Active Participation of FACTS Devices in Wholesale Electricity Markets

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Abstract

Traditionally, electric system operators have dispatched generation to minimize total production costs, assuming a fixed transmission topology within the dispatch horizon. Implementation of smart-grid systems could allow operators to co-optimize transmission topology alongside generator dispatch; the technologies that would enable such co-optimization are still regulated as part of the monopoly transmission system. Recent work (Gribik et al., 2005; O’Neill, et al., 2008) has proposed mechanisms for compensating transmission owners based on flexible electrical characteristics and availability; and integrating transmission into “complete” real-time electricity markets. We study two different designs for the market-based operation of Flexible Alternating Current Transmission Systems (FACTS), which allows some control over the electrical topology of transmission lines. The first market design compensates FACTS devices based on differences in locational prices (effectively with Financial Transmission Rights), while the second allows FACTS devices to submit supply offers just as generators would, being paid a market-clearing price for additional transfer capacity provided to the system. The variable social
costs of FACTS devices are modeled as the additional losses associated with changes in electrical characteristics of transmission lines.

Our problem formulation for a simple two-node system suggests a number of regulatory implications for flexible transmission architecture. First, we find that the marginal cost functions for FACTS device dispatch are increasing, suggesting that flexible transmission technologies may not possess the same natural-monopoly characteristics as the wires themselves. Second, the additional transfer capacity offered by FACTS devices may effectively clear the real-time market in some circumstances (i.e., the additional transfer capacity displaces higher-cost generation), suggesting that FACTS devices have the power to set prices. Third, if FACTS devices are compensated based on locational price differentials, the owners of such devices will not have incentives to offer the socially optimal amount of transfer capacity to the system operator.

1. Introduction

The annual revenue of the US electricity industry is around 350 billion dollars (EIA). The very large economic size of the industry emphasizes the need for efficient operation of the whole system. The industry was considered to be a natural monopoly before 1990s and was operated under regulation. One of the goals of restructuring, which began in the 1990s, is to decentralize the decision making process and hopefully improve the system’s efficiency.

Currently, the operation decisions in electric transmission are made centrally by the system operator. Payments to regulated transmission owners are also made according to a regulated rate of return that does not necessarily reflect the economic value of a certain transmission line to the system. The implementation of the “smart grid” could enable the deployment of flexible and
adaptive transmission networks, thus allowing for the transmission topology to be optimized depending on electricity demand and other system conditions. One technology that would allow this is Flexible Alternating Current Transmission Systems (FACTS).

In an analogy to the water networks FACTS devices act similar to water pumps (Fairley, 2011). Without water pumps, water only flows from higher altitudes to the lower altitudes based on the pressure difference which may not always be efficient in a network. Similarly electricity flows based on voltage and angle differences which may not be economically efficient. Economic inefficiencies can occur in the form of loop flows or counter intuitive flows from a cheap node to an expensive one. FACTS devices make it possible to control the flows and avoid such economically inefficient phenomena.

Recently some studies have suggested implementing market-based mechanisms for transmission sector. This would allow transmission owners to offer their services to the system operator on a bid basis, as generators currently do in deregulated electricity markets. Such a market has been termed a “complete real-time electricity market” (O’Neill et al., 2008). They conclude that it is not clear whether the FACTS devices are natural monopoly and provide a strong theoretical background for designing markets with active transmission participation. The existing literature, however, does not provide any insight as to how the equilibrium in a complete real-time market would be different than that of current markets, where supply offers are limited to generators (and to some degree demand response). Existing work has stopped at formulating the Independent System Operator (ISO)’s cost minimization problem. It should be noted that generating and transmission companies have their own profit maximization problem. In order to find the market equilibrium both the ISO level and firm level problems should be solved together.
simultaneously.

Here we explore the equilibrium conditions using supply function equilibrium (SFE) model when transmission participation in the market is allowed. This market problem is best modeled as a Mathematical Program with Equilibrium Constraints (MPEC), where individual decision makers maximize their profit considering the total cost minimization problem of the system operator as a constraint. We formulate and model the problem in a very simple system with two nodes and two parallel transmission lines. Although the system is simple, it is still suitable for initial study of bid-based dispatchable FACTS devices’ impact on market equilibrium and social welfare.

