MEASURING REACTIVE MARKET POWER

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Abstract

Market power refers to conditions where the providers of a service can consistently charge prices above those that would be established by a competitive market. There are many well known definitions of market power, including indices intended to quantify the degree of market concentration of energy supplies. This paper explores a method by which one of the standard indices in market power analysis (the Herfindahl-Hirschman Index) can be used to measure reactive power market concentration. The proposed method is illustrated by means of a simple example.
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1 Introduction

Market power refers to the concentration of resources in the hands of a single producer or an insufficient number of producers. One of the most common means for measuring market power is the Herfindahl-Hirschman Index (H) [1]. This index is defined as follows:

$$H = \sum_{i=1}^{N} s_i^2 \tag{1}$$

where the summation is over all N participants in the market and s refers to the market share of each. The share can be expressed in per unit (in which case the maximum value of H is 1) or in percent (in which case the maximum value of H is 10000). The latter is more common, and is used here[1].

Other measures of market concentration are possible. Two other common measures of concentration are the 4-firm and 8-firm concentration ratio (defined as the fraction of the total market held by the 4 or 8 largest firms). Yet another index is the entropy coefficient E, defined as:

$$E = \sum_{i=1}^{N} \log_2 (1/s_i) \tag{2}$$

Each market concentration index has advantages and disadvantages. It is impossible to establish a clear value below or above which market power exists for any index[2]. Many other aspects of a market not directly captured by these indices (most notably, ease of entry into a market) play heavily into the significance of specific quantitative values of an index. The greatest usefulness of these indices may be their value as relative market power indicators: a larger value of H indicates greater market concentration (and therefore the *potential* for greater market power) that a smaller value. The true measure of market power is the ratio between actual prices and the prices that would arise from true marginal cost pricing. This paper considers only market power as measured by H. For other efforts that study the effect of market power on electricity markets, refer to [3, 4, 5]. For a simulation analysis of the effect of network constraints on non-perfect markets refer to [6].

Because reactive power is of such localized nature, market power considerations can play an even greater role on reactive power than on active power. This paper addresses the specific issue of how to use market power ideas to measure the effect of reactive power, and proposes a simple measure to quantify market power concerns associated with reactive power.

2 The Proposed Market Power Measure

Reactive power can be provided by any of a number of means. Among other means are the following:

[1] H has the interpretation that $n = \frac{1}{H}$ (H in per unit) is the *equivalent number of equal-sized competing firms that are participating in a given market*. Thus, a value of H equal to 2500 indicates that there are four equal-sized firms in active competition.

[2] However, the US Department of Justice issues and revises guidelines for mergers [2]. These guidelines rely on the use use of the H to determine appropriate conditions that indicate market concentration. According to these guidelines, "the Agency divides the spectrum of market concentration as measured by the H into three regions that can be broadly characterized as unconcentrated (H below 1000), moderately concentrated (H between 1000 and 1800), and highly concentrated (H above 1800)."

- Shunt capacitors and switched shunt capacitors.
- Synchronous condensers.
- Synchronous generators.
- Static VAR compensators.

Because reactive power does not travel very far, it is usually necessary to produce reactive power close to the place where it is needed. Thus, the opportunity for market power arises as a result of the limited number of potential suppliers. An additional concern is that the ability to provide reactive power is not an all-or-nothing proposition, but is it rather an matter of degree. A supplier close to a location where the need occurs is in a much better position to provide reactive power than one that is located far from this location. Further complicating the issue is the observation that reactive power supplies are in many cases closely tied to the ability to deliver active power. In this paper we do not consider the value of reactive power in terms of active power effects it has. Rather, we concentrate exclusively on the issue of determining how many suppliers are able to regulate the voltage at any location, and to use market power-like indices to measure the degree to which this is possible.

The following features are sought in a measure of reactive power:

- It should be simple to compute.
- It should incorporate the locational nature of reactive power. A single index for the whole system is unlikely to be useful.
- It should adapt to changing conditions.

