Kai Van Horn *is a Ph.D. candidate in Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign. His research is focused on the grid integration of renewable energy sources and policy and market issues related to demand response, renewable energy, and energy storage. He received his B.S. in Multidisciplinary Engineering from Purdue University in 2007 and his M.S. in Electrical and Computer Engineering from University of Illinois at Urbana-Champaign in 2012.*

Isaac Castillo *is an energy consultant working on issues related to renewable energy, energy efficiency, and demand response. He received his B.S. in Electrical Engineering from the Technological University of Panama in 2009 and an M.S. in Electrical and Computer Engineering from the University of Illinois at Urbana-Champaign in 2012. During his graduate studies, Castillo worked on the economic aspects of the implementation of demand response resources in electricity markets.*

George Gross *is a professor of Electrical and Computer Engineering at the University of Illinois with an appointment as professor in the Institute of Government and Public Affairs. His major research activities are in power system analysis, economics and control and electric utility regulatory policy. Prior to coming to the University of Illinois as the Grainger Professor of Electrical and Computer Engineering in 1993, he held several management positions at Pacific Gas & Electric Company in San Francisco for nearly two decades. During 1992–1993 he held a one-year visiting appointment in the Electrical Systems and Integrated Energy Systems Divisions of the Electric Power Research Institute. He received his B.Eng. (Honors) in Electrical Engineering at McGill University in 1969, and his M.S. and Ph.D. from University of California, Berkeley, in 1971 and 1974, respectively.*

Fixing FERC's Order No. 745

While the Federal Energy Regulatory Commission's landmark ruling provides strong stimulus for demand response resources in wholesale electricity markets, extensive testing of the Order's net benefits test reveals several significant shortcomings. A couple of improvements can remedy these shortcomings without altering the nature of the Order.

Kai Van Horn, Isaac Castillo and George Gross

I. Introduction

The Federal Energy Regulatory Commission's Order No. 745 was promulgated on the premise that demand response resources (DRR) participation enhances the competitiveness of wholesale energy markets and that it is FERC's mandate to ''ensure the competitiveness of organized wholesale energy markets''[1] and thus ensure ''just and reasonable wholesale rates.''[2] Prior to the Order, the incentives for DRR participation in the wholesale electricity market varied from market to market and were insufficient to engender consequential DRR participation. FERC deemed the failure of independent system operators (ISOs)/regional transmission organizations (RTOs) to provide DRR incentive payments at the locational marginal price (LMP) as ''unjust and unreasonable''[3] and cited the level of the incentives DRRs received, and the lack of standardized DRR incentives, as significant barriers to DRR participation. The key objectives of FERC Order No. 745 are to remove the identified barriers to DRR participation in electricity markets and to ensure that DRRs are utilized only in instances in which they have the ''capability to

 1040-6190/$–see front matter http://dx.doi.org/10.1016/j.tej.2013.09.002

balance supply and demand''[4] and are a ''cost-effective''[5] alternative to supply-side resources. FERC Order No. 745 is a landmark ruling that provides significant stimulus for *DRR* participation in wholesale electricity markets and has been a major catalyst for the recent growth and development of the demand response industry. The Order aims to achieve its objectives via three main thrusts. The first thrust is to establish standardized incentives, payment at the LMP, for DRRs operating in any ISO/RTO-run electricity market. This thrust addresses the Order's first objective by establishing ''greater uniformity''[6] in the incentives provided to DRRs in ISO/RTO-run markets. The second thrust is to explicitly define a cost-effectiveness criterion, the *threshold price*, to determine the instances under which such incentives are provided, and to prescribe a methodology, the net benefits test (NBT), by which ISO/RTOs calculate the threshold price. The third thrust is to establish a mechanism by which to allocate the costs to the post-curtailment loads to provide the DRR incentive payments, which we term the incentive payment allocation (IPA). In other words, the IPA sets forth an explicit means by which the proportion of the costs of providing DRR incentive payments borne by each post-curtailment load is determined. The second and third thrusts address the second objective of the Order by providing a screen to filter out those hours in which DRRs may not reduce post-curtailment buyer payments and to ensure that FERC's cost causation principle[7] is upheld in the IPA.

While the thrusts of the Order make strides toward achieving its objectives, they have significant limitations, which prevent the full realization of those objectives. The principal limitation is the failure of the NBT to account for the impacts of transmission congestion. Though sufficient information, the LMPs, is currently available to integrate the impacts of transmission congestion on the cost-effectiveness of DRRs on a nodal basis into the NBT, FERC did not address or require the use of such information in the NBT methodology. A secondary limitation is the ambiguity of the IPA mechanism as stated in the Order. A lack of adequate specificity in the IPA provisions has left open the door to IPAs which are not consistent with the second objective of the Order. These limitations result in unintended economic consequences for the non-DRR buyers.

While the thrusts of the Order make strides toward achieving its objectives, they have significant limitations, which prevent the full realization of those objectives.

FERC NBT explicitly defines the DRR cost-effectiveness criterion, the so-called threshold price, as ''the point along the supply stack beyond which the overall benefit from the reduced LMP resulting from dispatching demand response resources exceeds the cost of dispatching and paying LMP to those resources.''[8] This threshold price is calculated on a *system-wide* basis making use of averaged historical supplier offers and historical fuel price data. If the LMP at a node exceeds the threshold price in a day-ahead or real-time market interval, all cleared DRR curtailments at the node must be provided incentive payments at the LMP. The explicit definition of a cost-effectiveness criterion benefits DRRs by providing a concrete condition under which they receive incentives at the LMP that reduces the level of uncertainty in the magnitude and frequency of their compensation. The threshold price is intended to benefit the non-DRR buyers by preventing the utilization of DRRs when they do not reduce post-curtailment buyer payments. However, the threshold price benefits to non-DRR buyers are not as certain as those for DRRs, and, while DRRs always receive incentive payments at the LMP when the threshold price is met, non-DRR buyer payments may not be reduced. When implemented, the threshold price is compared on a nodal basis to the LMPs, which explicitly account for the impacts of transmission congestion. The congestion impact information

 , http://dx.doi.org/10.1016/j.tej.2013.09.002

mismatch introduced by the direct comparison of the system-wide threshold price with the LMPs leads to cases of omission and commission in the determination of the level of DRR incentive payments that have important ramifications for the non-DRR buyer payments.

In a pre-curtailment network with transmission congestion, the LMPs differ from one node to another. As a result, cases arise in which DRR curtailments occur but do not result in a reduction in post-curtailment buyer payments i.e. cases of commission, and cases arise in which DRR curtailments do not occur that would have resulted in a reduction in post-curtailment buyer payments i.e. cases of omission. Moreover, the LMP impacts of DRRs differ on a nodal basis. In such a system, there may be a subset of nodes whose LMPs are above the threshold price and a subset of nodes whose LMPs are below the threshold price. At nodes where DRR curtailments occur, the post-curtailment LMPs are, in general, less than the pre-curtailment LMPs due to the load reductions brought about by the DRR curtailments. However, the *LMP* impacts of *DRR* curtailments at those nodes where there are no *DRR* curtailments are mixed. *The post-curtailment LMPs at nodes which have no DRR curtailments may be higher or lower than the pre-curtailment LMPs at the same nodes due to the transmission congestion impacts.* Clearly, those nodes which experience *LMP* increases as a result of *DRR* curtailments are made worse off, while those nodes which experience *LMP* reductions share in the benefits of *DRR* curtailments. The existence of cases omission and commission and cases in which loads at certain nodes are made worse off as a result of *DRR* curtailments are the unintended consequences of the failure to integrate transmission congestion impact information into *FERC NBT*. Further unintended consequences arise as a result of the Order's *IPA* definition.