The rest of this paper is organized as follows: Section 2 reviews the relevant literature. The two-node test system is presented and modeled in section 3 considering the existence of the FACTS devices. Two market mechanisms for FACTS devices and equilibrium conditions are presented in sections 4 and 5. Section 6 includes a numerical example and finally section 7 concludes this paper.

2. Literature Review

By utilizing communication and automation potentials of smart grids the transmission system topology can be controlled in real-time, either by the system operator or distributed decision-makers such as FACTS device owners. Recently some studies have suggested co-optimizing generation and transmission network topology to obtain a more efficient level of operation. The majority of research has focused on switching transmission lines (Hedman et al., 2008; Fisher et al., 2008; Khodaei and Shahidehpour, 2010). Based on the distribution of load and generation on
the power grid switching a line off the network can reduce loop flows. This can help reducing the power flow on some congested lines resulting to a lower total operating cost for the system. The findings show that switching the transmission lines can significantly save energy costs.

The switching control can be improved by using FACTS devices. A Thyristor Controlled Series Compensator (TCSC) can continuously control the reactance of a transmission line (Hug, 2008; Hug and Anderson, 2005). This technology allows for some amount of control over the power flowing through the line.

O’Neill et al. used this concept in their complete real-time market design which allows for transmission bidding (O’Neill et al., 2008). Their design has so far the most complete formulation to our knowledge. They allow for transmission owners to bid in the market for using their FACTS devices to change the admittance of their lines. However they limit their study to the case where transmission lines are price taker and bid zero into the system. They argue that the right way to compensate transmission owners is to pay them the difference between nodal prices times the power flowing along the line. Their research is a step towards decentralizing the centrally made optimization decisions regarding the transmission system. We build our research on their work and address two important problems. First, their design has an incentive problem which does not allow full utilization of the installed FACTS capacity. We explain this in more details in the next section. Second, they have only formulated the social welfare maximization problem of the system operator. In order to have a complete view of the market we need to consider the profit maximization problems of the firms as well. Consideration of firm level problems makes the total system a mathematical program with equilibrium constraints (MPEC). This technique has been used in the literature to analyze the potential strategic gaming (Hobbs et
al., 2000). Here we try to address both of these problems in a simple system.

(Ernst et al., 2004) used a dynamic method to analyze how a relatively simple transmission market works considering decision making of the firms. They use a dynamic Bertrand model for transmission and assume full controllability of the power flow. Here, we use a SFE model and base our payment mechanism on additional transfer capacity considering limited controllability to make our model more realistic.

There is another relevant trend in the literature about merchant transmission investment. Unlike regulated transmission, a merchant transmission project recovers its costs via market mechanisms such as Financial Transmission Rights (FTR). Hogan argues that transmission projects are alternatives to local generation projects. Therefore having regulatory mechanism for one spreads out to the other (Hogan, 2003). Yet, merchant transmission faces different classes of problems (Joskow and Tirole, 2004; Joskow and Tirole, 2005). (Brunekreeft, 2004) argues that these problems do not exist in the case of controllable flows such as HVDC lines or AC lines equipped with FACTS devices. A good market design for lines equipped with FACTS devices can potentially support the idea of merchant transmission.

When dealing with transmission lines, the payments can be based on different properties of a line. A method is introduced in (Gribik et al., 2005) for defining transmission rights under which the owner of the line (or the holder of the transmission right) receives payments based on the line’s capacity and its admittance. Currently transmission rights such as FTRs have positive value only when congestion makes the nodal prices at the delivery bus larger than at the source bus. The authors argue that capacity is not the only valuable characteristic of a transmission line and admittance should also be taken into account. In our model we use the concept of admittance
3. The two-node system with FACTS devices

3.1. The two-node system

We start the discussion with a simple two node system. The nodes are connected through two transmission lines. The example is taken from O’Neill et al (2008). The system is shown in Figure 1.

