2] In this section we present several numerical illustration of the impact *DRR*s can have on the public good dimension of reliability.

A. Simulating DRRs impacts

We demonstrate the peak-shaving capabilities of *DRR*s to provide tangible reliability benefits to the system. We use the simulation approach proposed in [12] to set of studies to quantify these reliability benefits. We limit our analysis to a single year to discuss the results in depth.

We use a realistic-sized test system in all studies discussed here. We use the load shapes from the Midwest *ISO* system [14]. The aggregate average hourly load for this summer peaking system is 70 *GW*, and the annual peak load is 117 *GW*. The supply-side resource mix capacity composition is summarized in Table I. We explicitly consider the maintenance schedule of the resource mix. We specify the total capacity of the *DRR*s in the system as a fraction of the annual peak load of the system. The load payback effects due to the *DRR* curtailments by player $\hat{b}$ are specified in terms of the *DRR* curtailment recovery factor (*DCRF*) $\chi^{\hat{b}}$. The independent grid operator (*IGO*) operates the electricity markets and the transmission grid. The loads of individual buyers are a prespecified fraction of the system load, and the buyers' demand bids are inelastic to electricity prices. The *IGO* is responsible for meeting the load requirements of all the buyers using offers from generators as well as *DRR*s. The *DRR*s are eligible to offer load curtailments from 8 a.m. to 6 p.m. for each weekday and the load recovery is restricted to the off-peak (night) hours. Further details on the test system are provided in [12].

[2]This is a common issue with public goods: private goods are needed to produce them. Let us go back to the in example of highways. Even public highways needs private goods such concrete, iron, etc, to be built.

TABLE I
The composition of the supply-side resource mix

technology	coal	CCGT	peakers	others	total
capacity (GW)	70	21	24	10	135

To study the effects of *DRR* integration, we simulate multiple *DRR* scenarios with varying degrees of load payback effects and *DRR* penetration. We use as a reference the scenario $\mathbb{R}$ with no *DRR*s in the system, and we use the variable effects from this scenario as benchmarks to assess the impacts of the *DRR*s on the system.

B. Impacts of DRRs in Capacity Margins

We start with a comparison of the reference scenario with the *DRR* scenario $\mathbb{D}_5$ having 5.6 *GW* of *DRR* capacity which is approximately 5 *%* of the peak load. We simulate the *DRR* scenario for two possibilities of load payback – no recovery of *DRR* curtailments, i.e. $\chi^{\hat{b}} = 0$ and recovery of 70 *%* of the load curtailed by *DRR*s, i.e. $\chi^{\hat{b}} = 0.7$. We first examine the impacts of *DRR*s on the system load. For each scenario, we obtain the range and the average values of the net system load cleared in the hourly markets and present the results in Table II. The comparison between the hourly net loads for the three scenarios provides a good illustration of the capability of the *DRR*s to reduce the load during the few critical hours in the study period when the load is high. The reduction in the system net load is observed in approximately 25% of the hours in the year. We illustrate the reduced loading of the system during the peak hours by using the corresponding portion of the annual *LDC*s in Fig. 1. The reduction in the peak load from 117.658 *GW* to 112.720 *GW* improves the capacity margin for the system from 14.739 *%* to 19.766 *%*. When the load payback effects are considered, we observe increases in the system load during the off-peak hours, which impacts the base load values.

TABLE II
Range and average values for the hourly net loads

scenario	range (*GW*)	average (*GW*)
reference	$[50.806, 117.658]$	69.910
5 *%* *DRR*s, with $\chi^{\hat{b}} = 0$	$[50.806, 112.720]$	69.830
5 *%* *DRR*s, with $\chi^{\hat{b}} = 0.7$	$[50.242, 112.720]$	69.575

To study the impacts of *DRR* penetration, we simulate the *DRR* scenarios with varying capacity of *DRR*s. We focus on the impacts of *DRR*s on the utilization of the system resources.

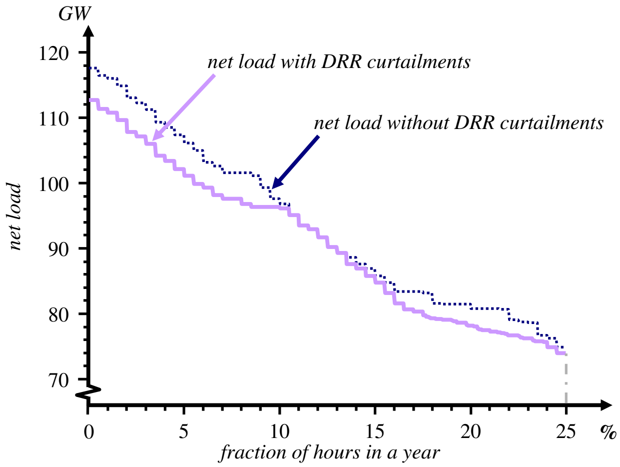

Fig. 1. Reduction in the net load demand during peak hours as illustrated on the portion of the *LDC* impacted by the *DRR* curtailments

For simplicity, we assume that $\chi^{\hat{b}} = 0$. We use Fig. 2 to illustrate the impacts of increasing *DRR* penetration on the capacity margin and the aggregate annual congestion rents. As