The IPA definition in the Order is ambiguous and has led to IPAs which have unintended consequences in congested systems.

According to the *IPA* mechanism in the third thrust of the Order, the *IPA* must be done ''proportionally to all entities that purchase from the relevant energy market in the area(s) where the demand response resource reduces the market price for energy at the time when the demand response resource is committed or dispatched.''[9] This mechanism aims to uphold *FERC*'s cost causation principle and ensure that costs of the incentive payments to *DRR*s are distributed among the buyers in the system so that all buyers benefit from *DRR*s in the form of reduced post-curtailment payments. However, the *IPA* definition in the Order is ambiguous as to the nature of the proportionality of the payment allocation and has led to *IPA*s which have unintended consequences in congested systems. The accepted Order No. 745 compliance filings to date have included load-proportional *IPA*s (*LP-IPA*s)[10] i.e. the allocation of the costs of the *DRR* incentive payments to the non-*DRR* buyers which benefit from *DRR* curtailments is in proportion to a buyer's load's contribution to the total load of those buyers who benefit. While such an *IPA* takes two steps toward achieving the objectives of the Order, it also takes one step away as it divorces the magnitude of the benefits of *DRR* curtailments received by buyers from the proportion of the costs of the incentive payment to the *DRR* for which the buyers are responsible. In a congested system, buyers at a node *i*, at which a *DRR* curtailment occurs, may experience only a modest buyer payment reduction as a result of the curtailment. The buyer payment reductions for buyers at node *i* may be less than the portion of the costs to provide *DRR* incentive payments for which buyers at that node are responsible. The result is that, though the node *i* post-curtailment *LMP* is less than the pre-curtailment *LMP*, the buyers at node *i* may face a *post-IPA LMP* which exceeds the pre-curtailment *LMP*. *Under a load-proportional IPA there is no guarantee that the post-IPA*

 1040-6190/$–see front matter http://dx.doi.org/10.1016/j.tej.2013.09.002

LMP will be less than the pre-curtailment LMP. Clearly, buyers which face a post-*IPA LMP* which exceeds the pre-curtailment *LMP* are worse off as a result of the *DRR* curtailments. Moreover, the accepted *IPA*s have not addressed the *DRR* benefit allocation issues which arises in cases in which the total post-curtailment buyer payments decrease but the buyers at some nodes experience post-curtailment *LMP* increases while buyers at other nodes experience post-curtailment *LMP* decreases. Such cases show a limitation of the Order which is counter to *FERC*'s intent in the second objective, and that can be addressed through the design of an appropriate *IPA*.

In this work, we identify and discuss several limitations of *FERC* Order No. 745 that have unintended economic consequences and provide the results of studies which give insights into the magnitude of the economic impacts of those consequences. We then propose effective modifications to *FERC* Order No 745 that address the limitations we have identified. Our proposed modifications maintain the spirit of the Order and are both simple, requiring few changes to the procedures outlined in the Order, and effective, significantly reducing the number of hours in which *DRR* curtailments are uneconomic. We propose the application of the *NBT* on a nodal basis, a nodal *NBT*, to calculate nodal threshold prices, the calculation of which takes explicit account of the transmission congestion impacts through the use of readily available *LMP* data. The nodal *NBT* brings the explicit representation of the grid and the deliverability of the supply to meet the demand into the prescribed *NBT* process. Such a nodal criterion provides a finer screen for the evaluation of *DRR* cost-effectiveness that reduces the frequency of the occurrence of uneconomic *DRR* outcomes and the cases of omission and commission. Furthermore, we put forth a benefit-proportional *IPA* with side payments which marries the benefits realized by non-*DRR* buyers with the proportion of the costs to provide incentive payments for which they are responsible and includes the additional post-curtailment payments by those buyers made worse of as a result of *DRR* curtailments as a ''cost'' to be allocated under the *IPA*. Our approach provides what the current approaches have so far failed to provide: the explicit assurance that no loads are made worse off by *DRR* curtailments in cases in which the *DRR* curtailments reduce the total post-curtailment buyer payments. This assurance, along with the nodal *NBT*, guarantees to a greater extent that the objectives of the Order will be achieved.

Our proposed modifications maintain the spirit of the Order, and are both simple and effective.

The remainder of the article is divided into three sections. In Section II, we provide a detailed discussion of the unintended consequences that result from the limitations of *FERC* Order No. 745 and show the significant impact these consequences have on non-*DRR* buyers. In Section III, we describe our proposed modifications to the Order to address its limitations and show the non-*DRR* payment impact improvements which can be gained by applying our modifications. In Section IV, we summarize the article.

II. The Unintended Consequences of *FERC* Order No. 745

FERC Order No. 745 is one of the most important rulings regarding *DRR* participation in the wholesale electricity markets to date. The incentives mandated by the Order are already beginning to have a major impact on increasing *DRR* participation in some wholesale electricity markets.[11] This increased *DRR* participation is a testament to the effectiveness of the thrusts of the Order at achieving its first objective: to encourage *DRR* participation by removing market barriers to *DRR*s. However, we question the effectiveness of the

  http://dx.doi.org/10.1016/j.tej.2013.09.002

thrusts at achieving the second objective, and whether the impacts of *DRR*s under the Order will be beneficial for all buyers. In this section we discuss in detail the limitations of *FERC* Order No. 745 we have identified, the unintended consequences which arise as a result of those limitations and the economic impacts of those unintended consequences on non-*DRR* buyers.

The second objective of *FERC* Order No. 745 is to ensure that *DRR*s are only used when they are a ''cost-effective'' alternative to generation i.e. the *DRR* curtailments results in reduced post-curtailment buyer payments. As we outlined in the introduction, the second thrust of the Order aims to ensure post-curtailment buyer payments do not increase through the establishment of the *NBT* and its corresponding threshold price. The *NBT* essentially provides a screen through the hours in which *DRR*s may be provided incentives at the *LMP* must pass. The goal of the use of such a screen is to prevent *DRR* curtailments in hours in which they will result in higher post-curtailment buyer payments. However, as we will show, the screen provided by *FERC NBT* is too coarse due to the system-wide nature of the data used to calculate the single system-wide threshold price and the failure to explicitly account for the impacts of transmission congestion. As a result, *FERC NBT* screen dictates that *DRR*s be provided incentive payments in many hours in which the provision of those incentives increases post-curtailment buyer payments for at least a subset of the buyers.