X indicates reactance of the lines and K shows their thermal capacity. Assume the marginal cost of production is lower for G1 than G2 and the thermal capacity is 400 MW for K1 and 480 MW for K2. Suppose that the generators have unlimited capacity and both lines have equal base reactances. They are both equipped with TCSC so they can adjust their reactance. The net reactances of the lines are shown in Equation 1:

\[
X_1 = X + \frac{n_1}{100}X, \quad -n_{\max} \leq n_1, n_2 \leq +n_{\max} \\
X_2 = X + \frac{n_2}{100}X
\]

where n shows the percentage by which the transmission line has adjusted its reactance. The
current technology allows for one percent change in reactance [3]. Considering the thermal limit of 400 MW on line one, the maximum amount of power which can flow over line two would be 400 MW. However by adjusting the reactance of the lines the power flowing along line two can be increased up to 480 MW which is its thermal capacity. The total transfer capacity from node 1 to node 2 can be calculated according to Ohm’s law. It is shown in Equation 2.

\[
\text{TC} = 400 + 400 \times \frac{X_1}{X_2} = 400 \times \frac{200 + n_1 + n_2}{100 + n_2}
\]

If the FACTS device on line 1 is used and the FACTS device on line 2 is not used, Equation 2 suggests a linear relationship between \(n_1\) and the transfer capacity. The relationship between \(n_2\) and the transfer capacity, however, is non-linear. The transfer capacity is depicted versus \(n_1\) and \(n_2\) in Figure 2.

If the FATCS devices on both of the lines are used the transfer capacity increases non-linearly with the change in reactances. We can use the linear part of the Taylor series to get a linear approximation. Figure 2 shows that the approximation is valid for small values of \(n\). Linear approximation means that we assume both lines behave like line 1 and the effect of using both FACTS devices is double the effect of line 1.
Figure 2. The transfer capacity when both the FACTS devices are used. It is assumed in this figure that $n_1 = n_2$.

We assume linear marginal cost of production at the two nodes of the system. They are shown in Equation 3 with $q$ being the power produced.

$$
\begin{align*}
MC(q_1) &= \alpha_1 q_1 + \beta_1 \\
MC(q_2) &= \alpha_2 q_2 + \beta_2
\end{align*}
$$

(3)

Based on the thermal limit of the lines, the nodal prices can be calculated. We assume that generator 2 is more expensive at the scale of this problem for all the values of demand. The nodal prices are calculated for the case when generator 2 is needed for serving the load.

$$
\begin{align*}
\lambda_1 &= \alpha_1 (TC^0 + 4n_1 + 4n_2) + \beta_1 \\
\lambda_2 &= \alpha_2 (L - TC^0 - 4n_1 - 4n_2) + \beta_2
\end{align*}
$$

(4)

$TC^0$ is the transfer capacity between the two nodes without using the FACTS devices.

The formulation developed by O’Neill et al. suggests paying the price difference times the
quantity flowing over the line to the transmission lines. However this type of payment removes the incentive for Line 1 to use its FACTS devices in order to increase the transfer capacity. As discussed earlier no matter which line uses its FACTS device the additional power flows along line 2. According to O’Neill et al. line 2 would be rewarded for the actions taken by line 1. This is a serious incentive problem with their formulation when independent companies own the FACTS devices.

The payment method we use is based on the incremental transfer capacity. Each FACTS device owner is paid the market price for reactance change times the amount of change. We use SFE which is a game theoretic model to analyze market equilibrium under this transmission operation policy. We assume that generators bid their marginal cost. FACTS device owners are paid the market clearing price for the FACTS devices based on the bids they submit to the ISO. This price comes out of the competition with the other FACTS device owners that could offer the same service, and alternative generators.

3.2. Cost Function Structure

Here we model the variable cost associated with FACTS devices as the costs associated with resistive power losses. The loss in a transmission line is presented in Equation 5.

\[
(5) \quad P_{\text{Loss}} = RI^2, \quad P = VI \Rightarrow I = \left(\frac{P}{V}\right) \Rightarrow P_{\text{Loss}} = R \left(\frac{P}{V}\right)^2
\]

\(R\) is the line’s resistance, \(P\) is the transmitted power and \(V\) is the line’s voltage. This equation can be used to describe the marginal system cost of FACTS device utilization. Assume the FACTS devices change the reactance of the lines by \(n_1\) and \(n_2\) percent respectively. The additional loss
associated with the FACTS devices are calculated in Equation 23.

\[
\Delta P_{Loss} = R \left( \frac{P_1}{V} \right)^2 - R \left( \frac{P_0}{V} \right)^2 = \frac{R}{V^2} \left( (4n_1 + 4n_2 + TC^0)^2 - TC^0 \right)
\]