Based on these general objectives, the following notion is proposed in this paper:

- Solve a base case power flow.
- Evaluate the Jacobian at the operating point.
- For every location of interest in the system, determine the sensitivity of the voltage at that location with respect to the reactive power injection at every generator in the system in turn.
- The size of available control for a given generator at a particular location is the product of the available generator reactive capability ($Q^{\max} - Q^{\min}$) times the ability of that generator to supply the necessary reactive control at that location, from above.
- The market power indices are then computed for any location based on this measure.

Number of buses	118
Number of lines	188
Total Load (MW)	3688
Total reactive load	1438

Table 1: Characteristics of the test system.

This index measures the degree of market concentration at any location based on the actual ability of separately owned suppliers to control the voltage at that location for specific system conditions. It does not take into consideration issues having to do with limits already reached and other such issues (a small degree of market power does not necessarily mean that the reactive power resources are adequate, just that there are an adequate number of suppliers able to provide it).

3 Numerical Example

We now proceed to test this idea in an actual system and see what kind of predictions are obtained. As a testbed we use the IEEE 118 bus test system. Table 1 illustrates in summary form some features of this system.

For purposes of this example, it is assumed that only generators are able to supply reactive power. This is a gross underestimate of the resources available for reactive power control, but it makes the illustration of the nature of the proposed index easier to illustrate.

Also for ease of illustration, it is assumed that a subset of 15 are selected as possible participants. All generators in the have the same nominal ability to supply reactive power. The reactive power range for any one unit ranges from -50 MVAR up to +150 MVAR, for a dynamic range of 200 MVAR, which is used for all the calculations.

A total of 6 distinct arbitrary locations are selected for analysis. Table 2 illustrates the sensitivities as computed from the Jacobian for each generator at each location. Computation of the H for each location follows the usual formula, except that the size of the participants (200 MVAR assumed for all) is first scaled by their ability to contribute to the control, as obtained from this table. The end result of the H computation are given in the last line of table 2.

Although there are many competing generators in this system, and presumably market power would not normally be an issue, an inspection of this table illustrates the point that the H can be rather restrictive for some locations, leading to suspect excessive reactive power market concentration. Since reactive resources are relatively easy to add to a system, these numbers can be useful in indicating locations where additionally diverse resources should be added.

19.1	11.1	0.0	0.0	70.7	0.0
3.2	3.9	0.0	0.0	0.0	0.1
1.8	1.6	0.0	0.0	0.0	0.0
8.7	13.4	0.0	0.0	0.0	2.4
4.1	2.2	0.0	0.0	0.0	0.0
0.0	0.0	19.3	0.0	29.3	71.2
8.0	14.5	0.1	0.0	0.0	8.0
4.2	8.6	7.5	0.0	0.0	10.1
9.7	7.5	0.0	0.0	0.0	0.0
7.3	5.9	0.0	0.0	0.0	0.0
0.0	0.0	68.4	0.0	0.0	0.0
16.7	16.9	0.0	0.0	0.0	2.5
6.1	4.2	0.0	50.6	0.0	0.0
1.0	4.0	4.8	49.3	0.0	5.7
10.1	6.3	0.0	0.0	0.0	0.0
1119.6	1056.3	5122.6	4999.6	5857.7	5285.7

Table 2: Distance sensitivity factors (%) and H for 6 locations.

4 Conclusions

A simple index to measure the degree of reactive power market concentration at any one location has been presented and tested. The index has been illustrated by means of an example, and it does seem to convey general information about the ability of multiple independent suppliers for vying for the supply of reactive power and voltage control at any one location. Much additional work needs to be done before this index can be adopted for general use. However, as a minimum this index has been useful to indicate locations within the grid where market concentration of reactive power resources is a relatively more significant concern, and where the addition of independently owned reactive resources may prove most valuable.

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