We illustrate several cases in which *DRR* curtailments result in increased buyer payment due to the limitations of the Order with two examples on a 7-bus system. In the first example, we consider a single 10 MW *DRR* at node 3, which represents approximately 1 percent of the total load of the system. Figure 1 shows the pre-curtailment and post-curtailment *LMP*s at the load nodes in the 7-bus system. The system is congested, as indicated by the fact that the pre-curtailment *LMP*s differ at each node. The highest pre-curtailment *LMP* in the system is at node 3 and we assume this price exceeds the threshold price. From Figure 1, we see that the post-curtailment *LMP*s at nodes 2, 3, and 6 are decreased by the *DRR* curtailment—the intended impact. However, changes in the network congestion patterns caused by the *DRR* curtailment result in post-curtailment *LMP* spikes at nodes 5 and 7. These *LMP* spikes overwhelm the *LMP* reductions at nodes 2, 3 and 6 and the overall buyer payment impact of the *DRR* curtailment is an increase in the total post-curtailment buyer payments. This example clearly shows the importance of transmission congestion impacts on the *DRR* curtailment outcomes. The resulting buyer payment increases are an unintended consequence of the *FERC NBT* and we will show that such cases arise frequently in congested systems.

The example in Figure 1 also highlights an issue that arises in transmission-congested networks: the non-*DRR* buyer benefits of *DRR* curtailments are different at each node. When there is no transmission congestion, the benefits of *DRR* curtailments received, or losses borne, by the non-*DRR* buyers are the same on a per-MW basis for each buyer regardless of the buyer's location. However, this is not the case when transmission congestion arises. *In a transmission-constrained system, the per-MW benefits*

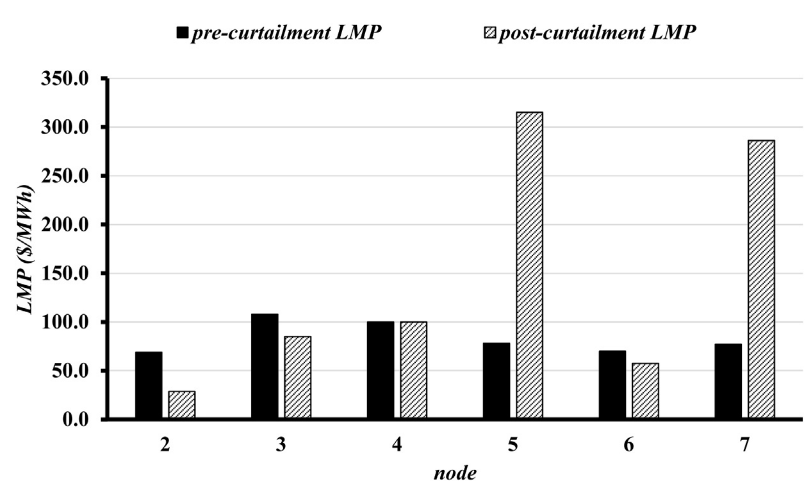

Figure 1: 7-Bus System Example 1, 10 MW DRR Curtailment at Node 3, Total Buyer Payment Increase

  http://dx.doi.org/10.1016/j.tej.2013.09.002

Please cite this article in press as: Van K, et al. Fixing FERC's Order No. 745, Electr. J. (2013), http://dx.doi.org/10.1016/j.tej.2013.09.002

(losses) received (borne) by each buyer as a result of DRR curtailments differ on a nodal basis. In the example, clearly the loads at nodes 5 and 7 have been negatively impacted by the *DRR* curtailment *despite their lack of participation as DRRs* while the loads at nodes 2, 3 and 6 benefit. Such a distribution of the *DRR* benefits and losses represents a second unintended consequence of the limitations of the Order.

A key stipulation of *FERC* Order No. 745 which plays a large role in the ultimate impact of *DRR* curtailments on the non-*DRR* buyer payments is the *IPA* stipulation. The *IPA* framework outlined in the Order requires that the costs of providing incentive payments to the *DRR*s for their curtailments be borne by the buyers who benefit from those curtailments in the form of reduced post-curtailment *LMP*s. However, how those ''costs'' are distributed to the buyers who benefit is not specified. Absent specific details from *FERC* about the proportionality of the allocation, *LP-IPA*s have emerged as the prevailing *IPA* approach. However, such *IPA*s fail to account for the impacts of transmission congestion on the distribution of the *DRR* benefits among the post-curtailment buyers. This shortcoming leads to cases under which the total post-curtailment buyer payments are reduced but, for buyers at some nodes, the post-*IPA* buyer payments increase. We illustrate such a case with a second example using the same 7-bus system as before with a different distribution of the loads to produce a different *LMP* profile. In this example, we introduce a 100 MW *DRR* curtailment at node 3, which represents approximately 10 percent of total load, and allocate the costs of the incentive payments via an *LP-IPA*. The pre- and post-curtailment *LMP*s and the post-*IPA LMP*s are shown in **Figure 2**.

We note that buyers at a single node, node 2, suffer a small increase in the post-curtailment *LMP* as a result of the *DRR* curtailment while buyers at the remaining nodes experience post-curtailment *LMP* decreases or no change in the post-curtailment *LMP*. The overall result of the *DRR* curtailment for the non-*DRR* buyers is a decrease in the total post-*IPA* buyer payments. We see in Figure 2 that the post-curtailment *LMP* is reduced for the loads at nodes 3-5 and node 7.[12] However, the *LMP* reductions are not uniform across the nodes and we see that, in particular, the buyers at nodes 3 and 4 experience far higher post-curtailment *LMP* reductions compared to the pre-curtailment *LMP*s than those buyers at nodes 5 and 7. This non-uniform accumulation of the *DRR* benefits on a per-MW basis, combined with the *LP-IPA*, which allocates uniformly to each buyer on a per-MW basis, results in buyers at nodes 5 and 7 paying a share of the *DRR* curtailment incentives which is higher than the benefits they receive from the curtailment. The result is the increased post-*IPA LMP*s compared to the pre-curtailment *LMP*s for buyers at nodes 5 and 7 shown in Figure 2. Furthermore, the *IPA* provides no compensation for the ''innocent bystander'' node 2, which has a higher post-curtailment *LMP* as a result of the *DRR* curtailment at node 3. The ultimate outcome in this example, despite the overall reduction in total post-*IPA* buyer payments, is that buyers at half of the load nodes pay higher *LMP*s than they would have without the *DRR* curtailment. The negative impact of the *IPA* in this case showcases another unintended consequence of the Order. This example also illustrates the importance of the

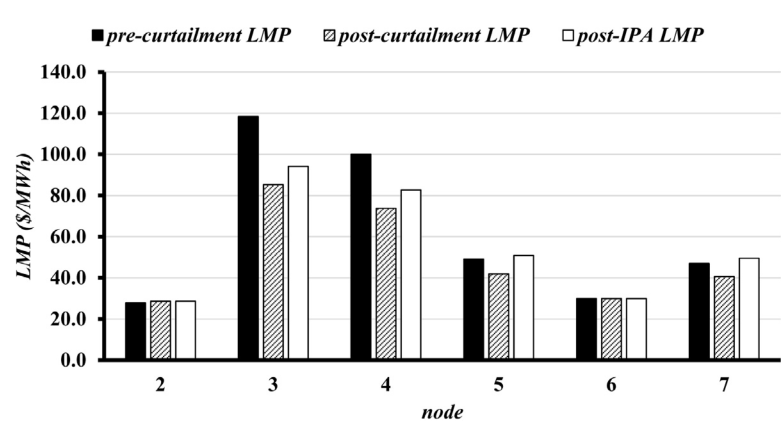

Figure 2: 7-Bus System Example 2, 100 MW *DRR* Curtailment at Node 3, Total Buyer Payment Decrease

Table 1: Reference Cases N_0 and M_0 and *DRR* Cases N_3 and M_3 System-Wide Metrics.