\( TC \) represents transfer capacity. Superscript \( 0 \) represents the state before using FACTS devices and \( 1 \) is when they are used. The total cost of using the FACTS devices can be calculated by multiplying losses from Equation 6 by the price of electricity at the source node. It should be noted that Equation 6 shows a non-linear relationship between reactance change and losses. The non-linearity creates computational challenges and more importantly does not support superposition principle. Therefore it is not easy to distribute the losses to the individual FACTS devices. For the sake of simplicity we assume that the relative changes in losses due to the effect of FACTS devices can be approximated by a linear relationship. Linearization of Equation 6 using first-order Taylor expansion is presented in Equation 7.

\[
\Delta P_{Loss} \approx \left( \frac{\partial \Delta P_{Loss}}{\partial \Delta P} \right)_{TC^0} \Delta P = \frac{2R}{V^2} TC^0 (4n_1 + 4n_2) = \frac{2R}{V^2} TC^0 (4n_1) + \frac{2R}{V^2} TC^0 (4n_2)
\]

Not only does the linear approximation make the problem computationally easier but also it obviously makes the superposition principle hold. From Equation 7 one can see that unlike Equation 6 the losses associated with each FACTS device can be separated.

To calculate the cost associated with the losses we need to multiply each term of Equation 7 by the price at the source node. In the two node system the resulting cost functions would be:

\[
C_1(n_1, n_2) = \frac{2R}{V^2} TC^0 (4n_1)(\alpha_1(TC^0 + 4n_1 + 4n_2) + \beta_1)
\]

\[
C_2(n_1, n_2) = \frac{2R}{V^2} TC^0 (4n_2)(\alpha_1(TC^0 + 4n_1 + 4n_2) + \beta_1)
\]
Marginal cost functions can be calculated by taking the derivative of the cost functions with respect to the related control variable.

\[
\begin{align*}
MC_1(n_1, n_2) &= \frac{\partial C_1}{\partial n_1} = \frac{8R}{V^2}TC^0(\alpha_1(TC^0 + 8n_1 + 4n_2) + \beta_1) \\
MC_2(n_1, n_2) &= \frac{\partial C_2}{\partial n_2} = \frac{8R}{V^2}TC^0(\alpha_1(TC^0 + 4n_1 + 8n_2) + \beta_1)
\end{align*}
\]

Equation 8 and 9 are valid only when the price at node 1 is less than the price at node 2 and the capacity of FACTS devices is not overused beyond the point that congestion is completely relieved \((4n_1+4n_2 \leq L-TC^0)\). An important property of marginal cost functions shown in Equation 9 is that they are increasing functions. Moreover the average variable cost functions which can be calculated from Equation 8 are increasing as well. Therefore one can conclude that the FACTS devices are not natural monopolies and operation decisions can be made in a market-mechanism.

4. LMP based compensation – Cournot model

First we model the market for FACTS devices as a Cournot game. We assume that each FACTS device owner is paid the nodal price difference times the incremental transfer capacity facilitated by the use of the FACTS device. We also assume that the generators bid their marginal cost.

From Equation 4 we can calculate the nodal price difference.

\[
\begin{align*}
\Delta \lambda &= \beta_2 - \beta_1 + \alpha_2L - (\alpha_1 + \alpha_2)(TC^0 + 4n_1 + 4n_2) \\
\gamma &= \beta_2 - \beta_1 + \alpha_2L - TC^0(\alpha_1 + \alpha_2), \quad \eta = 4(\alpha_1 + \alpha_2), \quad N = n_1 + n_2 \\
\Delta \lambda &= \gamma - \eta N, \quad 4n_1 + 4n_2 \leq L - TC^0
\end{align*}
\]

Firms that own FACTS devices are assumed to be profit maximizers. The profit functions are presented in Equation 11.
To find Nash-Cournot equilibrium for this game the following conditions should hold:

\[
\begin{align*}
\Pi_1(n_1, n_2) &= 4n_1 \Delta \lambda - \frac{2R}{V^2} TC^0(4n_1)(\alpha_1(TC^0 + 4n_1 + 4n_2) + \beta_1) \\
\Pi_2(n_1, n_2) &= 4n_2 \Delta \lambda - \frac{2R}{V^2} TC^0(4n_2)(\alpha_1(TC^0 + 4n_1 + 4n_2) + \beta_1)
\end{align*}
\]

The solution to the above set of equation is presented in Equation 13.

\[
\begin{align*}
\frac{\partial \Pi_1}{\partial n_1} &= 4\Delta \lambda + 4n_1 \frac{\partial \Delta \lambda}{\partial n_1} = MC_1 \\
\frac{\partial \Pi_2}{\partial n_2} &= 4\Delta \lambda + 4n_2 \frac{\partial \Delta \lambda}{\partial n_2} = MC_2
\end{align*}
\]