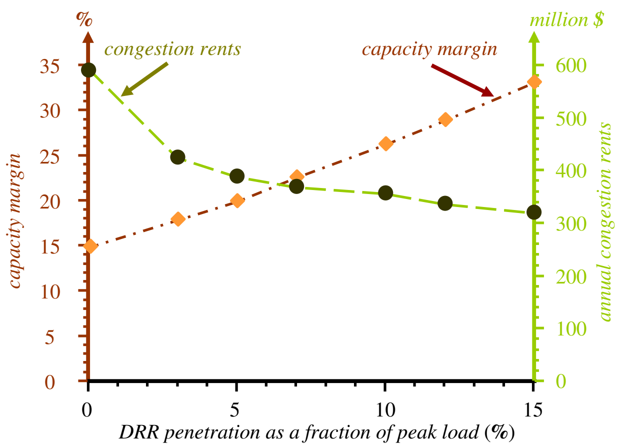

Fig. 2. Impacts of increasing penetration of *DRR*s on the capacity margin and the congestion rents

the *DRR* penetration deepens, we observe higher reductions in the peak loads, thereby resulting in further improvements in the capacity margin of the system. The *DRR* load curtailments provide congestion relief and hence, increasing deployment of the *DRR*s in the high penetration scenarios results in significant reductions in the congestion rents. The simulation results also indicate a decrease in the electricity payments and CO_2 emissions with the increasing *DRR* penetration. A more detailed discussion of these results is available in [12].

C. DRRs as an alternative to generation additions

Next, we investigate the impacts of *DRR*s on the need for additional generation. We simulate scenarios $\mathbb{R}$ and $\mathbb{D}_5$ assuming 3% growth in the load demand and with no modifications in the resource mix. We compute the hourly net loads for both scenarios and compare it with the forecasted loads of the system. The simulation studies indicate that there is a shortage of available generation for 2% of all hours in the reference scenario $\mathbb{R}$ without *DRR*s, which results in mandatory load curtailments at some nodes. However, in *DRR* scenario $\mathbb{D}_5$, the voluntary load curtailments by the *DRR*s reduce the loading on the system during the peak hours and hence, there is no shortage of available generation. The illustration in Fig. 3 clearly indicates the shortfall of available generation in the top 2% hours for the scenario $\mathbb{R}$. We observe that to prevent

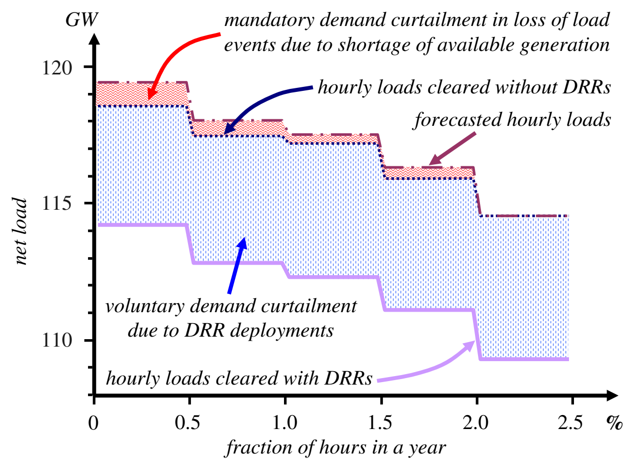

Fig. 3. Reduction in loss of load events due to voluntary load reduction

this generation shortage, an additional peaking generation capability of approximately 1 *GW* is needed. As seen from the scenario $\mathbb{D}_5$ simulation, the effective use of *DRR*s does indeed defer the need for this additional generation. We conclude that *DRR* curtailments bring about a tangible reduction in the total loading of the generation units and help avoid *loss of load* situations that may arise due to the forced outages of generators.

D. DRRs as an alternative to transmission upgrades

The last set of simulation studies investigates the interplay between the transmission congestion and effective deployment of the *DRR*s. For our investigations, we use scenario $\mathbb{R}$ and scenario $\mathbb{D}_5$ with $\chi^{\hat{b}} = 0$ and each scenario is simulated with four different configurations of the transmission grid: the existing grid, the existing grid with line ℓ_a upgraded, the existing grid with lines ℓ_a and ℓ_b upgraded, and, the existing grid with lines ℓ_a, ℓ_b and ℓ_c upgraded. We compute the annual congestion rents for the two scenarios – with and without *DRR*s – for each system configuration and present the same in Fig. 4. As expected, an improvement in the transfer capability due to the line upgrade(s) decreases the congestion rents for both scenarios – with and without *DRR*s. A comparison of the annual congestion rents for all the case studies provides a significant finding – the lowest congestion rents for the reference scenario $\mathbb{R}$ without *DRR*s – \$406 million for the system with 3 line upgrades – are higher than the congestion rents in *DRR* scenario $\mathbb{D}_5$ – \$387 million on the existing transmission system. Thus, we conclude that effective utilization of the *DRR*s may lead to more reduction in the congestion rents than undertaking the capital intensive projects

Fig. 4. Congestion rents for the scenarios with and without *DRR*s for cases with transmission line upgrades

such as transmission line upgrades. This finding also implies that the *DRR* integration into the power system may defer the need for additional transmission.

IV. Concluding Remarks

In this paper, we discuss the new scenario created by the Smart Grid in which reliability may have both public and private good characteristics. We explore *DRR*s as a successful implementation with the Smart Grid. We present several numerical illustrations showing tangible reliability benefits associated with *DRR*s. We demonstrate how *DRR*s contribute towards provision of the public good dimension of reliability. Our findings show how *DRR*s can improve capacity margins and provide attractive alternatives to generation resource additions and transmission line upgrades. An exciting future research topic in this area is the design of appropriate products and markets to be able to capture the new physical/technological setting created by the Smart Grid.

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