Metrics	N_0 Annual Metrics	N_3 Annual Metrics	M_0 Annual Metrics	M_3 Annual Metrics
Cleared demand (h)	47,700,000	47,300,000	53,100,000	52,700,000
Buyer payments (M$)	3,320	3,240	3,090	3,060
Congestion rents (M$)	295	216	116	85.9

nature of the proportionality of the distribution of the costs to provide *DRR* incentive payments in the *IPA* and further highlights the importance of the explicit consideration of transmission congestion to ensure the thrusts of the Order meet its second objective.

The examples given above have highlight several cases in which the failure of *FERC* to account for transmission congestion considerations leads to unintended outcomes that are inconsistent with the second objective of the Order for buyers at some or all nodes in the system. We turn next to the aggregate impact of such cases over a one-year period to shed some light on the magnitude of *FERC* Order No. 745's unintended consequences.

We present a representative selection of results from our extensive simulation studies to facilitate the discussion of the aggregate impact of the unintended consequences of *FERC* Order No. 745.[13] We simulate the day-ahead markets (*DAM*s) with *DRR* penetrations in the range of [1,11]% of system peak load for the year 2010 on the IEEE 118-bus test system using data from *ISO-NE*, the cases from which we label N_c, and *MISO*, the cases from which we label M_c, where c case *DRR* capacity as a percentage of the system peak load.[14] Furthermore, we assume *DRR* curtailments occur between the hours of 1:00 p.m. and 9:00 p.m., in compliance with *FERC NBT* and that an *LP-IPA* is used. Our reference case for comparison in both the N_c and M_c cases is the study system without *DRR*s, N_0 and M_0, respectively.

Table 1 shows the metrics for the one year simulated in the reference cases and in the 3 percent *DRR* cases. We see that *DRR*s are a net benefit to the system reducing the overall buyer payments in the N_3 and M_3 cases. *DRR* curtailments result in 2.4 percent and 1.9 percent reductions in the total buyer payments from the reference case in the N_3 and M_3 cases, respectively.

Though the annual buyer payments are reduced in both of the *DRR* cases presented, there are many hours in which *DRR* curtailments do not reduce buyer payments. In Figure 3, we present the monthly number of hours in which *DRR* curtailments resulted in post-curtailment buyer payment increases in case N_3.

In most months, we see that the number of hours in which *DRR* curtailments result in increased buyer payments remains below 20 indicating the capability of *FERC NBT* to screen out the hours in which providing *DRR* incentive payments at the *LMP* would be detrimental to the non-*DRR* buyers. However, we see several months in which a large number of hours had curtailments which increased the total buyer payments. Surprisingly, one of these months is August when we would expect *DRR* curtailments to be the most

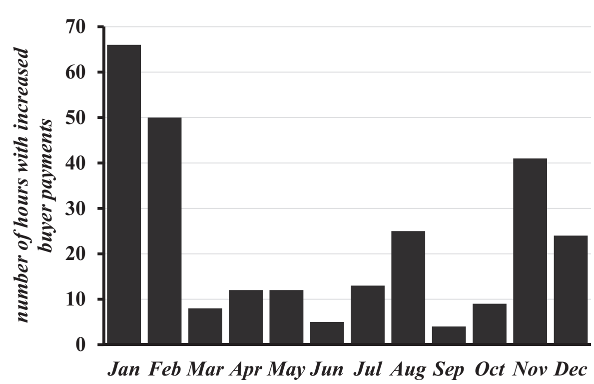

Figure 3: Post-Curtailment Buyer Payment Increases Due to *DRR* Curtailments for Case N_3

 1040-6190/$–see front matter http://dx.doi.org/10.1016/j.tej.2013.09.002

effective due to the higher loads and higher prices most systems experience during the summer. We conclude that *FERC NBT* performs poorly in August due to shifts in the congestion patterns caused by the *DRR* curtailments which increase payments for buyers at many nodes. *FERC NBT* breaks down primarily during the winter months. In January and February, the hardest-hit months, approximately 71 percent and 62 percent of the hours during which *DRR* curtailments occurred, resulted in a total buyer payment increases post-curtailment. For these two months, *FERC NBT* failed to screen out the majority of hours that in the end resulted in higher buyer payments than if the load had been served by generators.

In **Figure 4**, we show the monthly number of hours in which *DRR* curtailments resulted in post-curtailment buyer payment increases in case M_3. In this case, we see that the limitations of *FERC NBT* are even more pronounced. In nearly every month the number of hours in which *DRR* curtailments increase the post-curtailment buyer payments exceeds 20 hours.

In fact, in the months of October and November, in every hour in which there are *DRR* curtailments, those *DRR* curtailments result in increased post-curtailment buyer payments. Furthermore, only in the months of June, July, and August does the number of hours in which *DRR* curtailments result in decreased post-curtailment buyer payments

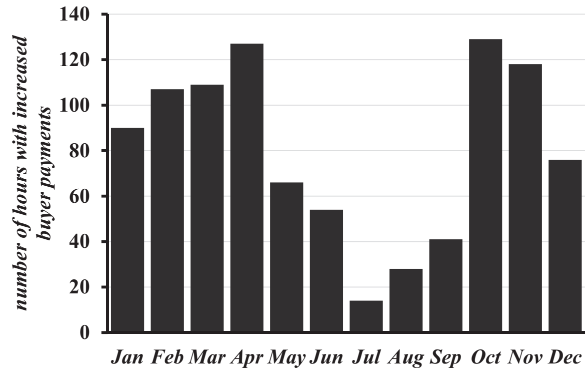

Figure 4: Post-Curtailment Buyer Payment Increases Due to DRR Curtailments for Case M_3

exceed the number of hours in which *DRR* curtailments do not. Clearly, *FERC NBT* screen is too coarse (Figures 3 and 4).

We also investigated the distribution of *DRR* benefits and losses among the buyers. Indeed, our analysis of the N_3 and M_3 case studies indicates that *there are nodes in the system that experience higher post-curtailment LMP so often that, at the end of the year, their buyer payments in the case with DRRs are higher than in the case with no DRR participation*. Out of the 99 load nodes in the N_3 test system, 19 experienced an increase in the annual buyer payments due to the *DRR* curtailments for case N_3. In **Figure 5**, we show buyer-payment related metrics for the 10 nodes that experienced the greatest percentage increase in buyer payments at the end of the year for case N_3. For contrast, we also show the nodes that experienced the highest decrease in consumer payments in this case. These nodes have greater demand response