The solution to the above set of equation is presented in Equation 13.

\[
n_1^* = n_2^* = \frac{\gamma - 2\sigma \alpha_1 TC^0 - 2\sigma \beta_1}{3(8\sigma \alpha_1 + 4\alpha_1 + 4\alpha_2)} , \quad \sigma = \frac{TC^0 R}{V^2}
\]

If \( n^* > \frac{L - TC^0}{8} \):

\[
n_1^* = n_2^* = \frac{L - TC^0}{8} - \epsilon
\]

Since the FACTS device owners are paid the nodal price difference the equilibrium shown in Equation 13 never relieves the congestion. The term epsilon ensures that the prices are different at the two nodes of the system and FACTS devices have positive value.

5. **SFE model for FACTS devices**

Here we assume that each FACTS device owner bids a linear affine function to the market which puts a price on percentage change in reactance. Then ISO clears the market and specifies the market clearing price based on the submitted bids. The bid functions are shown in Equation 14.

\[
\begin{align*}
B_1 &= a_1 n_1 + b_1 \\
B_2 &= a_2 n_2 + b_2
\end{align*}
\]

\[
a_1 = a_2 = \frac{64R}{V^2} TC^0 \alpha_1
\]

\( B \) is the bid function and gets the unit of dollar per percentage change in reactance. \( a \) and \( b \) are
the parameters of the bid functions. We assume that the slope of the bid function \((a)\) equals the slope of the marginal cost function and the decision variable is the intercept \((b)\). For loads larger than \(TC^0\) it is economical to use the FACTS devices to relieve the congestion. Having the bid functions ISO finds the cheapest way of relieving the congestion.

\[
\begin{align*}
B_1 &= B_2 \\
n_1 + n_2 &= \frac{L - TC^0}{4} \\
n_1 &= \frac{a_2 (L - TC^0) - b_1 + b_2}{a_1 + a_2}, n_2 = \frac{a_1 (L - TC^0) + b_1 - b_2}{a_1 + a_2}
\end{align*}
\]

The set of dispatched FACTS capacity calculated in Equation 15 results in the price for the operation of FACTS devices shown in Equation 16.

\[
(16) \quad p = \frac{a_1 a_2 (L - TC^0)}{4} + a_1 b_2 + a_2 b_1 \quad (\$)\%
\]

Not only do the FACTS devices compete against each other but also they compete with generator 2. Thus the marginal cost of generator 2 imposes an ad hoc cap on the FACTS device bids. The price cap for the market would be the difference between nodal prices if generator 2 was marginal. If the FACTS owners asked for more than that it would be better to buy from generator 2 instead of asking FACTS devices to relieve the congestion. The profit functions are shown in Equation 17.

\[
(17) \quad \Pi_1 = p n_1 - c_1 \\
\Pi_2 = p n_2 - c_2
\]

To find Nash-SFE we need to maximize each profit function with respect to the related player’s
decision variable. The set of equations presented in Equation 18 determines the conditions for Nash-SFE.

\[(18 - a) \quad \frac{\partial \Pi_1}{\partial b_1} = \frac{\partial p}{\partial b_1} n_1 + \frac{\partial n_1}{\partial b_1} p - \frac{\partial C_1}{\partial b_1} n_1 = \frac{\partial p}{\partial b_1} n_1 + \frac{\partial n_1}{\partial b_1} (p - MC_1) = 0\]

\[(18 - b) \quad \frac{\partial \Pi_2}{\partial b_2} = \frac{\partial p}{\partial b_2} n_2 + \frac{\partial n_2}{\partial b_2} p - \frac{\partial C_2}{\partial b_2} n_2 = \frac{\partial p}{\partial b_2} n_2 + \frac{\partial n_2}{\partial b_2} (p - MC_2) = 0\]

The solution to above set of equations specifies Nash equilibrium strategies for FACTS devices owners. At the equilibrium we have:

\[b_1^* = b_2^* = \frac{8R}{V^2} TC^0 \left( \beta_1 - \frac{\alpha_1 TC^0}{2} \right) + \frac{12R}{V^2} TC^0 \alpha_1 L\]

\[n_1^* = n_2^* = \frac{L - TC^0}{8}\]

If the solution provided in Equation 16 resulted in a price higher than market cap, the ISO would automatically pay the FACTS owner the market cap. In the case that market cap constraint is active we have a corner solution. We assume that marginal cost would never be higher than market cap which means the cost of marginal losses is always smaller than the marginal benefits of using FACTS devices. This means that even when the bids are reduced to the market cap, the players still make money.

6. Numerical example

We discuss how our FACTS device market would work in the context of a numerical example. Assume that line 1 has a thermal capacity of 400 MW which makes the TC^0 equal 800 MW. The other parameters of the system are presented in Table 1.
TABLE I- PHYSICAL CHARACTERISTICS OF THE SYSTEM.

<table>
<thead>
<tr>
<th>R</th>
<th>V</th>
<th>$\alpha_1$</th>
<th>$\beta_1$</th>
<th>$\alpha_2$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5  $\Omega$</td>
<td>400 KV</td>
<td>0.05 $$/MW^2$</td>
<td>18.5 $$/MW$</td>
<td>0.1 $$/MW^2$</td>
<td>65 $$/MW$</td>
</tr>
</tbody>
</table>

We increase the load at node 2 from 800 MW to 856 MW. We look at different market variables such as equilibrium quantities (% reactance changes); nodal prices; FACTS profits; overall social welfare improvement; congestion rent. The first set of results is shown in Figure 3.

Figure 3. (a) top: total amount of reactance change at equilibrium. (b) bottom left: Clearing price for FACTS devices. (c) bottom right: The profit for FACTS device owners.

Figure 3 shows that at equilibrium in SFE model, enough FACTS capacity is offered to relieve the congestion. However in Cournot model the device owners strategically withhold some of their capacity in order to increase their profit. It seems from part (a) of figure 3 that SFE and
Cournot give the same capacity at equilibrium when load is lower than 828 MW. However, it should be noticed that the capacity offered under Cournot is always slightly below SFE because of the epsilon in Equation 13. This is why the both prices and profits for FACTS device owners are larger when they are paid based on LMP difference under a Cournot model.

In SFE model, since the firms compete against each other and the market clears the price, the price increases when there is more demand for FACTS devices. Thus we observe an increasing trend in the price graph. Figure 4 shows nodal prices as well as changes in social welfare and congestion rent.

Figure 4. (a) top left: Locational marginal price at node 1. (b) top right: Locational marginal price at node 2. (c) bottom left: Social welfare improvement. (d) bottom right: Changes in congestion rent.

Parts (a) and (b) of figure 4 show the nodal prices at the two nodes of the system with and without the FACTS devices. When the devices are not utilized the price at node one remains at
58.5 $/MWh which is the marginal cost of production at node 1 when the production level is 800MW. The price at node 2 without having the FACTS devices comes from the marginal cost of production at node 2. When the devices are utilized, SFE gives lower nodal price at node 2. In this case the price at node 2 equals the price at node 1 plus the price charged by FACTS devices. LMP based compensation results in a larger price at node 2 compared to the case when the device owners are allowed to actively bid into the market. This is because of the strategic capacity withholding which occurs under LMP compensation. Parts (c) and (d) of figure 4 show that both Cournot and SFE models increase the social welfare and reduce the congestion rent. However as the results show, SFE model makes the society better off by providing more FACTS capacity.

7. Conclusion and future work

With the smart grid technology transmission topology can be optimized with generation simultaneously. Here we study the possibility of having a market for FACTS devices in order to control the admittance of the lines. It was shown that if the device owners are charged the cost of the additional loss their device imposes on the system, they end up with an increasing marginal and average variable cost function. Under such circumstance they do not fall into the problem of natural monopoly and a market mechanism can be employed for operation of the FACTS devices. We investigated two different market structures for compensating FACTS devices: first, they were paid based on the LMP differences similar to FTR. Second: They were allowed to submit their offers to the market which means they put prices on the percentage changes in the admittance of the line. The design was formulated and simulated on a simple two-node system. It was shown that both designs can be beneficial to the system and also to the players. However
bid-based FACTS market was more efficient for the society compared to LMP compensation design. It was shown that when the device owners are being paid based on LMP differences they strategically withhold some capacity and deviate from socially optimal point.

In future we need to expand our study on larger test systems to be able to better understand how such a market would work on a more realistic scale. We also need to consider how employment of FACT devices would affect the current revenues coming from current Financial Transmission Rights (FTRs).

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