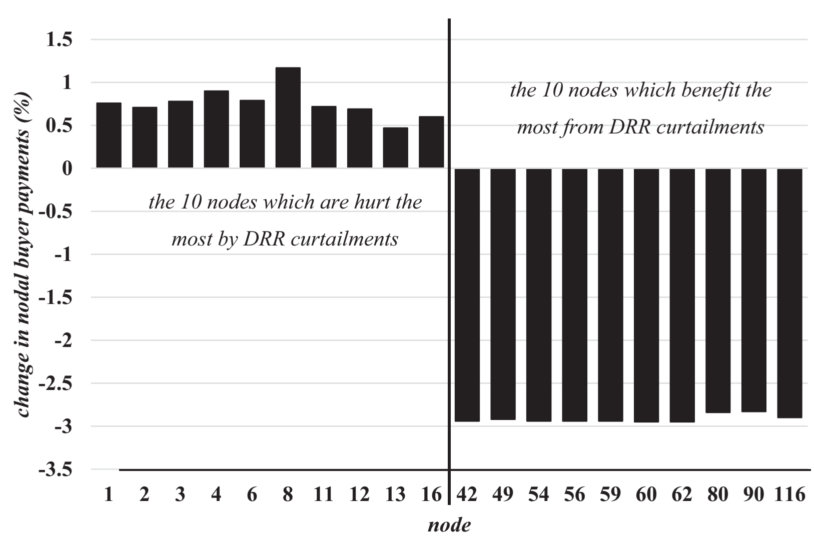

Figure 5: The Impact of DRR Curtailments on the Top 10 Nodes Which Benefit and Top 10 Which Experience Losses over the One-Year Period in Case N_3

  http://dx.doi.org/10.1016/j.tej.2013.09.002

Please cite this article in press as: Van K, et al. Fixing FERC's Order No. 745, Electr. J. (2013), http://dx.doi.org/10.1016/j.tej.2013.09.002

participation and also experience a decrease in the annual consumer payments of approximately 3 percent compared to case N_0. The node that experienced the highest percentage increase in the buyer payments with respect to case N_0, is node 8 at 1.17 percent.

The situation in our cases with the *MISO* data is no different. In those cases, there are a total of 29 nodes that experience higher annual buyer payments with *DRR* participation. The emergence in both the *ISO*-NE and *MISO* cases of a set of nodes at which buyers are made worse off by *DRR*s, while *DRR*s benefit buyers overall, highlights the differences in the distribution of the *DRR* benefits that can arise under the stipulations of *FERC* Order 745 in a congested system.

We draw three conclusions from our studies into the aggregate impacts of the unintended consequences resulting from the limitations of *FERC* Order No. 745:

- *FERC NBT* provides an insufficiently fine screen to filter out *DRR* curtailments in hours in which they cause increases in the total post-curtailment buyer payments.
- The distribution of *DRR* benefits and losses among the buyers under the Order is a serious issue and the prevailing *LP-IPA* fails to fully address it.
- The failure of the thrusts of the Order to integrate the transmission congestion impacts is a driving force behind the outcomes we observe.

The cases we have described in which *DRR*s lead to increased post-curtailment buyer payments for some or all buyers occur in a large number of *DRR* curtailment hours under the current stipulations of *FERC* Order No. 745. The number of hours in which *DRR* curtailments are uneconomic highlights the importance of the Order's failure to account for the

network effects and points to the need of a finer screen to capture hours in which *DRR* curtailments are uneconomic. The failure to account for network congestion impacts also raises issues with the *LP-IPA*, and we have shown that the result may be a tacit picking of winners and losers among the buyers through the distribution of the *DRR* benefits and losses. It is clear that the limitations of *FERC* Order No. 745 have a significant impact on the magnitude and the distribution of *DRR* benefits. These unintended consequences work against the thrusts of the Order in achieving its second objective. In the following section, we describe proposed modifications to the Order to integrate transmission congestion impacts into the *NBT* and the *IPA* and show the improvements in the market outcomes that can be achieved by doing so.

III. The Proposed Modifications to FERC Order No. 745

The thrusts of *FERC* Order No. 745 have come close to hitting their mark of achieving the Order's objectives. However, the unintended consequences limit the effectiveness of the Order at achieving the second objective. In this section we describe modifications to the Order to address the limitations. We propose two modifications which, in essence, integrate the transmission congestion impacts. The modifications preserve the spirit of 745 and make precise adjustments to the *NBT* to provide a finer screen to determine the hours in which *DRR*s are compensated at the *LMP* and to the *IPA* to address the distribution of *DRR* benefits. We first discuss the modifications to *FERC NBT* to reduce the number of hours in which *DRR* curtailments occur but result in increased total buyer payments.

Our proposed *NBT* modifications are based on the clear need to integrate congestion information into *FERC NBT* methodology. The system-wide nature of *FERC NBT* is insufficient to capture the often serious impact of transmission congestion on the market outcomes. To this end, we

 1040-6190/$–see front matter http://dx.doi.org/10.1016/j.tej.2013.09.002

propose the use of a *nodal NBT*. The nodal *NBT* retains many of the same characteristics of the system-wide *FERC NBT* and keeps the basic format of *FERC NBT* unchanged. The key differences between the nodal *NBT* and *FERC NBT* are that the former is applied on a nodal basis and that the former makes use of available *LMP* data, instead of seller offer data, to calculated threshold prices on a nodal basis, which we term the locational threshold prices (*LTP*s). When there is transmission congestion, the markets clear on a nodal basis. Therefore, to apply *FERC NBT* on a nodal basis, we would need to reconstruct the nodal offer curves in every hour. However, it is not straightforward to reconstruct the nodal offer curves and so we use the hourly *LMP*s over a month as a proxy for the nodal seller offer curves in a congested system. For each node we take the hourly *LMP*s and cleared load in the peak hours of a month and construct an ''offer'' curve by arranging the hourly *LMP*s in increasing order and cumulatively summing the cleared load associated with each *LMP*.[15] This *LMP*-based proxy offer curve represents the purchase price at the node, which includes transmission congestion impacts, under a range of load conditions and so captures the transmission congestion impacts under each of those conditions.

This offer curve is then treated within the *NBT* framework of the Order to determine the *LTP*s at each node. The modifications to *FERC NBT* to arrive at the nodal *NBT* give rise to a finer screen by integrating a greater amount of the relevant system information into the *NBT* cost-effectiveness test. As we will show, the nodal *NBT* reduces the number of hours in which *DRR* curtailments occur but result in increased total buyer payments. The integration of congestion information into the *NBT* via the

nodal *NBT* impacts the frequency and location of *DRR* curtailments and thus impacts the distribution of the *DRR* curtailment benefits among the non-*DRR* buyers. However, the nodal *NBT* does not directly address the distribution of *DRR* benefits. To address the benefit distribution issue, we propose a more specific *IPA*.

We propose a benefit-proportional *IPA* with side payments (*BP-IPA* w/ *SP*). Under the *BP-IPA* w/ *SP*, the increased post-curtailment payments experienced by some buyers as a result of *DRR* curtailments are considered a 'cost' of the *DRR* curtailment to be allocated among the beneficiaries of the curtailment and the buyers which were made worse off by the *DRR* curtailment are made whole by a side payment. The costs of providing these side payments, combined with the costs to provide the *DRR* incentive payments are allocated to those buyers which benefit from the curtailment *in proportion to the benefits they receive*. For example, consider a congested three bus system and suppose there are three buyers, A, B and C, each with a 10 MW load at different nodes and one *DRR*. Now suppose a *DRR* curtailment occurs that reduces buyer A's payments by \$60, buyer B's payments by \$40 and increases buyer C's payments by \$20. Suppose the incentive payment to the *DRR* is \$80. The total ''cost'' to the buyers which benefit from the curtailment (buyers A and B) under the *BP-IPA* w/ *SP* is \$80 for the *DRR* incentive payment plus \$20 for the make-whole payment to buyer C, a total of \$100. The total benefit is the sum of the individual benefits of buyers A and B, or \$100. We note the curtailment does not increase total buyer payments since the total ''cost'' is equal to the total benefits. Buyer A received 60 percent of the total benefits of the curtailment and so, under the *BP-IPA* w/ *SP*, is responsible for 60 percent, or \$60, of the ''cost.'' Similarly, Buyer B received 40 percent of the benefits of the curtailment and so is allocated 40 percent or \$40, of the ''cost.'' In this example, the benefits are exactly equal to the ''costs'' for all the buyers and thus no buyer is made worse off by the curtailment. Note that under an

  http://dx.doi.org/10.1016/j.tej.2013.09.002

Please cite this article in press as: Van K, et al. Fixing FERC's Order No. 745, Electr. J. (2013), http://dx.doi.org/10.1016/j.tej.2013.09.002

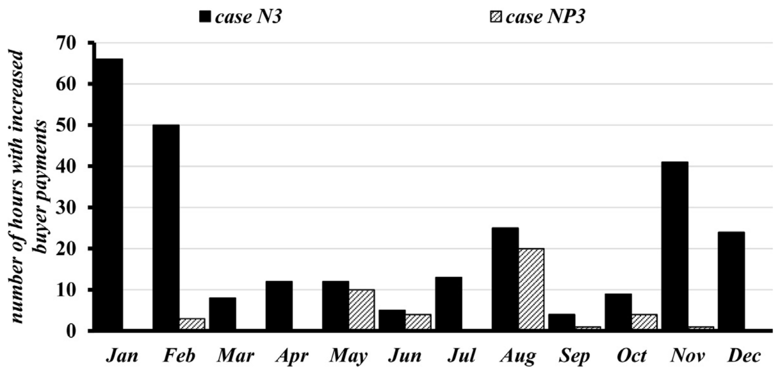

Figure 6: Number of Hours in Each Month in Which DRR Curtailments Increase Buyer Payments in Case N_3

LP-IPA buyer B would suffer an increase in the post-*IPA* buyer payments. This example illustrates an important strength of the *BP-IPA* w/ *SP*: under this *IPA*, we can guarantee that no buyers are made worse off by the *DRR* curtailment provided that the *DRR* curtailment reduces total post-curtailment buyer payments. In the case where the *DRR* curtailment does not reduce the total post-curtailment buyer payments, which are the cases which we address with the nodal *NBT*, we suggest a distribution of the losses such that the final outcome is a load-proportional sharing of the losses i.e. individual buyer's benefits and losses are taken into account and those buyers which are made worse off by the *DRR* curtailment due to congestion patterns are allocated a lesser portion of the costs and vice versa. The *BP-IPA* w/ *SP* reduces the instances where some buyers are made worse off while others benefit from *DRR*s, which arise when *DRR* curtailments occur in congested systems, by redistributing the benefits of the curtailment to compensate those buyers that are made worse off. Such an *IPA* is consistent with *FERC*'s cost-causation principle and enhances the ability of the thrusts of the Order to effectively achieve its second objective.

To show the impacts of the proposed nodal *NBT* and *BP-IPA* w/ *SP* and the reductions in the impacts of the unintended consequences which might be achieved under these proposed modifications we present a set of simulation studies. For all the simulation studies presented in this section, we use the same test system and set-up that was used for the simulation studies presented in Section II. We denote the simulation studies using the nodal *NBT* as: NP_c for the cases using *ISO-NE* data and MP_c for the cases using *MISO* data, with c as the demand response capacity. To start, we explore the impacts on the number of curtailment hours which result in buyer payment increases of using the nodal *NBT* in place of *FERC NBT* under which, in many curtailment hours, the payments to the *DRR*s exceed the benefits attained.

In Figure 6, we summarize the monthly number of hours in which the payments to the *DRR*s exceeded the benefits attained for case NP_3 using the nodal *NBT* and show the same for case N_3 for comparison. In this case a total of 43 instances resulted in higher *DRR* payments than system benefits, which represents approximately 5.7 percent of the total curtailment hours. Compared to case N_3, where 17.8 percent of the curtailment hours resulted in extra payments due to the demand curtailments, the nodal *NBT* screened out more of the hours in which *DRR* curtailments resulted in increased total post-curtailment buyer payments. The percentage of hours with such unintended consequences is reduced for all cases with the nodal *NBT*, compared to *FERC NBT* cases.

We note that, even with the proposed changes to the *NBT*, there are still hours in which the societal costs exceed the benefits of *DRR* participation. This is due to the fact that, while the nodal *NBT* explicitly includes transmission congestion information, it does not account for the impacts of concurrent *DRR* curtailments at multiple nodes on the buyer payments at each node. Consequently, while considerably reduced in number, there still arise cases where the collective impact of the *DRR* curtailments results in an increase in the total buyer payments under the nodal *NBT*.

In Figure 7, we show the monthly number of hours in which the societal costs of *DRR* participation exceed the benefits in the MP_3 and M_3 cases. For all

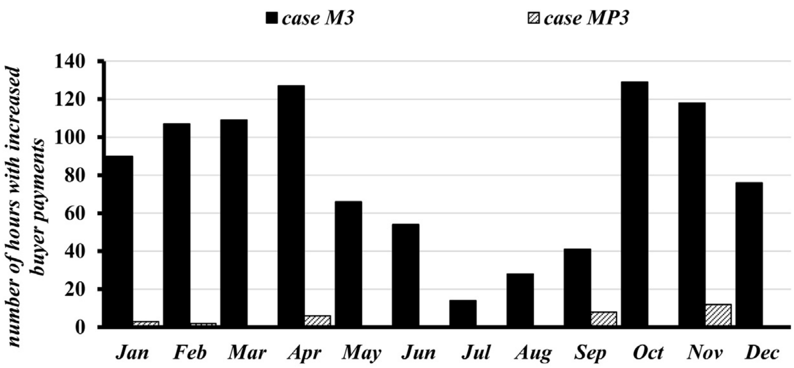

Figure 7: Number of Hours in Each Month in Which DRR Curtailments Increase Buyer Payments in Case M_3

the cases using the *MISO* data, there was a significant drop in the number of curtailment hours. Some 66 percent of the curtailment hours resulted in higher payments than benefits in case M_3. In case MP3, the 31 instances of hours with higher *DRR* payments than benefits represent 20 percent of the total curtailment hours. As in the NP_3 case, the application of *LTP*s in the MP_3 case, and the finer screen they provide, reduces considerably the number of hours in which *DRR*s increase the total post-curtailment buyer payments.

Next, we discuss the differences between the impacts of *DRR* curtailments on individual nodes under the nodal *NBT LTP*s compared to *FERC NBT* system-wide threshold. Since, under the nodal *NBT*, we use the *LTP*s, there is no longer a set of nodes whose *LMP*s are above the threshold price and a set whose *LMP*s are below, but rather hours in which a node's *LMP* is above the *LTP* and hours in which it is not. We examine the buyer payment impacts under the nodal *NBT* on a node which was previously made worse off as a result of *DRR* curtailments. In **Figure 8**, we show the pre- and post-curtailment *LMP*s at node 8 during the first week of May 2010 in case study NP_3.

Under *FERC NBT*, node 8 had no *DRR* curtailments during this week and experience post-curtailment *LMP* increases in most of the hours in which *DRR* curtailments occurred at other nodes in the system due to the network effects. However, the *LTP* is lower than the peak hour pre-curtailment *LMP*s and so, under the nodal *NBT*, *DRR* curtailments occur at node 8 and result in post-curtailment *LMP* decreases in most hours, an indication that these *DRR* curtailments represented cases of omission which are corrected by the nodal *NBT*. The few hours in which the post-curtailment *LMP*s still increase are due to the impacts of concurrent *DRR* curtailments at other nodes whose impacts have not been captured by the nodal *NBT*. The application of the nodal *NBT* has reversed the fortunes of the buyers at node 8 such that they too enjoy the benefits of *DRR* curtailments rather than becoming an unintended consequence and bear the cost of *DRR* curtailments at other nodes in the system. For cases such as node 8, the *LTP* provides a more appropriate metric than the system-wide threshold price. The former is a better measure of whether *DRR* curtailments at a specific node will bring about greater benefits *to that node* than the costs to provide incentive payments which will be incurred.

We now examine the impacts of the nodal *NBT* on a node which was the beneficiary of *DRR* curtailments under *FERC NBT*. In **Figure 9**, we show the

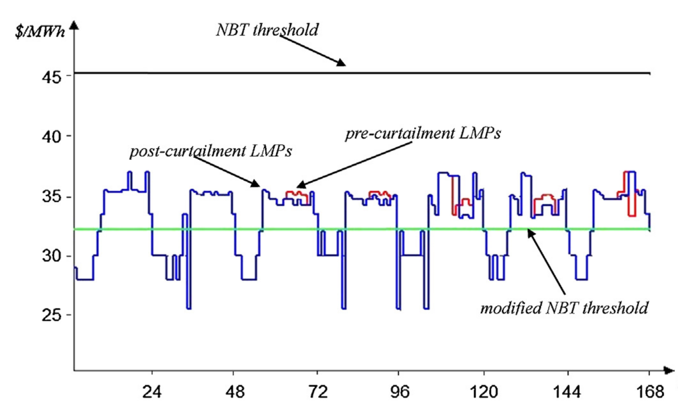

Figure 8: Pre- and Post-curtailment LMPs during the Week of May 1–7 at Node 8 in Study Case NP_3

  http://dx.doi.org/10.1016/j.tej.2013.09.002

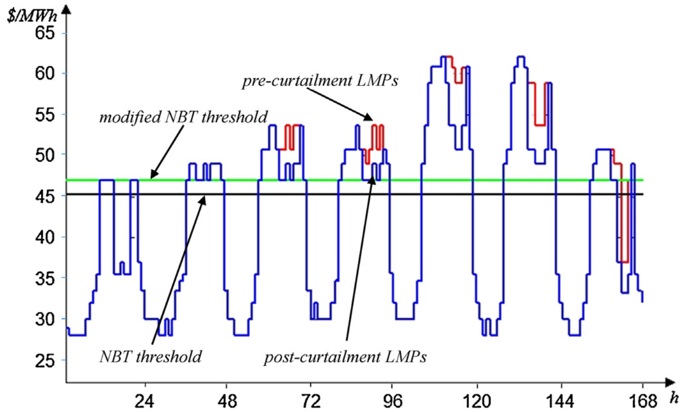

Figure 9: Pre- and Post-curtailment LMPs during the Week of May 1–7 at Node 116 in Study Case NP_3

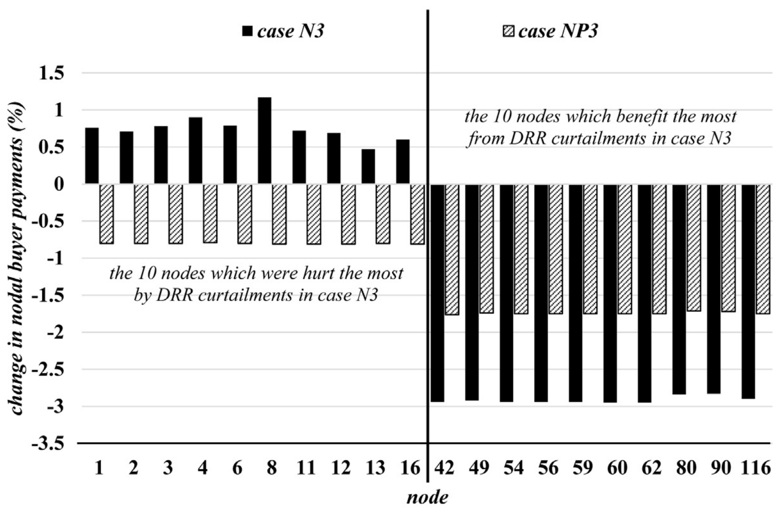

Figure 10: The Impact of DRR Curtailments Under the Nodal NBT and BP-IPA with Side Payments on the Top 10 Nodes Which Benefit and Top 10 Nodes Which Experience Losses over the One-Year Period under FERC NBT in Case N_3

pre- and post-curtailment *LMP*s during the first week of May at node 116 in study case NP_3. We note that the *LTP* is slightly higher than the system-wide threshold.

Nodes such as node 116 experienced persistently higher pre-curtailment *LMP*s, which were higher than the system-wide threshold price, than other nodes in the system and so such nodes benefited more frequently from *DRR* curtailments both due to the frequency of the curtailments at such nodes and the magnitude of the *LMP* reductions those curtailments brought about. The persistently high pre-curtailment *LMP*s explain why the *LTP* is higher than the system-wide threshold at node 116, since the *LTP* is calculated from these higher peak-hour *LMP*s. That the *LTP* is higher than the system-wide threshold price also indicates that, under *FERC NBT*, *DRR* curtailments at node 116 which occurred in cases which the *LMP*s were between system-wide threshold price and the *LTP* would not result in buyer payment reductions at node 116. Such cases would represent a cases of commission which *FERC NBT* screen would fail to filter out and that the *LTP* captures. However, the pre-curtailment *LMP*s at node 116 are above the *LTP*, and consequently well above the system-wide threshold price, and so the curtailments at node 116 are largely unaffected by the introduction of the *LTP* i.e. *FERC NBT* was an effective screen for curtailments at node 116 in the week pictured. However, our observations of node 116 are not the case for all nodes, and the nodal impacts of *DRR* curtailments may not be well represented by *FERC NBT*, as we observed in the case of node 8 and as reported in our studies presented in Section II.

The nodal *NBT* provides the finer screen needed to account for the nodal differences in *DRR* value which arise due to transmission congestion and which have a profound impact on conditions under which *DRR* curtailments result in nodal benefits.

Though the nodal *NBT* addresses the cases of omission and commission which arise under *FERC NBT* and reduces the number of hours in which *DRR* curtailments result in buyer payment increases, it does not address the distribution of *DRR* benefits among the buyers in congested systems. We now turn to the impacts of our proposed *IPA* modifications to show the effectiveness of the *BP-IPA* w/ *SP* in addressing the distributional impacts of the *DRR*

1040-6190/$–see front matter , http://dx.doi.org/10.1016/j.tej.2013.09.002

Please cite this article in press as: Van K, et al. Fixing FERC's Order No. 745, Electr. J. (2013), http://dx.doi.org/10.1016/j.tej.2013.09.002

curtailment benefits in congested systems.

To show the reduction in the number cases in which nodes experience post-*IPA LMP* increases which can be gained by the use of the *BP-IPA* w/ *SP*, we show in **Figure 10** the percentage decrease in buyer payments in case NP_3 at the same nodes that were worse off in case N_3 using *FERC NBT*, presented in Section II. We see that, due to the side-payments, buyers at no nodes incur higher total payments due to *DRR* curtailments in case NP_3. In fact, all those nodes which were made worse off under *FERC NBT* and *IPA* now benefit from the curtailments. The *IPA* methodology we suggested addresses the distribution of *DRR* benefits such that all nodes in the case presented benefit from the *DRR* curtailments.

We also show the percentage decrease in consumer payments in case NP_3 at the same nodes that benefited the most from demand curtailments under *FERC NBT* in case N_3. All these nodes continue to benefit from demand curtailments but, as expected with *BP-IPA* w/ *SP*, these benefits are reduced due to the inclusion of the side payment to the buyers at nodes that were worse off. Such a redistribution of the *DRR* benefits ensures that *DRR* curtailments are beneficial *for all buyers* and so such curtailments are in line with the second objective of the Order.[16]

In this section we described our proposed *NBT* and *IPA* modifications and showed the improvements which can be realized by applying those modifications. The nodal *NBT* applies the same basic structure in *FERC NBT* but includes relevant system information to integrate the impacts of transmission congestion. These additional considerations reduce considerably the incidence of *DRR* curtailments when they result in total buyer payment increases under the nodal *NBT* compared to *FERC NBT* in our test cases. The *BP-IPA* w/ *SP* follows the thrust of the order to allocate the costs of *DRR* on a proportional basis to those buyers that benefit from the curtailments. Further, the explicit inclusion of side payments and the benefit-proportional allocation ensures that, in cases in which *DRR* curtailments reduce total buyer payments, no load is made worse off. Our results showed that the *BP-IPA* w/ *SP* eliminates instances in which some buyers benefit from *DRR*s while others are made worse off. The combination of the nodal *NBT* and *BP-IPA* w/ side payments provide a more effective approach to ensure that *DRR*s are use only when they are truly a ''cost-effective'' alternative to supply-side resources.

IV. Concluding Remarks

FERC Order No. 745 set out to break down the putative barriers to *DRR*s in *ISO*/*RTO*-run electricity markets to encourage greater *DRR* participation and, to this end, it is proving to be successful. However, the Order's second aim, to implement a set of mechanisms to ensure that *DRR*s are called upon to curtail their load only when they reduce buyer payments, has come up short. The failure of the Order to integrate the impacts of transmission is a significant limitation that has unintended consequences for the total benefits which *DRR*s may bring to the system and for the distribution of those benefits among the buyers in the system. We identify the sources of the unintended consequences and provide modifications to some aspects of the Order to improve the outcomes for non-*DRR* buyers. We show the specific cases that arise from these limitations and that the aggregate impact of those cases can be significant over the course of a year. Our simulation studies show that *DRR* curtailments may actually increase the overall buyer payments for a subset of buyers and that the distribution of the *DRR* benefits presents a major issue.

  http://dx.doi.org/10.1016/j.tej.2013.09.002

Please cite this article in press as: Van K, et al. Fixing FERC's Order No. 745, Electr. J. (2013), http://dx.doi.org/10.1016/j.tej.2013.09.002

These significant impacts motivate the need for our proposed modifications to the thrust of the Order.

We propose improvements that do not alter the nature of the Order and provide additional considerations to ensure *DRR* curtailments, when provided, are beneficial to non-*DRR* buyers. The modifications we introduce are:

- The nodal *NBT* and the corresponding *LTP*s which reduce the incidence of hours in which *DRR*s increase total buyer payments, and
- The *BP-IPA* w/ *SP* which ensures that, in cases in which *DRR* curtailments do not increase total buyer payments, no buyer is made worse off as a result of the *DRR* curtailments.

By using *LTP*s instead of a system-wide threshold price, we provide a more appropriate signal for the dispatch of *DRR*s. The introduction of the *BP-IPA* w/*SP* addresses the benefit distribution issues. We showed that these modifications considerably reduce the magnitude of the unintended consequences of *FERC* Order No. 745 and more effectively achieve the second objective of the Order.

Our approach provides a means by which to improve of the Order without changing its ''spirit.''■

Endnotes:

1. *FERC*, *Final Rule, Order No. 745, Demand Response Compensation in Organized Wholesale Energy Markets*, 18 CFR Part 35, issued Mar. 15, 2011, at 1.

2. *Id.*, *FERC, Final Rule, Order No. 745*, at 1.

3. *Id.*, *FERC, Final Rule, Order No. 745*, at 39.

4. *Id.*, *FERC, Final Rule, Order No. 745*, at 1.

5. *FERC* defines a *DRR* to be cost-effective if ''the overall benefit [for buyers] of the reduced *LMP* that results from dispatching demand response resources exceeds the cost of dispatching and paying *LMP* to those resources.''

6. *FERC, Final Rule, Order No. 745*, at 15, *supra*.

7. *FERC*, *Order on Rehearing and Clarification, Order No. 745-A, Demand Response Compensation in Organized Wholesale Energy Markets*, 18 CFR Part 35, issued Dec. 15, 2011, at 45.

8. *FERC, Final Rule, Order No. 745*, at 62, *supra*.

9. *FERC, Final Rule, Order No. 745*, at 77, *supra*.

10. See, for example, for *MISO*, *FERC*, *Order on Compliance Filing*, Docket No. ER11-4337-000, issued Dec. 15, 2011, at 5; for *PJM*, *FERC*, *Order on Compliance Filing*, Docket No. ER11-4106-000, issued Dec. 15, 2011, at 24; and for *ISO-NE*, *FERC*, *Order on Compliance Filing*, Docket No. ER11-4337-000, issued Jan. 19, 2012, at 16.

11. Significant growth in the quantity of cleared *DRR*s and in the payments to *DRR*s has occurred in PJM's energy markets since it implemented *FERC* Order No. 745 in April 2012. The *PJM DRR* monthly activity reports are available at http://www.pjm.com/markets-and-operations/demand-response/dr-reference-materials.aspx.

12. The post curtailment *LMP* at node 6 is unaffected due to the existence of a marginal generator at this node.

13. For additional results, see I. Castillo, *Assessment of the Impacts of Demand Curtailments in the Day-Ahead Markets: Issues in and Proposed Modifications of the FERC Order No. 745*, M.S. thesis, Univ. of Illinois at Urbana Champaign, Urbana, IL, 2012, at 36–50.

14. The test system data are taken from the Univ. of Washington Dept. of Electrical Engineering Power Systems Test Case Archive at http://www.ee.washington.edu/research/pstca/. Offer and load data for the *MISO* are found at https://www.midwestiso.org/Library/MarketReports/Pages/MarketReports.aspx. Offer and load data for the *ISO-NE* are found at http://www.is-one.com/markets/hrlydata/index.html.

15. A detailed treatment of the *LTP* methodology can be found in Castillo, 2012, at 51–58, supra.

16. We observe similar improvements in the unintended consequences in case MP_3 and so we omit them for the sake of brevity.

 1040-6190/$–see front matter , http://dx.doi.org/10.1016/j.tej.2013.09.002

Please cite this article in press as: Van K, et al. Fixing FERC's Order No. 745, Electr. J. (2013), http://dx.doi.org/10.1016/j.tej.2013.09.002